The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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FOREWORD

The *Aluminum Design Manual* includes an aluminum structural design specification and accompanying commentary, a supplemental design guide, material properties, properties of common shapes, design aid tables, illustrative design examples, guidelines for aluminum sheet metal used in construction, and a code of standard practice for fabricating and erecting structural aluminum.

This edition of the *Aluminum Design Manual* is the product of the efforts of the Aluminum Association Engineering and Design Task Force, whose members are listed below.

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The Engineering and Design Task Force thanks Debra Campbell Weston for assisting in the production of the Aluminum Design Manual.

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Please check **www.aluminum.org** for postings of 2020 *Aluminum Design Manual* errata.

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PART I
SPECIFICATION FOR ALUMINUM STRUCTURES

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Aluminum Design Manual

PART I

Specification for Aluminum Structures

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I
Specification for Aluminum Structures

FOREWORD

The first edition of the *Specification for Aluminum Structures* was published in November, 1967, followed by subsequent editions in 1971, 1976, 1982, 1986, 1994, 2000, 2005, 2010, and 2015. This 11th edition of the *Specification*, developed as a consensus document, includes new or revised provisions concerning

- Adding 6005A-T5 extrusions, 6063-T832 drawn tube, and 6360 extrusions
- Deleting 7178-T6 rivets
- The strength of weld-affected zones
- Elevated temperature exposure of weldments
- Deleting bridge-type structures from the scope
- Strength and buckling constants for curved elements
- The strength of elements with an intermediate stiffener
- Post weld heat treated strengths for 6005A and 6061
- Units
- Pull-out strength of screws in screw chases
- Flexural strengths
- Block shear strength
- Flanges and webs with concentrated forces
- The strength of PJP groove welds normal to tension or compression
- Evaluation by load testing
- Bracing

The Aluminum Association gratefully acknowledges the efforts of the Engineering Advisory Committee in developing the *Specification*.

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GUIDELINES FOR THE PREPARATION OF TECHNICAL INQUIRIES ON THE SPECIFICATION FOR ALUMINUM STRUCTURES

Technical inquiries to obtain an interpretation or request a revision to the *Specification for Aluminum Structures* should be directed to:

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jweritz@aluminum.org
The Aluminum Association
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Arlington, VA 22202
www.aluminum.org

Comments on other parts of the *Aluminum Design Manual* are also welcome.

Inquiries should include the inquirer's name, affiliation, and address. Each inquiry should address a single section of the *Specification* unless the inquiry involves two or more interrelated sections. The section and edition of the *Specification* should be identified.

Requests for interpretations should be phrased, where possible, to permit a "yes" or "no" answer and include the necessary background information, including figures where appropriate.

Requests for revisions should include proposed wording for the revision and technical justification.

Inquiries are considered at the first meeting of the Engineering and Design Task Force following receipt of the inquiry.

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Symbols

The section numbers in which the symbol appears is given in parentheses after the symbol.

A_b = nominal cross-sectional area of the bolt (unthreaded body area) (J.3.7.4)

A_b = bearing area (J.8)

A_{BM} = cross-sectional area of the base metal (J.2.5, Table J.2.2)

A_{BM} = area of the base metal in the weld-affected zone (A.4.2)

A_e = effective net area (D.2, D.3.2, J.7.1)

A_{ewz} = effective net area in the weld-affected zone (D.2)

A_f = area of the member farther than $2c/3$ from the neutral axis, where c is the distance from the neutral axis to the extreme compression fiber (F.4)

A_{FM} = area of the filler metal (A.4.2)

A_g = gross cross-sectional area (B.5.4, D.2, E.2, E.2.2, E.3.1, E.3.2, E.4, H.2, J.7.1, J.7.2)

A_{gc} = gross cross sectional area of the element in compression (B.5.5)

A_{gto} = gross area not weld-affected area in tension (J.7.3)

A_{gtw} = gross weld-affected area in tension (J.7.3)

A_{gv} = gross area in shear (J.7.3)

A_{gvo} = gross area not weld-affected in shear (J.7.3)

A_{gvw} = gross weld-affected area in shear (J.7.3)

A_i = area of element i (E.3.1)

A_L = cross-sectional area of the longitudinal stiffener (B.5.5.3)

A_n = net area (D.3.1, D.3.2, G.2, G.3, G.4, G.5, J.7.1)

A_{nt} = net area in tension (J.7.3)

A_{nv} = net area in shear (J.7.2, J.7.3)

A_r = root area of the screw (J.5.4.3, J.5.5.3)

A_s = area of the intermediate stiffener (B.5.4.4)

A_{sn} = thread stripping area of internal thread per unit length of engagement (J.5.4.1.1)

A_v = web area (G.1, G.2, G.3, G.4, G.5)

A_{we} = effective area of a weld (J.2.3, J.2.5, Table J.2.2)

A_{wz} = area of the weld-affected zone (A.4.2, B.5.4, D.2, E.2, F.4, G.1, G.2, G.3, G.4, G.5, H.2)

A_{wzc} = cross sectional area of the weld-affected zone in compression (B.5.5)

B_{br} = buckling constant intercept for flexural compression in flat elements (Table B.4.1, Table B.4.2, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.5, F.5)

B_c = buckling constant intercept for member buckling (Table B.4.1, Table B.4.2, B.5.4.4, E.2)

B_p = buckling constant intercept for uniform compression in flat elements (Table B.4.1, Table B.4.2, B.5.4.1, B.5.4.2, B.5.4.6, F.3.2, F.5)

B_s = buckling constant intercept for shear in flat elements (Table B.4.1, Table B.4.2, G.2, G.3, G.4, H.2.1)

B_t = buckling constant intercept for uniform compression in curved elements (Table B.4.1, Table B.4.2, B.5.4.5, B.5.5.4)

B_{tb} = buckling constant intercept for flexural compression in curved elements (Table B.4.1, Table B.4.2, B.5.5.4)

C = torsional shear constant (H.2.2)

C_b = coefficient that accounts for moment gradient along a beam's length (F.4.1, F.4.1.1, F.4.1.2, F.4.2.1, F.4.2.3, F.4.2.4, F.4.2.5, F.4.3, F.5(c), F.5.1, F.5.2, 6.3.2.1)

C_{br} = buckling constant intersection for flexural compression in flat elements (Table B.4.1, Table B.4.2, B.5.5.2, F.5)

C_c = buckling constant intersection for member buckling (Table B.4.1, Table B.4.2, B.5.4.4, E.2, F.4)

C_d = brace coefficient (6.3.1.1, 6.3.1.2)

C_f = coefficient used to determine the allowable stress range for fatigue (Table 3.2, 3.2, 3.3)

C_n = correction factor for the number of tests (1.3.2)

C_p = buckling constant intersection for uniform compression in flat elements (Table B.4.1, Table B.4.2, B.5.4.1, F.3.2, F.5)

C_{pov} = coefficient for determining the pull-over strength of a screw (J.5.4.2)

C_s = buckling constant intersection for shear in flat elements (Table B.4.1, Table B.4.2, G.2, G.3, G.4, H.2.1)

C_t = buckling constant intersection for uniform compression in curved elements (Table B.4.1, Table B.4.2, B.5.4.5, B.5.5.4)

C_{tb} = buckling constant intersection for flexural compression in curved elements (Table B.4.1, Table B.4.2, B.5.5.4)

C_w = warping constant (E.2.2, F.4.2.1, F.4.2.5)

C_{wa}, C_{wb}, C_{w1}, C_{w2}, C_{w3} = coefficients used to determine web crippling strength (J.9.3.2)

C_1 = coefficient used to determine U (F.4.2.5)

C_2 = coefficient used to determine U (F.4.2.5)

D = nominal diameter of the fastener (Table J.2.2, J.3.1, J.3.4, J.3.5, J.3.6, J.5, J.5.4.1.1, J.5.4.1.2, J.5.4.1.3, J.5.4.2, J.5.5.1, J.5.5.2, J.6.4, J.6.5)

D = diameter of a rod (G.5, H.2.3)

D = outside diameter of a tube (Table 3.1)

D_{br} = buckling constant slope for flexural compression in flat elements (Table B.4.1, Table B.4.2, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.5, F.5)

D_c = buckling constant slope for member buckling (Table B.4.1, Table B.4.2, B.5.4.4, E.2)

D_h = nominal diameter of the hole (J.4.5, J.4.6, Table J.5.1, Table J.5.2, J.5.4.2)

D_i = inside diameter of the pipe or tube (G.4)

D_n = nominal dead load (1.3.2, 4.1.3, 5.4)

D_o = outside diameter of the pipe or tube (G.4)

D_p = buckling constant slope for uniform compression in flat elements (Table B.4.1, Table B.4.2, B.5.4.1,

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B.5.4.2, B.5.4.6, F.3.2, F.5)

D_S = depth of a stiffener (B.5.4.3)

D_s = buckling constant slope for shear in flat elements (Table B.4.1, Table B.4.2, G.2, G.3, G.4, H.2.1)

D_{ss} = screw slot inside diameter (Table J.5.3)

D_t = buckling constant slope for uniform compression in curved elements (Table B.4.1, Table B.4.2, B.5.4.5, B.5.5.4)

D_{tb} = buckling constant slope for flexural compression in curved elements (Table B.4.1, Table B.4.2, B.5.5.4)

D_{ws} = larger of the nominal washer diameter and the screw head diameter, but no greater than 5/8 in. (16 mm) (J.5.4.2)

E = modulus of elasticity (Table A.4.1, Table B.4.1, Table B.4.2, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, B.5.5.5, Table B.5.1, E.2, E.2.2, E.4, F.3.2, F.4, F.4.2.5, F.4.3, F.5, F.5.1, F.5.2, G.2, G.3, G.4, H.2.1, J.9.3.1, J.9.3.2, Table 4.1, 6.3.2.1, 6.3.2.2)

E_m = modulus of elasticity at elevated temperatures (4.2.3.1, Table 4.1)

F_b = stress corresponding to the flexural strength (B.5.5, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, B.5.5.5, F.4.3, F.3.1, H.3.1, H.3.2)

F_{bo} = stress corresponding to the flexural compressive strength for an element if no part of the cross section were weld-affected (B.5.5)

F_{bw} = stress corresponding to the flexural compressive strength for an element if the entire cross section were weld-affected (B.5.5)

F_c = stress corresponding to the uniform compressive strength (B.5.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, E.2, E.3.2, E.4, F.3.1, H.3.1, H.3.2)

F_{ci} = local buckling stress of element i computed per Section B.5.4.1 through B.5.4.5 (E.3.1)

F_{co} = stress corresponding to the uniform compressive strength for an element if no part of the cross section were weld-affected (B.5.4)

F_{cw} = stress corresponding to the uniform compressive strength for an element if the entire cross section were weld-affected (B.5.4)

F_{cy} = compressive yield strength (Table A.4.1, Table B.4.1, Table B.4.2, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.5, E.2, E.3.1, F.2, F.3.1, F.3.2, F.4, F.5, J.9.3.2)

F_{cyw} = compressive yield strength of weld-affected material (E.2, F.4)

F_e = elastic buckling stress (B.5.4.6, B.5.5.5, Table B.5.1, E.2.2, E.4, F.3.2, F.4.3, L.3)

F_{ex} = elastic buckling stress for buckling about the x-axis (E.2.2)

F_{ey} = elastic buckling stress for buckling about the y-axis (E.2.2)

F_{ez} = elastic buckling stress for torsional buckling (E.2.2)

F_m = mean value of the fabrication factor (1.3.2)

F_n = strength of an A 325 bolt (J.3.7.4)

F_{nBM} = nominal stress of the base metal corresponding to its welded ultimate strength from Table A.4.3 or Table A.4.3M (J.2.5)

F_{nt} = tensile strength of an A 325 bolt determined in accordance with the *Specification for Structural Steel Buildings(ANSI/AISC 360)* (J.3.7.4)

F_{nv} = shear strength of an A 325 bolt determined in accordance with the *Specification for Structural Steel Buildings(ANSI/AISC 360)* (J.3.7.4)

F_{nw} = nominal stress of the weld metal corresponding to its ultimate strength from Table A.4.6 (J.2.5)

F_s = shear stress corresponding to the shear strength (G.1, G.2, G.3, G.4, G.5, H.2, H.2.1, H.2.2, H.3.1, H.3.2)

F_{so} = shear stress corresponding to the unwelded shear strength (G.1, H.2)

F_{ST} = stress corresponding to the uniform compressive strength of an element supported on both edges (B.5.4.3)

F_{su} = shear ultimate strength (Table A.4.1, A.4.5, Table A.4.7, A.4.6, Table A.4.8, G.2, G.3, G.4, G.5, H.2, H.2.3, J.3.5, J.4.5, J.5.5.3, J.6.4, J.7.2, J.7.3)

F_{suw} = shear ultimate strength of weld-affected material (G.2, G.3, G.4, G.5, H.2, H.2.3, J.7.3)

F_{sw} = shear stress corresponding to the welded shear strength (G.1, H.2)

F_{sy} = shear yield strength (Table A.4.1, Table B.4.1, Table B.4.2, G.1, G.2, G.3, G.4, G.5, H.2.1, H.2.3, J.6.4, J.7.2)

F_{syw} = shear yield strength of weld-affected material (G.1, H.2.3)

F_{tu} = tensile ultimate strength (Table A.4.1, Table A.4.3, A.4.2, Table A.4.4, A.4.3, Table A.4.7, A.4.5, A.4.6, Table A.4.8, D.2, F.2, J.3.4, J.3.6, J.4.6, J.5.4.1.2, J.5.4.1.3, J.5.4.3, J.5.5.1, J.6.4, J.6.5, J.7.3, J.8, Table 4.2)

F_{tum} = tensile ultimate strength at elevated temperatures (4.2.3.1)

F_{tuw} = tensile ultimate strength of weld-affected material (Table A.4.3, A.4.2, Table A.4.6, A.4.4, D.2, Table J.2.2, J.7.3)

F_{tuwBM} = tensile ultimate strength of the weld-affected base metal (A.4.2)

F_{tuwFM} = tensile ultimate strength of the filler metal (A.4.2)

F_{tuwz} = tensile ultimate strength of the weld-affected zone (A.4.2)

F_{tu1} = tensile ultimate strength of the part in contact with the screw head or washer (J.5.4.2)

F_{tu2} = tensile ultimate strength of member not in contact with the screw head or washer (J.5.4.1.1, J.5.5.2)

F_{ty} = tensile yield strength (Table A.4.1, Table A.4.3,

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Table A.4.4, A.4.2, A.4.3, D.2, F.2, J.6.4, J.9.5, 1.4, Table 4.2)

F_{tyfw} = welded tensile yield strength of the flange (J.9.1)

F_{tym} = tensile yield strength at elevated temperatures (4.2.3.1)

F_{tyw} = tensile yield strength of weld-affected material (A.4.2, Table A.4.3, Table A.4.6, A.4.4, D.2)

F_{tywz} = tensile yield strength of the weld-affected zone (A.4.2)

F_{tywBM} = tensile yield strength of the weld-affected base metal (A.4.2)

F_{tywFM} = tensile yield strength of the filler metal (A.4.2)

F_{ty1} = tensile yield strength of the part in contact with the screw head or washer (J.5.4.2)

F_{ty2} = tensile yield strength of member not in contact with the screw head or washer (J.5.4.1.1)

F_{UT} = stress corresponding to the uniform compressive strength of an element supported on one edge only (B.5.4.3)

F_{yf} = tensile yield strength of the flange (use the welded strength if the flange is welded) (J.9.2)

F_{yw} = tensile yield strength of the web (use the welded strength if the web is welded) (J.9.2, J.9.3.1)

G = shear modulus of elasticity (Table A.4.1, E.2.2)

G_f = the grip of a bolt (J.3.5)

$$H = 1 - \frac{x_o^2 + y_o^2}{r_o^2} \quad \text{(E.2.2)}$$

I_f = moment of inertia of the flange group about the cross section's neutral axis. The flange group consists of the flat elements in uniform compression or uniform tension and their edge or intermediate stiffeners (F.3.1)

I_L = moment of inertia of the longitudinal stiffener about the web of the beam (B.5.5.3)

I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent subelements and the transition corners between them taken about the centroidal axis of the section parallel to the stiffened element (B.5.4.4)

I_s = moment of inertia of the transverse stiffener (G.2)

I_w = moment of inertia of the web group about the cross section's neutral axis. The web group consists of the flat elements in flexure and their intermediate stiffeners. (F.3.1)

I_w = moment of inertia about the major principal axis (F.5.2)

I_x = moment of inertia about the x-axis (E.2.2, F.4.2.5)

I_y = moment of inertia about the y-axis (E.2.2, F.4.1.1, F.4.2.1, F.4.2.2, F.4.2.3, F.4.2.5, 6.3.2.1)

I_{yc} = moment of inertia of the compression flange about the y-axis (F.4.1.1, F.4.2.2, F.4.2.5, 6.3.2.1)

I_{yeff} = effective out-of-plane moment of inertia (6.3.2.1)

I_{yf} = moment of inertia of the flange on the negative side of the midheight (where the direction of the load is the positive direction) about the minor axis of the shape (F.4.1.1)

I_{yt} = moment of inertia of the tension flange about the y-axis (F.4.2.2, 6.3.2.1)

J = torsion constant (E.2.2, F.4.2.1, F.4.2.2, F.4.2.3, F.4.2.5, H.2.1)

K = statistical coefficient based on the number of tests n (1.3.1)

K_s = a coefficient used to determine the pull-out strength of a screw in a hole (J.5.4.1.1)

K_{sc} = a coefficient used to determine the pull-out strength of a screw in a screw chase (J.5.4.1.3)

L = member length (E.2, E.2.1, F.4, J.1.3, 6.1, 6.2.2, 6.3.2.1, 6.3.2.2)

L = live load (5.4)

L_b = length of a beam between brace points or between a brace point and a cantilever's free end (F.4.2.1, F.4.2.3, F.4.2.4, F.4.2.5, F.4.3, F.5.1, F.5.2, 6.1, 6.3.2.1, 6.3.2.2, 6.4)

L_{br} = unbraced length for bracing (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)

L_C = length of the connection in the direction of load, measured from the center of fasteners or the end of welds (D.3.2)

L_e = length of full thread engagement of a screw in a hole, screw slot, or screw chase not including tapping or drilling point (J.5.4.1.1, J.5.4.1.2, J.5.4.1.3)

L_n = nominal live load (1.3.2, 4.1.3)

L_r = nominal roof live load (5.4)

L_s = length of pipe or tube between transverse stiffeners, or overall length if no transverse stiffeners are present (H.2.1)

L_v = length of pipe or tube from maximum to zero shear force (G.4)

L_{we} = effective length of a weld (J.2.1.3, J.2.2.2, Table J.2.2)

L_x = unbraced length for buckling about the x-axis (E.2.2)

L_y = unbraced length for buckling about the y-axis (E.2.2)

L_z = unbraced length for twisting (E.2.2)

M_A = absolute value of the moment at the quarter point of the unbraced segment (F.4.1.1)

M_B = absolute value of the moment at the midpoint of the unbraced segment (F.4.1.1)

M_C = absolute value of the moment at the three-quarter point of the unbraced segment (F.4.1.1)

M_{br} = the required flexural stiffness of the brace (6.3.2.1)

M_c = available flexural strength (F.1, H.1, J.6.4, J.9.3.3)

M_e = elastic lateral-torsional buckling moment (F.4.2.5, F.5, F.5.1, F.5.2)

M_i = flexural strength of member of intermediate thickness t_i (1.4.2)

M_m = mean value of the material factor (1.3.2)

M_{max} = absolute value of the maximum moment in the unbraced segment (F.4.1.1)

M_n = nominal strength moment (F.1, F.5, F.5.1, F.5.2,

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J.6.4)

M_{nlb} = nominal flexural strength for the limit state of local buckling (F.3, F.3.1, F.3.2, F.3.3)

M_{nmb} = nominal flexural strength for the limit state of lateral-torsional buckling (F.4, F.4.3)

M_{nmbo} = lateral-torsional buckling strength if no part of the cross section were weld-affected (F.4)

M_{np} = nominal flexural strength for the limit state of yielding (F.2, F.3.2, F.4)

M_{nmbw} = lateral-torsional buckling strength if the entire cross section were weld-affected (F.4)

M_{nu} = nominal flexural strength for the limit state of rupture (F.2)

M_r = required flexural strength using LRFD or ASD load combinations (H.1, J.6.4, J.9.3.3, 6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2, 6.4)

M_y = yield moment about the axis of bending (F.5)

M_1 = flexural strength of member of thinnest material (1.4.2)

M_2 = flexural strength of member of thickest material (1.4.2)

N = number of stress cycles (3.2, 3.3, Table 3.2)

N_S = number of stress ranges in the spectrum (3.3)

P_{br} = required bracing strength (6.2.2, 6.3.1.2)

P_c = available axial force (D.1, E.1, H.1)

P_{nc} = nominal axial compressive strength (E.1, E.2, E.3.1, E.3.2, E.4)

P_{no} = nominal member buckling strength if no part of the cross section were weld-affected (E.2)

P_{nt} = nominal axial tensile strength (D.2)

P_{nw} = nominal member buckling strength if the entire cross section were weld-affected (E.2)

P_r = required axial force using LRFD or ASD load combinations (C.2, H.1, 6.2.1, 6.2.2, 6.4)

P_y = axial yield strength (C.2)

R = outside radius of a pipe or tube (H.2.1)

R = transition radius of a fatigue detail (Table 3.1)

R = nominal load due to rainwater or snow, exclusive of the ponding contribution (5.4)

R_a = required strength for ASD (B.3.2.2)

R_b = radius of curved elements taken at the mid-thickness of the element (B.5.2, B.5.4.5, B.5.5.4, Table B.5.1, G.4, H.2.1)

R_c = available concentrated force determined in accordance with Section J.9.3.1 or J.9.3.2 (J.9.3, J.9.3.3)

R_i = inside bend radius at the juncture of the flange and web (J.9.3.2)

R_m = bending coefficient factor for singly-symmetric members subjected to double-curvature bending from transverse loading (F.4.1.1)

R_n = nominal strength (B.3.2.1, B.3.2.2, J.2, J.2.5, J.3.4, J.3.5, J.3.6, J.3.7.4, J.4.5, J.4.6, J.5.4, J.5.4.1.1, J.5.4.1.2, J.5.4.1.3, J.5.4.2, J.5.4.3, J.5.5, J.5.5.1, J.5.5.2, J.5.5.3, J.6.4, J.6.5, J.7.1, J.7.2, J.7.3, J.7.4, J.8, J.9.1, J.9.2, J.9.3, J.9.3.1, J.9.3.2, 1.3.1)

R_r = required concentrated force (J.9.3.3)

R_S = the ratio of minimum stress to maximum stress for fatigue design (Table 3.1)

R_{ti} = strength of ith test (1.3.2)

R_{tm} = mean strength of all tests (1.3.1, 1.3.2)

R_u = required strength for LRFD (B.3.2.1)

S_c = section modulus on the compression side of the neutral axis (F.2, F.5, F.5.1)

S_n = nominal snow load (4.1.3, 5.4)

S_{ra} = applied stress range, the algebraic difference between the minimum and maximum nominal stresses perpendicular to the plane of expected cracking determined by elastic methods (3.2)

S_{rd} = design stress range (3.2, 3.3)

S_{re} = equivalent applied stress range (3.3)

S_{ri} = ith applied stress range in the spectrum (3.3)

S_t = section modulus on the tension side of the neutral axis (F.2)

S_w = size of a weld (J.2.1.2, J.2.2.2, Table J.2.2)

S_{we} = effective throat of a fillet weld (J.2.2.1)

S_x = section modulus about the x-axis (F.4.2.1, F.4.2.2)

S_{xc} = section modulus about the compression side of the x-axis (F.3.2, F.4, F.4.2.3, F.4.2.5, F.4.3)

T, T_1, T_2 = temperature (A.4.1.1)

T = nominal forces and deformations due to the design-basis fire defined in Section 4.2.1 (4.1.3)

T_n = nominal torsional strength (H.2, H.2.1, H.2.2, H.2.3, H.2.4)

U = coefficient used to determine M_e (F.4.2.5)

V = shear force on the web at the transverse stiffener (G.2)

V_{br} = the required shear strength of the bracing system in the direction perpendicular to the longitudinal axis of the column (6.2.1, 6.3.1.1)

V_c = available shear strength (G.1, J.6.4)

V_F = coefficient of variation of the fabrication factor (1.3.2)

V_M = coefficient of variation of the material factor (1.3.2)

V_n = nominal shear strength (G.1, G.2, G.3, G.4, G.5, J.6.4)

V_P = coefficient of variation of the ratio of the observed failure loads divided by the average value of all the observed failure loads (1.3.2)

V_Q = coefficient of variation of the loads (1.3.2)

V_r = required shear strength (J.6.4)

X_i = result of the ith test (1.3.2)

Z = plastic section modulus (F.2)

a = fatigue detail dimension parallel to the direction of stress (Table 3.1)

a_1 = shorter dimension of rectangular panel (G.2)

a_2 = longer dimension of rectangular panel (G.2)

b = element width (B.5.1, B.5.3, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.5.1, B.5.5.2, B.5.5.3, Table B.5.1, F.5, F.5.1, F.5.2, G.2, G.3, J.1.3, L.3)

b = fatigue detail dimension normal to the direction of stress and the surface of the base metal (Table 3.1)

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b_e = element's effective width for determining deflections (L.3)
b_f = flange width (J.9.2)
b_s = stiffener width (6.3.2.1)
c = distance from the neutral axis to the extreme fiber (F.4)
c_c = distance from neutral axis to the element extreme fiber with the greatest compressive stress (B.5.5.1)
c_{cf} = distance from the centerline of the compression flange to the cross section's neutral axis (F.3.1)
c_{cs} = distance from the cross section's neutral axis to the extreme fiber of compression flange stiffeners (F.3.1)
c_{cw} = distance from the web group's extreme compression fiber to the cross section's neutral axis (F.3.1)
c_o = distance from neutral axis to the extreme fiber of the element with the greatest tensile stress (B.5.5.1)
d = full depth of the section (F.4.2.1, F.4.2.2, F.4.2.4, G.2, J.9.3.1, J.10.1)
d_e = distance from the center of the fastener to the edge of the part in the direction of force (J.3.6, J.4.6, J.5.5.1, J.6.5)
d_f = the distance between the flange centroids; for T-shapes d_f is the distance between the flange centroid and the tip of the stem. (F.4.2.5)
d_s = stiffener's flat width (B.5.4.3)
d_1 = distance from the neutral axis to the compression flange (B.5.5.3)
e = base for natural logarithms = 2.71828… (1.3.2)
f = compressive stress at the toe of the flange (B.5.5.3)
f_a = maximum compressive stress in the element from the service load combinations (L.3)
f_b = compressive stress due to flexure (H.3.1, H.3.2)
f_c = compressive stress due to axial compression (H.3.1, H.3.2)
f_s = shear stress due to shear and torsion (H.3.1, H.3.2)
g = transverse center-to-center spacing (gage) between fastener gage lines (D.3.1, J.1.3)
g_0 = distance from the shear center to the point of application of the load; g_0 is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$. (F.4.2.5)
h = distance between flanges (J.9.5)
h_o = distance between flange centroids (6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2)
k = effective length factor for buckling (C.3, E.2.1, J.1.3, 6.1, 6.2.2)
k_t = tension coefficient (Table A.4.3, A.4.3, D.2, F.2, G.2, G.3, G.4, G.5, H.2, H.2.3, J.2.7, J.6.4, J.7.2, J.7.3)
k_x = effective length factor for flexural buckling about the x-axis (E.2.2)
k_y = effective length factor for flexural buckling about the y-axis (E.2.2)
k_z = effective length factor for torsional buckling (E.2.2)
k_1 = coefficient for determining the λ_2 slenderness limit for elements with postbuckling strength (Table B.4.3, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.5)
k_2 = coefficient for determining postbuckling strength (Table B.4.3, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.5, F.3.2)
l_b = length of the bearing at the concentrated force (J.9.2, J.9.3.1, J.9.3.2)
m = coefficient for elements in flexure and supported on both edges (B.5.5.1)
m = coefficient used to determine the allowable stress range for fatigue (Table 3.2, 3.2, 3.3)
n = number of threads/in. (mm) (Table J.2.2, J.3.4, J.3.5, J.5.4.1.1, J.5.4.1.3)
n = number of braced points in the span (6.3.2.1, 6.3.2.2)
n = number of tests (1.3.1, 1.3.2)
q = design pressure load for roofing and siding (1.4)
r = radius of gyration (E.2.1)
r_o = polar radius of gyration of the cross section about the shear center (E.2.2)
r_s = stiffener's radius of gyration about the stiffened element's mid-thickness (B.5.4.3)
r_x = radius of gyration about the x-axis (E.2.2, F.4.2.1)
r_y = radius of gyration about the y-axis (E.2.2, F.4.2.1)
r_{ye} = effective radius of gyration about the y-axis for lateral-torsional buckling (F.4.2.1, F.4.2.2, F.4.3)
r_z = radius of gyration about the minor principal axis (F.5.2)
s = transverse stiffener spacing. For a stiffener composed of a pair of members, one on each side of the web, the stiffener spacing s is the clear distance between the pairs of stiffeners. For a stiffener composed of a member on only one side of the web, the stiffener spacing s is the distance between fastener lines or other connecting lines. (B.5.5.3, G.2)
s = longitudinal center-to-center spacing (pitch) of any two consecutive holes (D.3.1, J.1.3)
t = element thickness (B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, Table B.5.1, F.4.2.4, F.5, F.5.1, F.5.2, G.2, G.3, G.4, H.2.1, J.1.3, J.2.2.1, J.3.6, J.4.6, J.5.5.1, J.6.5)
t = time (A.4.1.1)
t = distance from the neutral axis to the extreme tensile fibers (6.3.2.1)
t_{avg} = average thickness of a tapered thickness element (B.5.3)
t_f = flange thickness (J.9.1, J.9.2, J.9.3.1)
t_i = thickness of intermediate thickness material (1.4.2)
t_{max} = maximum thickness of a tapered thickness element (B.5.3)
t_{max} = thickness of thickest material tested (1.4.2)
t_{min} = minimum thickness of a tapered thickness element (B.5.3)

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t_{min} = thickness of thinnest material tested (1.4.2)
t_{st} = beam web stiffener thickness (6.3.2.1)
t_w = beam web thickness (J.9.2, J.9.3.1, J.9.3.2, J.9.5, 6.3.2.1, 6.3.2.2)
t_1 = nominal thickness of the part in contact with the screw head or washer (J.5.4.2, J.5.5.2)
t_1 = time corresponding to temperature T_1 (A.4.1.1)
t_2 = nominal thickness of the part not in contact with the screw head or washer (J.5.5.2)
t_2 = time corresponding to temperature T_2 (A.4.1.1)
w_c = nominal width of a screw chase (J.5.4.1.3)
$\overline{x}$ = eccentricity of the connection in the x-axis direction (D.3.2)
x_o = the shear center's x-coordinate (E.2.2)
$\overline{y}$ = eccentricity of the connection in the y-axis direction (D.3.2)
y_o = the shear center's y-coordinate (E.2.2, F.4.2.5)
z_o = coordinate along the z-axis of the shear center with respect to the centroid (F.5.2)
Ω = safety factor (B.3.2.2, D.1, E.1, F.1, G.1, H.2, H.3.1, H.3.2, J.2, J.3.4, J.3.5, J.3.6, J.3.7.4, J.3.7.5, J.4.5, J.4.6, J.5.4, J.5.5, J.6.4, J.6.5, J.7.1, J.7.2, J.7.3, J.7.4, J.8, J.9.1, J.9.2, J.9.3, 1.3.2, 6.1, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1)
α = factor used to determine reduced flexural stiffness (C.2)
α = ratio of nominal dead load to nominal live load (1.3.2)
α = coefficient of thermal expansion (Table A.4.1)
α_i = number of stress cycles in the spectrum of the ith stress range divided by the total number of stress cycles (3.3)
α_s = coefficient for a longitudinal stiffener (B.5.5.3)
β_{br} = required shear stiffness of the bracing (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1)
β_o = target reliability index (1.3.2)
β_{sec} = web distortional stiffness (6.3.2.1, 6.3.2.2)
β_T = overall brace system stiffness (6.3.2.1)
β_x = coefficient of monosymmetry about the x-axis (F.4.2.5)
β_w = coefficient of monosymmetry (F.5.2)
γ = density (Table A.4.1)

$\delta = \dfrac{(t_{max} - t_{min})}{t_{min}}$ = a measure of taper in tapered thickness elements (B.5.3)
θ_s = angle between a stiffener and the stiffened element (B.5.4.3)
θ_w = angle between the plane of web and the plane of the bearing surface ($\theta_w \le 90^o$) (J.9.3.2)
$\varkappa$ = metric conversion factor (Table B.4.1, Table B.4.2)
λ = slenderness
λ_1 = slenderness at the intersection of the equations for yielding and inelastic buckling
λ_2 = slenderness at the intersection of the equations for inelastic buckling and elastic buckling, or inelastic buckling and postbuckling.
$\lambda_e = 1.28\sqrt{E/F_{cy}}$ (B.5.4.3)
$\lambda_{eq} = \pi\sqrt{\dfrac{E}{F_e}}$
= equivalent slenderness for alternate determination of compressive strength for flexural or axial compression (B.5.4.6, B.5.5.5, F.3.2)
λ_s = slenderness of an element with an intermediate stiffener (B.5.4.4, Table B.5.1)
μ = mean slip coefficient (J.3.7.5)
ν = Poisson's ratio (Table A.4.1)
ρ_{ST} = stiffener effectiveness ratio (B.5.4.3, Table B.5.1)
σ_x = standard deviation of the test strengths (1.3.1)
τ_b = parameter for reduced flexural stiffness (C.2)
ϕ = resistance factor (B.3.2.1, D.1, E.1, F.1, G.1, H.2, H.3.1, H.3.2, J.2, J.3.4, J.3.5, J.3.6, J.3.7.4, J.3.7.5, J.4.5, J.4.6, J.5.4, J.5.5, J.6.4, J.6.5, J.7.1, J.7.2, J.7.3, J.7.4, J.8, J.9.1, J.9.2, J.9.3, 1.3.2, 6.1, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1)

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allowable strength: nominal strength divided by the safety factor, R_n/Ω.

allowable stress: allowable strength divided by the appropriate section property, such as section modulus or cross section area.

aluminum: aluminum or an aluminum alloy.

analysis: the rational determination of the effects of loads on and the strength of structures, members, and connections based on appropriate theory, relevant test data, and sound engineering judgment.

applicable building code: the building code under which the structure is designed.

ASD (Allowable Strength Design): the method of proportioning structural components such that the allowable strength equals or exceeds the required strength of the component under the action of the ASD load combinations.

ASD load combination: the load combination in the applicable building code intended for allowable strength design.

available strength: for LRFD, design strength; for ASD, allowable strength.

beam: a structural member that has the primary function of resisting bending moments.

bearing-type connection: a bolted connection where shear forces are transmitted by the bolt bearing against the connection elements.

blind rivet: a rivet that can be installed with access to only one side of the parts being joined.

block shear rupture: in a connection, the limit state of tensile fracture or yielding along one path and shear yielding or fracture along another path.

bolt: a headed and externally threaded mechanical device designed for insertion through holes in assembled parts to mate with a nut and normally intended to be tightened or released by turning that nut.

buckling: the limit state of a sudden change in the geometry of a structure or any of its elements under a critical loading condition.

building-type structure: a structure of the type addressed by a building code.

camber: curvature fabricated into a beam or truss so as to compensate for deflection induced by loads.

closed shape: a hollow shape that resists lateral-torsional buckling primarily by torsional resistance rather than warping resistance, that is, for which C_w is much less than $0.038JL_b^2$. See Section F.4.2.3.

column: a structural member that has the primary function of resisting a compressive axial force.

contract documents: documents that define the responsibilities of the parties that design, fabricate, or erect the structure.

design load: the applied load determined in accordance with either LRFD load combinations or ASD load combinations, whichever is applicable.

design strength: the resistance factor multiplied by the nominal strength, ϕR_n.

design stress: the design strength divided by the appropriate section property, such as section modulus or cross section area.

doubler: a plate added to, and parallel with, a beam or column web to increase the strength at locations of concentrated forces.

effective length: the length of an otherwise identical column with the same strength when analyzed with pinned end conditions.

effective length factor: ratio between the effective length and the unbraced length of the member.

effective net area: net area modified to account for the effect of shear lag.

elastic analysis: structural analysis based on the assumption that the structure returns to its original geometry on removal of the load.

element: a component of a shape's cross section. Elements are connected to other elements only along their longitudinal edges. Elements addressed by the *Specification* include flat elements, described by their width b and thickness t, and curved elements, described by their mid-thickness radius R_b and thickness t. An Aluminum Association standard W shape, for example, consists of five flat elements: a web element and two elements in each flange.

engineer of record: engineer responsible for the structural design.

factored load: the product of a load factor and the nominal load.

fastener: a device such as a bolt, rivet, screw, or pin used to mechanically connect two or more parts.

fatigue: the limit state of crack initiation and growth resulting from repeated application of loads.

filler metal: metal to be added in making a welded joint.

fillet weld: weld of generally triangular cross section made between intersecting surfaces of elements.

flexural buckling: a buckling mode in which a compression member deflects laterally without twist or change in cross-sectional shape.

flexural-torsional buckling: a buckling mode in which a compression member bends and twists simultaneously without change in cross-sectional shape.

gage: transverse center-to-center spacing of fasteners.

gauge: a term previously used in referring to the thickness of a wrought product. Thickness is preferred in dimension description.

geometric axis: axis parallel to a web, flange, or angle leg.

grip: thickness of material through which a fastener passes.

lateral-torsional buckling: the buckling mode of a flexural member involving deflection normal to the plane of bending occurring simultaneously with twist about the

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shear center of the cross-section.

limit state: a condition in which a structure or component becomes unfit for service and is judged either to be no longer useful for its intended function (serviceability limit state) or to have reached its ultimate load-carrying capacity (strength limit state).

load effect: forces, stresses, and deformations produced in a structural component by the applied loads.

load factor: a factor that accounts for deviations of the nominal load from the actual load, for uncertainties in the analysis that transforms the load into a load effect and for the probability that more than one extreme load will occur simultaneously.

local buckling: the limit state of buckling of a compression element within a cross section.

lockbolt: a two-piece fastener consisting of a shaft (bolt) and collar. The softer, smooth bore collar is mechanically swaged (reduced or tapered by squeezing) onto the pin and into either zero pitch, annular lock grooves or special thread form grooves in a tension-tension installation method. Hydraulic or pneumatic installation tools provide the tension and swaging action.

longitudinal centroidal axis: axis through the centroid of a member along its length

LRFD (*Load and Resistance Factor Design*): a method of proportioning structural components such that the design strength equals or exceeds the required strength of the component under the action of the LRFD load combinations.

LRFD load combination: a load combination in the applicable building code intended for strength design (load and resistance factor design).

member: an individual, discrete component of a larger structure, such as a beam or column.

member buckling: flexural, torsional, or flexural-torsional buckling of the overall member.

net area: gross area reduced to account for removed material.

nominal dimension: designated or theoretical dimension, as in the tables of section properties.

nominal load: magnitude of the load specified by the applicable building code.

nominal strength: strength of a structure or component (without the resistance factor or safety factor applied) available to resist load effects, as determined in accordance with this *Specification*.

pin: a fastener that is a rod about which the connected parts are free to rotate.

pitch: longitudinal center-to-center spacing of fasteners; center-to-center spacing of bolt threads along the axis of a bolt.

post-buckling strength: the load or force that can be carried by an element, member, or frame after initial elastic buckling has occurred.

pull-out: the tensile load required to pull a screw out of a threaded part.

pull-over: the tensile load required to pull a part over the head of a screw.

quality assurance: monitoring and inspection tasks performed by an agency or firm other than the fabricator or erector to ensure that the material provided and work performed by the fabricator and erector meet the requirements of the approved construction documents and referenced standards. Quality assurance includes those tasks designated "special inspection" by the applicable building code.

quality control: controls and inspections implemented by the fabricator or erector, as applicable, to ensure that the material provided and the work performed meet the requirements of the approved construction documents and referenced standards.

required strength: Forces, stresses and deformations acting on a structural component determined by either structural analysis, for the LRFD or ASD load combinations, as appropriate, or as specified by this *Specification*.

resistance factor: a factor, ϕ, that accounts for unavoidable deviations of the actual strength from the nominal strength and for the manner and consequences of failure.

rivet: a headed and unthreaded mechanical device used to assemble two or more components by an applied force which deforms the plain rivet end to develop a completed mechanical joint.

rod: a solid wrought product that is long in relation to its circular cross section, which is not less than 0.375 in. diameter.

safety factor: a factor, Ω, that accounts for deviations of the actual strength from the nominal strength, deviations of the actual load from the nominal load, uncertainties in the analysis that transforms the load into a load effect, and for the manner and consequences of failure.

screw: a headed and externally threaded fastener held in place by threading into one of the connected parts.

screw chase: a groove parallel to the longitudinal axis of an extrusion, intended to retain a screw whose axis is perpendicular to the longitudinal axis of the extrusion. (See Figure GL.1).

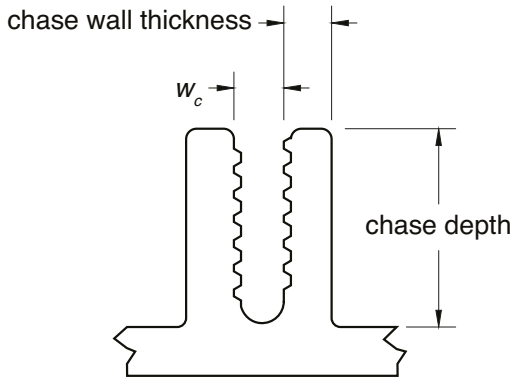

Figure GL.1a
CROSS SECTION OF A RIBBED-WALL SCREW CHASE

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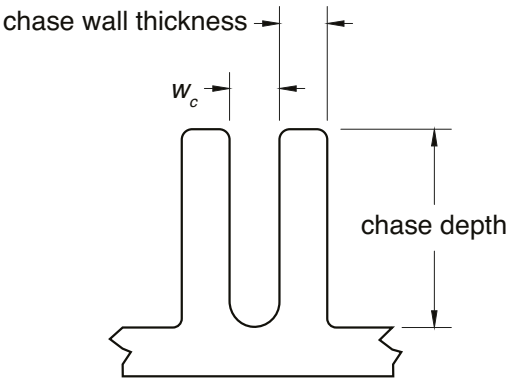

Figure GL.1b
CROSS SECTION OF A FLAT-WALL SCREW CHASE

screw slot: a semi-hollow in an extrusion intended to retain a screw parallel to the axis of the extrusion. (See Figure GL.2).

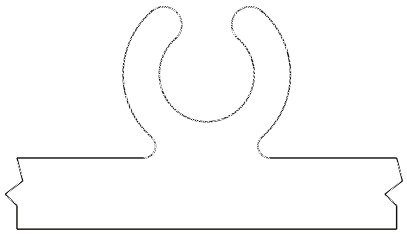

Figure GL. 2
CROSS SECTION OF A SCREW SLOT

self-drilling screw: a screw that drills and taps its own hole as it is being driven.

service load: load under which serviceability limit states are evaluated.

service load combination: load combinations under which serviceability limit states are evaluated.

slip-critical connection: a bolted connection designed to resist movement by friction on the faying surface of the connection under the clamping forces of the bolts.

stiffener: a structural element attached or integral to a member to distribute load, transfer shear, or prevent buckling. Stiffeners may be longitudinal or transverse to the member's longitudinal axis.

structural component: member, connector, connecting element or assemblage.

structure: an object, including but not limited to buildings, walls, fences, towers, bridges, railings, signs, and luminaires, designed to support loads.

tapping screw: a screw that threads a preformed hole as it is being driven.

thread cutting screw: a tapping screw that is installed into a preformed hole, with internal mating threads formed as a result of cutting out the material being tapped to form the relief area of the threaded shank.

thread forming screw: a tapping screw that is installed into a preformed hole, with internal mating threads formed as a result of cold flow of the material being tapped into the relief area of the threaded shank.

torsional buckling: a buckling mode in which a compression member twists about its shear center axis.

unbraced length: the length of a member between brace points or between a brace point and a cantilever's free end, measured between the longitudinal centroidal axes of the bracing members. For columns, brace points are points at which lateral translation is restrained for flexural buckling or twisting is restrained for torsional buckling. For beams, brace points are points at which the compression flange is restrained against lateral deflection or the cross section is restrained against twisting.

weld-affected zone: metal within 1 in. (25 mm) of the centerline of a groove weld or the heel of a fillet weld

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A.1 SCOPE

The *Specification for Aluminum Structures*, hereafter referred to as the *Specification*, shall apply to the design, fabrication, and erection of aluminum load-carrying structures, members, and connections.

This *Specification* includes the symbols, glossary, Chapters A through N, and Appendices 1, 3, 4, 5, and 6.

The provisions of this *Specification*, or a more rigorous analysis, shall be used for all cases addressed by this *Specification*. Appropriate analysis shall be used for cases not addressed by this *Specification*.

A.2 REFERENCED DOCUMENTS

The following documents are referenced in this *Specification*:

Aluminum Association

Code of Standard Practice for Fabricating and Erecting Structural Aluminum (2020)

Standards for Aluminum Sand and Permanent Mold Castings (2008)

American Institute for Steel Construction

Specification for Structural Steel Buildings (ANSI/AISC 360-16)

American Society for Nondestructive Testing (ASNT)

ASNT CP-189-2016, *Standard for the Qualification and Certification of Nondestructive Testing Personnel*

American Society of Civil Engineers (ASCE)

ASCE/SEI 7-16 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*

American Society of Mechanical Engineers (ASME)

ASME B18.6.4-1998(R2005) *Thread Forming and Thread Cutting Tapping Screws and Metallic Drive Screws, Inch Series*

ASME B46.1-2009 *Surface Texture (Surface Roughness, Waviness, and Lay)*

American Welding Society (AWS)

AWS A.5.10/A5.10M:2017 *Welding Consumables – Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum-Alloys - Classification*

AWS B5.1:2013, *Specification for the Qualification of Welding Inspectors*

AWS D1.2/D1.2M:2014 *Structural Welding Code – Aluminum*

ASTM International (ASTM)

A194/A194M-18 *Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

A563-15 *Standard Specification for Carbon and Alloy Steel Nuts*

A563M-07(2013) *Standard Specification for Carbon and Alloy Steel Nuts [Metric]*

B26/B26M-18e1 *Standard Specification for Aluminum-Alloy Sand Castings*

B108/B108M-18e1 *Standard Specification for Aluminum-Alloy Permanent Mold Castings*

B209-14 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

B209M-14 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate [Metric]*

B210/B210M-19 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*

B211/B211M-19 *Standard Specification for Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire*

B221-14 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*

B221M-13 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]*

B241/B241M-16 *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*

B247-15 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*

B247M-15 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings [Metric]*

B308/B308M-10 *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*

B316/B316M-15 *Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*

B429/B429M-10e1 *Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube*

B557-15 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*

B557M-15 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)*

B632/B632M-18 *Standard Specification for Aluminum-Alloy Rolled Tread Plate*

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B928/B928M-15 *Standard Specification for High Magnesium Aluminum-Alloy Products for Marine Service and Similar Environments*

E119-18ce1 *Standard Test Methods for Fire Tests of Building Construction and Materials*

E330/E330M-14 *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*

E1592-05(2017) *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*

F436/F436M-18a *Standard Specification for Hardened Steel Washers Inch and Metric Dimensions*

F467-13(2018) *Standard Specification for Nonferrous Nuts for General Use*

F467M-06a(2018) *Standard Specification for Nonferrous Nuts for General Use [Metric]*

F468-16 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use*

F468M-06(2018) *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]*

F606/F606M-16 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*

F3125/F3125M-18 *Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength*

Research Council on Structural Connections (RCSC)
Specification for Structural Joints Using High Strength Bolts, 2014

A.3 UNITS

This *Specification* has requirements given in two alternate systems of units. Users shall comply with either:

a) all the requirements given in this *Specification* in US customary units, or

b) all the requirements given in this *Specification* in SI units.

The system used shall be used consistently for a given structure.

A.4 MATERIAL

A.4.1 General Provisions

The properties listed in Table A.4.1 shall be used unless more precise values are specified.

Table A.4.1
MATERIAL PROPERTIES

PROPERTY	SYMBOL	VALUE
Poisson's ratio	ν	0.33
Modulus of elasticity	E	10,100 ksi 70,000 MPa
Shear modulus of elasticity	G	3,800 ksi 26,000 MPa
Coefficient of thermal expansion	α	13×10^{-6}/°F 23×10^{-6}/°C
Density	γ	0.10 lb/in^3 2.7×10^3 kg/m^3
Shear yield strength	F_{sy}	0.6 F_{ty}
Shear ultimate strength	F_{su}	0.6 F_{tu}
Compressive yield strength		
unwelded - H temper material	F_{cy}	0.9 F_{ty}
all other material	F_{cy}	F_{ty}

A.4.1.1 Properties at Elevated Temperatures

Except as noted in Section A.4.1.2, the properties given in Section A.4 apply to material held at temperatures of 200°F (93°C) or less for any period of time and for the alloys and tempers listed in Table A.4.2 held at the temperatures listed in Table A.4.2 for cumulative periods of time no greater than the times listed in Table A.4.2. When alloys not addressed in Table A.4.2 are heated above 200°F or alloy-tempers addressed in Table A.4.2 are heated beyond the time-temperature limits of Table A.4.2, properties used in design shall be adjusted to the properties after heating. Table 4.1 gives the modulus of elasticity for 6xxx alloys at elevated temperatures and Table 4.2 gives strengths of 6061-T6, 6063-T5, and 6063-T6 at elevated temperatures.

Table A.4.2
TIME-TEMPERATURE LIMITS FOR T5 AND T6 TEMPERS OF 6005, 6005A, 6061, AND 6063

TEMPERATURE		TIME
°F	°C	
450	230	5 min
425	220	15 min
400	205	30 min
375	190	2 hr
350	175	10 hr
325	165	100 hr
300	150	1,000 hr
212	100	100,000 hr

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Interpolate time (t) for other temperatures T using

$$\log t = \log t_2 + \frac{\log\left(T_2 / T\right)}{\log\left(T_2 / T_1\right)} \log\left(t_1 / t_2\right) \qquad \text{(A.4-1)}$$

where

T_1 = next lower temperature in Table A.4.2 than T
T_2 = next higher temperature in Table A.4.2 than T
t_1 = time corresponding to T_1
t_2 = time corresponding to T_2

A.4.1.2 Temperature Limits

Base metal alloys 535.0, 5083, 5086, 5154, and 5456 and weldments made with filler metal alloys 5183, 5356, 5556, or 5654 shall not be subjected to temperatures greater than 150°F (66°C), except during fabrication in accordance with Section M.3.

A.4.2 Wrought Products

This *Specification* applies to the wrought products listed in Table A.4.3 and produced to one of the ASTM specifications listed in Table A.4.3 or A.4.3M.

The tensile ultimate strength F_{tu}, tensile yield strength F_{ty}, and tension coefficient k_t of non-weld affected wrought material and the tensile ultimate strength F_{tuw} and tensile yield strength F_{tyw} of weld-affected wrought material used to determine available strength shall be as listed in Table A.4.3 or A.4.3M. The tensile ultimate strength F_{tuwz} and tensile yield strength F_{tywz} of the weld-affected zone used to determine available strength is the weighted average of the strengths of the weld-affected wrought material and the filler metal as determined by equations A.4-2 and A.4-3, respectively.

$$F_{tuwz} = (F_{tuwBM}\, A_{BM} + F_{tuwFM}\, A_{FM})/A_{wz} \qquad \text{(A.4-2)}$$

$$F_{tywz} = (F_{tywBM}\, A_{BM} + F_{tywFM}\, A_{FM})/A_{wz} \qquad \text{(A.4-3)}$$

where

F_{tuwBM} = tensile ultimate strength of the weld-affected base metal given in Table A.4.3 or A.4.3M

F_{tuwFM} = tensile ultimate strength of the filler metal given in Table A.4.6.

F_{tywBM} = tensile yield strength of the weld-affected base metal given in Table A.4.3 or A.4.3M

F_{tywFM} = tensile yield strength of the filler metal given in Table A.4.6.

A_{BM} = area of the base metal in the weld-affected zone

A_{FM} = area of the filler metal

A_{wz} = area of the weld-affected zone, which extends 1 in. (25 mm) from the centerline of a groove weld or the heel of a fillet weld

$$A_{wz} = A_{BM} + A_{FM} \qquad \text{(A.4-4)}$$

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Table A.4.3
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS in		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	ksi	ksi	ksi	ksi	
1060	H12[1]	B209, sheet & plate	0.017	2.000	11	9	8	2.5	1
1060	H12	B210, drawn tube	0.010	0.500	10	4	8.5	2.5	1
1060	H14[1]	B209, sheet & plate	0.009	1.000	12	10	8	2.5	1
1060	H14	B210, drawn tube	0.010	0.500	12	10	8.5	2.5	1
1100	H12[1]	B209, sheet & plate	0.017	2.000	14	11	11	3.5	1
1100	H12	B210, drawn tube	0.014	0.500	14	11	11	3.5	1
1100	H14[1]	B209, sheet & plate	0.009	1.000	16	14	11	3.5	1
1100	H14	B210, drawn tube	0.014	0.500	16	14	11	3.5	1
2014	T6	B209, sheet & plate	0.040	0.249	66	58	–	–	1.25
2014	T651	B209, sheet & plate	0.250	2.000	67	59	–	–	1.25
2014	T6, T6510, T6511	B221, extrusion	–	0.499	60	53	–	–	1.25
2014	T6, T651	B211, bar, rod, & wire	0.125	8.000	65	55	–	–	1.25
2014	T6	B210, drawn tube	0.018	0.500	65	55	–	–	1.25
Alclad 2014	T6	B209, sheet & plate	0.040	0.050	63	55	–	–	1.25
Alclad 2014	T6	B209, sheet & plate	0.051	0.124	64	57	–	–	1.25
Alclad 2014	T651	B209, sheet & plate	0.250	0.499	64	57	–	–	1.25
2219	T87	B209, sheet & plate	0.250	3.000	64	51	35	26	1.25
3003	H12[1]	B209, sheet & plate	0.017	2.000	17	12	14	5	1
3003	H12	B210, drawn tube	0.010	0.500	17	12	14	5	1
3003	H14[1]	B209, sheet & plate	0.009	1.000	20	17	14	5	1
3003	H14	B210, drawn tube	0.010	0.500	20	17	14	5	1
3003	H16[1]	B209, sheet & plate	0.006	0.162	24	21	14	5	1
3003	H16	B210, drawn tube	0.010	0.500	24	21	14	5	1
3003	H18[1]	B209, sheet & plate	0.006	0.128	27	24	14	5	1
3003	H18	B210, drawn tube	0.010	0.500	27	24	14	5	1
Alclad 3003	H12[1]	B209, sheet & plate	0.017	2.000	16	11	13	4.5	1
Alclad 3003	H14[1]	B209, sheet & plate	0.009	1.000	19	16	13	4.5	1
Alclad 3003	H16[1]	B209, sheet & plate	0.006	0.162	23	20	13	4.5	1
Alclad 3003	H14	B210, drawn tube	0.010	0.500	19	16	13	4.5	1
Alclad 3003	H18	B210, drawn tube	0.010	0.500	26	23	13	4.5	1
3004	H32[1]	B209, sheet & plate	0.017	2.000	28	21	22	8.5	1
3004	H34[1]	B209, sheet & plate	0.009	1.000	32	25	22	8.5	1
3004	H36[1]	B209, sheet & plate	0.006	0.162	35	28	22	8.5	1
3004	H38[1]	B209, sheet & plate	0.006	0.128	38	31	22	8.5	1
Alclad 3004	H32[1]	B209, sheet & plate	0.017	2.000	27	20	21	8	1
Alclad 3004	H34[1]	B209, sheet & plate	0.009	1.000	31	24	21	8	1
Alclad 3004	H36[1]	B209, sheet & plate	0.006	0.162	34	27	21	8	1
3005	H25	B209, sheet & plate	0.016	0.080	26	22	–	–	1
3005	H28	B209, sheet & plate	0.016	0.080	31	27	–	–	1
3105	H25	B209, sheet & plate	0.013	0.080	23	19	–	–	1
5005	H12	B209, sheet & plate	0.017	2.000	18	14	15	5	1
5005	H14	B209, sheet & plate	0.009	1.000	21	17	15	5	1
5005	H16	B209, sheet & plate	0.006	0.162	24	20	15	5	1
5005	H32[1]	B209, sheet & plate	0.017	2.000	17	12	15	5	1

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Table A.4.3 (Continued)
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS in		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	ksi	ksi	ksi	ksi	
5005	H34[1]	B209, sheet & plate	0.009	1.000	20	15	15	5	1
5005	H36[1]	B209, sheet & plate	0.006	0.162	23	18	15	5	1
5050	H32[1]	B209, sheet & plate	0.017	0.249	22	16	18	6	1
5050	H32	B210, drawn tube	0.010	0.500	22	16	18	6	1
5050	H34[1]	B209, sheet & plate	0.009	0.249	25	20	18	6	1
5050	H34	B210, drawn tube	0.010	0.500	25	20	18	6	1
5050	H36[1]	B209, sheet & plate	0.006	0.162	27	22	18	6	1
5052	O	B209, sheet & plate	0.006	3.000	25	9.5	25	9.5	1
5052	H32[1]	B209, sheet & plate	0.017	2.000	31	23	25	9.5	1
5052	H32	B210, drawn tube	0.010	0.450	31	23	25	10	1
5052	H34[1]	B209, sheet & plate	0.009	1.000	34	26	25	9.5	1
5052	H34	B210, drawn tube	0.010	0.450	34	26	25	10	1
5052	H36[1]	B209, sheet & plate	0.006	0.162	37	29	25	9.5	1
5083	O, H112	B221, extrusion	–	2.999	39	16	39	16	1
5083	O	B209, sheet & plate	0.051	1.500	40	18	40	18	1
5083	H111	B221, extrusion	–	2.999	40	24	39	16	1
5083	H111	B247, forging	–	4.000	42	22	38	16	1
5083	H116	B928, sheet & plate	0.125	1.500	44	31	40	18	1
5083	H116	B928, sheet & plate	1.501	3.000	41	29	39	17	1
5083	H32	B209, sheet & plate	0.125	1.500	44	31	40	18	1
5083	H32	B209, sheet & plate	1.501	3.000	41	29	39	17	1
5083	H321	B928, sheet & plate	0.125	1.500	44	31	40	18	1
5083	H321	B928, sheet & plate	1.501	3.000	41	29	39	17	1
5086	O, H112	B221, extrusion	–	2.999	35	14	35	14	1
5086	O	B209, sheet & plate	0.020	2.000	35	14	35	14	1
5086	H111	B221, extrusion	–	2.999	36	21	35	14	1
5086	H112	B209, sheet & plate	0.188	0.499	36	18	35	14	1
5086	H112	B209, sheet & plate	0.500	1.000	35	16	35	14	1
5086	H112	B209, sheet & plate	1.001	2.000	35	14	35	14	1
5086	H112	B209, sheet & plate	2.001	3.000	34	14	34	14	1
5086	H116	B928, sheet & plate	0.063	2.000	40	28	35	14	1
5086	H32[1]	B209, sheet & plate	0.020	2.000	40	28	35	14	1
5086	H32	B210, drawn tube	0.010	0.450	40	28	35	14	1
5086	H34[1]	B209, sheet & plate	0.009	1.000	44	34	35	14	1
5086	H34	B210, drawn tube	0.010	0.450	44	34	35	14	1
5086	H321	B928, sheet & plate	0.063	2.000	40	28	35	14	1
5154	H38[1]	B209, sheet & plate	0.006	0.128	45	35	30	11	1
5454	O, H112	B221, extrusion	–	2.999	31	12	31	12	1
5454	O	B209, sheet & plate	0.020	3.000	31	12	31	12	1
5454	H111	B221, extrusion	–	2.999	33	19	31	12	1
5454	H32[1]	B209, sheet & plate	0.020	2.000	36	26	31	12	1
5454	H34[1]	B209, sheet & plate	0.020	1.000	39	29	31	12	1
5456	O	B209, sheet & plate	0.051	1.500	42	19	42	19	1
5456	H116	B928, sheet & plate	0.063	1.250	46	33	42	19	1

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Table A.4.3 (Continued)
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS in		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	ksi	ksi	ksi	ksi	
5456	H116	B928, sheet & plate	1.251	1.500	44	31	42	19	1
5456	H116	B928, sheet & plate	1.501	3.000	41	29	41	18	1
5456	H32	B209, sheet & plate	0.188	0.499	46	33	42	19	1
5456	H32	B209, sheet & plate	0.500	1.500	44	31	42	19	1
5456	H32	B209, sheet & plate	1.501	3.000	41	29	41	18	1
5456	H321	B928, sheet & plate	0.188	0.499	46	33	42	19	1
5456	H321	B928, sheet & plate	0.500	1.500	44	31	42	19	1
5456	H321	B928, sheet & plate	1.501	3.000	41	29	41	18	1
6005	T5	B221, extrusion	–	1.000	38	35	24	15	1.25
6005A	T5	B221, extrusion	–	0.999	38	31	24	15	1
6005A	T61	B221, extrusion	–	1.000	38	35	24	15	1
6061	T6, T651	B209, sheet & plate	0.010	4.000	42	35	24	15	1
6061	T6	B632, tread plate	0.100	0.625	42	35	24	15	1
6061	T6, T6510, T6511	B221, extrusion	All		38	35	24	15	1
6061	T6, T651	B211, bar, rod, & wire	0.125	8.000	42	35	24	15	1
6061	T6	B210, drawn tube	0.025	0.500	42	35	24	15	1
6061	T6	B241, pipe & tube	All		38	35	24	15	1
6061	T6	B429, pipe & tube	All		38	35	24	15	1
6061	T6	B247, forging	–	4.000	38	35	24	15	1
6061	T6	B308, std structural profile	0.062		38	35	24	15	1
6063	T5	B221, extrusion	–	0.500	22	16	17	8	1
6063	T5	B221, extrusion	0.501	1.000	21	15	17	8	1
6063	T52	B221, extrusion	–	1.000	22	16	17	8	1
6063	T6	B221, extrusion	–	1.000	30	25	17	8	1
6063	T6	B241, pipe & tube	–	1.000	30	25	17	8	1
6063	T6	B429, pipe & tube	–	1.000	30	25	17	8	1
6063	T832	B210, drawn tube	0.050	0.259	40	35	17	8	1
6066	T6, T6510, T6511	B221, extrusion	All		50	45	–	–	1.1
6070	T6	B221, extrusion	–	2.999	48	45	–	–	1.1
6082	T6, T6511	B221, extrusion	0.200	6.000	45	38	28	16	1
6105	T5	B221, extrusion	–	1.000	38	35	–	–	1.25
6351	T5	B221, extrusion	–	1.000	38	35	24	15	1
6351	T6	B221, extrusion	–	0.749	42	37	24	15	1
6360	T5	B221, extrusion	–	0.250	22	16	–	–	1
6360	T6	B221, extrusion	–	0.250	30	25	–	–	1
6463	T6	B221, extrusion	–	0.500	30	25	–	–	1
7005	T53	B221, extrusion	–	0.750	50	44	40	24	1

1. Material in either of these tempers (H32 or H22), (H34 or H24), (H36 or H26), (H38 or H28), (H12 or H22), (H14 or H24), (H16 or H26), (H18 or H28), is acceptable if the supplied H2x temper material meets all of the respective H1x or H3x temper tensile property limits.

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Table A.4.3M
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	MPa	MPa	MPa	MPa	
1060	H12[1]	B209, sheet & plate	0.40	50.00	75	60	55	15	1
1060	H12	B210, drawn tube	0.25	12.50	70	30	60	15	1
1060	H14[1]	B209, sheet & plate	0.20	25.00	85	70	55	15	1
1060	H14	B210, drawn tube	0.25	12.50	85	70	60	15	1
1100	H12[1]	B209, sheet & plate	0.40	50.00	95	75	75	25	1
1100	H12	B210, drawn tube	0.32	12.50	95	75	75	25	1
1100	H14[1]	B209, sheet & plate	0.20	25.00	110	95	75	25	1
1100	H14	B210, drawn tube	0.32	12.50	110	95	75	25	1
2014	T6	B209, sheet & plate	1.00	6.30	455	400	–	–	1.25
2014	T6, T651	B209, sheet & plate	6.30	50.00	460	405	–	–	1.25
2014	T6, T6510, T6511	B221, extrusion	–	12.50	415	365	–	–	1.25
2014	T6, T651	B211, bar, rod, & wire	3.20	200.00	450	380	–	–	1.25
2014	T6	B210, drawn tube	0.45	12.50	450	380	–	–	1.25
Alclad 2014	T6	B209, sheet & plate	0.63	1.00	435	380	–	–	1.25
Alclad 2014	T6	B209, sheet & plate	1.00	6.30	440	395	–	–	1.25
Alclad 2014	T651	B209, sheet & plate	6.30	12.50	440	395	–	–	1.25
2219	T87	B209, sheet & plate	6.30	80.00	440	350	240	180	1.25
3003	H12[1]	B209, sheet & plate	0.40	50.00	120	85	95	35	1
3003	H12	B210, drawn tube	0.25	1.20	120	85	95	35	1
3003	H14[1]	B209, sheet & plate	0.20	25.00	140	115	95	35	1
3003	H14	B210, drawn tube	0.20	25.00	140	115	95	35	1
3003	H16[1]	B209, sheet & plate	0.15	4.00	165	145	95	35	1
3003	H16	B210, drawn tube	0.25	12.50	165	145	95	35	1
3003	H18[1]	B209, sheet & plate	0.15	3.20	185	165	95	35	1
3003	H18	B210, drawn tube	–	12.50	185	165	95	35	1
Alclad 3003	H12[1]	B209, sheet & plate	0.40	50.00	115	80	90	30	1
Alclad 3003	H14[1]	B209, sheet & plate	0.20	25.00	135	110	90	30	1
Alclad 3003	H16[1]	B209, sheet & plate	0.15	4.00	160	140	90	30	1
Alclad 3003	H14	B210, drawn tube	0.25	12.50	135	110	90	30	1
Alclad 3003	H18	B210, drawn tube	0.25	12.50	180	160	90	30	1
3004	H32[1]	B209, sheet & plate	0.40	50.00	190	145	150	60	1
3004	H34[1]	B209, sheet & plate	0.20	25.00	220	170	150	60	1
3004	H36[1]	B209, sheet & plate	0.15	4.00	240	190	150	60	1
3004	H38[1]	B209, sheet & plate	0.15	3.20	260	215	150	60	1
Alclad 3004	H32[1]	B209, sheet & plate	0.40	50.00	185	140	145	55	1
Alclad 3004	H34[1]	B209, sheet & plate	0.20	25.00	215	165	145	55	1
Alclad 3004	H36[1]	B209, sheet & plate	0.15	4.00	235	185	145	55	1
3005	H25	B209, sheet & plate	0.15	2.00	180	150	–	–	1
3005	H28	B209, sheet & plate	0.15	2.00	215	185	–	–	1
3105	H25	B209, sheet & plate	0.32	1.60	160	130	–	–	1
5005	H12	B209, sheet & plate	0.40	50.00	125	95	105	35	1
5005	H14	B209, sheet & plate	0.20	25.00	145	115	105	35	1
5005	H16	B209, sheet & plate	0.15	4.00	165	135	105	35	1
5005	H32[1]	B209, sheet & plate	0.40	50.00	120	85	105	35	1

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Table A.4.3M (Continued)
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	MPa	MPa	MPa	MPa	
5005	H34[1]	B209, sheet & plate	0.20	25.00	140	105	105	35	1
5005	H36[1]	B209, sheet & plate	0.15	4.00	160	125	105	35	1
5050	H32[1]	B209, sheet & plate	0.40	6.30	150	110	125	40	1
5050	H32	B210, drawn tube	0.25	12.50	150	110	125	40	1
5050	H34[1]	B209, sheet & plate	0.20	6.30	170	140	125	40	1
5050	H34	B210, drawn tube	0.25	12.50	170	140	125	40	1
5050	H36[1]	B209, sheet & plate	0.15	4.00	185	150	125	40	1
5052	O	B209, sheet & plate	0.15	80.00	170	65	170	65	1
5052	H32[1]	B209, sheet & plate	0.40	50.00	215	160	170	65	1
5052	H32	B210, drawn tube	0.25	11.50	215	160	170	70	1
5052	H34[1]	B209, sheet & plate	0.20	25.00	235	180	170	65	1
5052	H34	B210, drawn tube	0.25	11.50	235	180	170	70	1
5052	H36[1]	B209, sheet & plate	0.15	4.00	255	200	170	65	1
5083	O, H112	B221, extrusion	–	130.00	270	110	270	110	1
5083	O	B209, sheet & plate	6.30	80.00	270	115	270	115	1
5083	H111	B221, extrusion	–	130.00	275	165	270	110	1
5083	H111	B247, forging	–	100.00	290	150	270	110	1
5083	H116	B928, sheet & plate	1.60	40.00	305	215	270	115	1
5083	H116	B928, sheet & plate	40.00	80.00	285	200	270	115	1
5083	H32	B209, sheet & plate	3.20	40.00	305	215	270	115	1
5083	H32	B209, sheet & plate	40.00	80.00	285	200	270	115	1
5083	H321	B928, sheet & plate	3.20	40.00	305	215	270	115	1
5083	H321	B928, sheet & plate	40.00	80.00	285	200	270	115	1
5086	O, H112	B221, extrusion	–	130.00	240	95	240	95	1
5086	O	B209, sheet & plate	0.50	50.00	240	95	240	95	1
5086	H111	B221, extrusion	–	130.00	250	145	240	95	1
5086	H112	B209, sheet & plate	4.00	12.50	250	125	240	95	1
5086	H112	B209, sheet & plate	12.50	40.00	240	105	240	95	1
5086	H112	B209, sheet & plate	40.00	80.00	235	95	240	95	1
5086	H116	B928, sheet & plate	1.60	50.00	275	195	240	95	1
5086	H32[1]	B209, sheet & plate	0.50	50.00	275	195	240	95	1
5086	H32	B210, drawn tube	0.25	11.50	275	195	240	95	1
5086	H34[1]	B209, sheet & plate	0.20	25.00	300	235	240	95	1
5086	H34	B210, drawn tube	0.25	11.50	300	235	240	95	1
5086	H321	B928, sheet & plate	1.60	8.00	275	195	240	95	1
5154	H38[1]	B209, sheet & plate	0.50	3.20	310	240	205	75	1
5454	O, H112	B221, extrusion	–	130.00	215	85	215	85	1
5454	O	B209, sheet & plate	0.50	80.00	215	85	215	85	1
5454	H111	B221, extrusion	–	130.00	230	130	215	85	1
5454	H32[1]	B209, sheet & plate	0.50	50.00	250	180	215	85	1
5454	H34[1]	B209, sheet & plate	0.50	25.00	270	200	215	85	1
5456	O	B209, sheet & plate	6.30	80.00	285	125	285	125	1
5456	H116	B928, sheet & plate	1.60	30.00	315	230	285	125	1
5456	H116	B928, sheet & plate	30.00	40.00	305	215	285	125	1

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Table A.4.3M (Continued)
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			from	to	MPa	MPa	MPa	MPa	
5456	H116	B928, sheet & plate	30.00	40.00	305	215	285	125	1
5456	H116	B928, sheet & plate	40.00	80.00	285	200	285	125	1
5456	H32	B209, sheet & plate	4.00	12.50	315	230	285	125	1
5456	H32	B209, sheet & plate	12.50	40.00	305	215	285	125	1
5456	H32	B209, sheet & plate	40.00	80.00	285	200	285	125	1
5456	H321	B928, sheet & plate	4.00	12.50	315	230	285	125	1
5456	H321	B928, sheet & plate	12.50	40.00	305	215	285	125	1
5456	H321	B928, sheet & plate	40.00	80.00	285	200	285	125	1
6005	T5	B221, extrusion	–	25.00	260	240	165	105	1.25
6005A	T5	B221, extrusion	–	25.00	260	215	165	105	1
6005A	T61	B221, extrusion	–	25.00	260	240	165	105	1
6061	T6	B209, sheet & plate	0.15	6.30	290	240	165	105	1
6061	T651	B209, sheet & plate	6.30	100.00	290	240	165	105	1
6061	T6	B632, tread plate	5.00	16.00	290	240	165	105	1
6061	T6, T6510, T6511	B221, extrusion	All		260	240	165	105	1
6061	T6, T651	B211, bar, rod, & wire	3.20	200.00	290	240	165	105	1
6061	T6	B210, drawn tube	0.63	12.50	290	240	165	105	1
6061	T6, T6510, T6511	B241, pipe & tube	All		260	240	165	105	1
6061	T6, T6510, T6511	B429, pipe & tube	All		260	240	165	105	1
6061	T6	B247, forging	–	100.00	260	240	165	105	1
6061	T6	B308, std structural profile	1.20	–	260	240	165	105	1
6063	T5	B221, extrusion	–	12.50	150	110	115	55	1
6063	T5	B221, extrusion	12.50	25.00	145	105	115	55	1
6063	T52	B221, extrusion	–	25.00	150	110	115	55	1
6063	T6	B221, extrusion	–	25.00	205	170	115	55	1
6063	T6	B241, pipe & tube	–	25.00	205	170	115	55	1
6063	T6	B429, pipe & tube	–	25.00	205	170	115	55	1
6063	T832	B210, drawn tube	1.20	6.30	275	240	115	55	1
6066	T6, T6510, T6511	B221, extrusion	All		345	210	–	–	1.1
6070	T6	B221, extrusion	–	80.00	330	310	–	–	1.1
6082	T6	B221, extrusion	5.00	20.00	310	260	190	110	1
6082	T6511	B221, extrusion	20.00	150.00	310	260	190	110	1
6105	T5	B221, extrusion	–	25.00	250	240	–	–	1.25
6351	T5	B221, extrusion	–	25.00	260	240	165	105	1
6351	T6	B221, extrusion	–	20.00	290	255	165	105	1
6360	T5	B221, extrusion	–	6.30	150	110	–	–	1
6360	T6	B221, extrusion	–	6.30	205	170	–	–	1
6463	T6	B221, extrusion	–	12.50	205	170	–	–	1
7005	T53	B221, extrusion	–	25.00	345	305	275	165	1

1. Material in either of these tempers (H32 or H22), (H34 or H24), (H36 or H26), (H38 or H28), (H12 or H22), (H14 or H24), (H16 or H26), (H18 or H28), is acceptable if the supplied H2x temper material meets all of the respective H1x or H3x temper tensile property limits.

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A.4.3 Castings

This Specification applies to cast products listed in Table A.4.4 and that meet all of the following requirements:

a) Sand casting meet the requirements of ASTM B26/B26M *Aluminum-Alloy Sand Castings* and permanent mold castings meet the requirements of ASTM B108/B108M *Aluminum-Alloy Permanent Mold Castings*.

b) The casting's dimensional tolerances conform to *Standards for Aluminum Sand and Permanent Mold Castings*.

c) The casting producer reports tensile yield strengths of the castings.

d) Radiographic inspection in accordance with ASTM B26 Grade C or B108 Grade C criteria is performed. The number of castings radiographed and the lot acceptance criteria shall be as listed in Table A.4.5.

The tensile strength F_{tu}, yield strength F_{ty}, and tension coefficient k_t of non-weld affected material used to determine available strength shall be as listed in Table A.4.4. Welded strengths of castings shall be those established in the AWS D1.2 weld procedure qualification test.

Table A.4.4
NOMINAL STRENGTHS OF ALUMINUM CASTINGS

ALLOY	TEMPER	ASTM Specification	CASTING TYPE	F_{tu} ksi	F_{ty} ksi	F_{tu} MPa	F_{ty} MPa	NOTE	k_t
356.0	T6	B26	sand	22.5	15	155	105	①	1.0
A356.0	T6	B26	sand	25.5	18	175	125	①	1.0
354.0	T61	B108	permanent mold	47	36	325	250	②	1.0
				43	33	295	230	①	1.0
C355.0	T61	B108	permanent mold	40	30	275	205	②	1.0
				37	30	255	205	①	1.0
356.0	T6	B108	permanent mold	24.7	16.5	170	110	①	1.0
A356.0	T61	B108	permanent mold	33	26	230	180	②	1.0
				28	26	195	180	①	1.0
A357.0	T61	B108	permanent mold	46	36	315	250	②	1.0
				41	31	285	215	①	1.0
359.0	T61	B108	permanent mold	45	34	310	235	②	1.0
				40	30	275	205	①	1.0
359.0	T62	B108	permanent mold	47	38	325	260	②	1.0
				40	30	275	205	①	1.0
535.0	F	B108	permanent mold	26.2	13.5	180	95	①	1.0

① These strengths apply at any location in the casting if the purchaser specifies that the strength of test specimens cut from any location in the casting equal or exceed these strengths.

②.These strengths apply in the locations specified by the purchaser if the purchaser specifies that strengths equal or exceed these strengths at these locations. At other locations, the strengths in ① apply.

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Table A.4.5
RADIOGRAPHIC INSPECTION CRITERIA FOR CASTINGS

Lot Size	Number of Castings Required to be Radiographed	Number of Castings Required to Meet Grade C to Pass Lot
2 through 50	2	2
51 through 500	8	7
over 500	13	11

A.4.4 Filler Metal for Welding

This *Specification* applies to filler alloys produced to AWS A5.10/A5.10M and listed in Tables M.9.1 and M.9.2. Filler metal nominal strengths used to determine available strength shall be as listed in Table A.4.6.

Table A.4.6
NOMINAL STRENGTHS OF ALUMINUM FILLER METALS

Filler	Tensile Ultimate Strength F_{tuw} ksi	Tensile Yield Strength F_{tyw} ksi	Tensile Ultimate Strength F_{tuw} MPa	Tensile Yield Strength F_{tyw} MPa
1100	11	3.5	75	25
2319	35	26	240	180
4043	24	11	165	75
4047	25	–	170	–
5183	40	18	275	125
5356	35	14	240	95
5554	31	12	215	85
5556	42	19	290	130
5654	30	11	205	75

A.4.5 Bolts, Washers, and Nuts

This *Specification* applies to aluminum fasteners produced to ASTM specifications

F 468 *Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use*
F 468M *Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]*

and aluminum nuts produced to ASTM specifications

F 467 *Nonferrous Nuts for General Use*
F 467M *Nonferrous Nuts for General Use [Metric]*

Nuts for ¼ in. (M6) bolts and smaller shall be 2024-T4; larger nuts shall be 6061-T6 or 6262-T9.

Flat washers shall be Alclad 2024-T4. Spring lock washers shall be 7075-T6.

Nominal strengths used to determine available strength for aluminum bolts shall be as listed in Table A.4.7.

Table A.4.7
NOMININAL STRENGTHS OF ALUMINUM BOLTS

Alloy and Temper	Shear Ultimate Strength① F_{su} ksi	Tensile Ultimate Strength① F_{tu} ksi	Shear Ultimate Strength② F_{su} MPa	Tensile Ultimate Strength② F_{tu} MPa
2024-T4	37	62	255	425
6061-T6	25	42	170	290
7075-T73	41	68	280	470

① From ASTM B 316/B 316M and F 468
② From ASTM B 316/B 316M

A.4.6 Rivets

This *Specification* applies to rivets of material that meets ASTM B316/B316M. Nominal strengths used to determine available strength of aluminum rivets shall be as listed in Table A.4.8.

Table A.4.8
NOMINAL STRENGTHS OF ALUMINUM RIVETS

Designation Before Driving	Shear Ultimate Strength F_{su} ksi ①	Shear Ultimate Strength F_{su} MPa ①
2017-T4	33	225
2024-T42	37	255
2117-T4	26	180
2219-T6	30	205
6053-T61	20	135
6061-T6	25	170
7050-T7	39	270
7075-T6	42	290
7075-T73	41	280

① From ASTM B316/B316M

A.4.7 Screws

This *Specification* applies to aluminum tapping screws that meet ASME B18.6.4.

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B.1 SECTION PROPERTIES

Section properties such as cross-sectional area, moment of inertia, section modulus, radius of gyration, and torsion and warping constants shall be determined using nominal dimensions. Section properties used to determine bending deflections shall be determined in accordance with Section L.3. Cross section dimensions shall comply with the tolerances required by the material specifications of Section A.4.

B.2 LOADS AND LOAD COMBINATIONS

B.2.1 Building-Type Structures

Building-type structures shall be designed for the nominal loads and load combinations given in the applicable building code or contract documents, or in ASCE 7 in the absence of a building code or contract documents.

B.2.2 Other Structures

Other structures shall be designed for the nominal loads and load combinations given in the applicable code or contract documents.

B.3 DESIGN BASIS

Designs shall be made according to the provisions for Load and Resistance Factor Design (LRFD) or Allowable Strength Design (ASD).

B.3.1 Limit States

No applicable strength or serviceability limit state shall be exceeded by the loads and load combinations given in Section B.2.

B.3.2 Required Strength

The required strength of structural members and connections shall be determined by structural analysis using the loads and load combinations stipulated in Section B.2. Computation of forces and moments shall be by elastic analysis in accordance with Chapter C. The effect of eccentricities at connections shall be addressed as required by Section J.1.1.

B.3.2.1 Design for Strength Using Load and Resistance Factor Design (LRFD)

Design using the provisions for Load and Resistance Factor Design (LRFD) meets the requirements of this *Specification* when the design strength of each structural component equals or exceeds the required strength determined on the basis of the LRFD load combinations. All provisions of this *Specification* except Section B.3.2.2 shall apply.

Design shall satisfy Equation B.3-1:

$$R_u \le \phi R_n \qquad \text{(B.3-1)}$$

where

R_u = required strength for LRFD
R_n = nominal strength
ϕ = resistance factor
ϕR_n = design strength

Resistance factors for building-type structures shall be as given in this *Specification*. Resistance factors for other structures shall be as given in the applicable code

B.3.2.2 Design for Strength Using Allowable Strength Design (ASD)

Design using the provisions for Allowable Strength Design (ASD) meets the requirements of this *Specification* when the allowable strength of each structural component equals or exceeds the required strength determined on the basis of the ASD load combinations. All provisions of this *Specification* except Section B.3.2.1 shall apply.

Design shall satisfy Equation B.3-2:

$$R_a \le R_n / \Omega \qquad \text{(B.3-2)}$$

where

R_a = required strength for ASD
R_n = nominal strength
Ω = safety factor
R_n / Ω = allowable strength

Safety factors for building-type structures hall be as given in this *Specification*. Safety factors for other structures shall be as given in the applicable code.

B.3.3 Design for Stability

Stability of the structure and its components shall be determined in accordance with Chapter C.

B.3.4 Design for Serviceability

Structures and their components shall meet the serviceability requirements given in Chapter L.

B.3.5 Design for Fatigue

Structures and their components subjected to repeated loading shall meet the requirements of Appendix 3. Fatigue need not be considered for seismic loads.

B.3.6 Design for Fire Conditions

Design for fire conditions shall meet the requirements of Appendix 4.

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B.3.7 Design of Braces

Braces for columns and beams shall meet the requirements of Appendix 6.

B.4 BUCKLING CONSTANTS

Buckling constants B, D, and C shall be determined from Tables B.4.1 and B.4.2. Postbuckling constants k_1 and k_2 shall be determined from Table B.4.3.

Table B.4.1
BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH O, H, T1, T2, T3, OR T4, AND WELD-AFFECTED ZONES OF ALL TEMPERS

TYPE OF STRESS AND MEMBER	INTERCEPT	SLOPE	INTERSECTION
Member Buckling	$B_c = F_{cy}\left(1+\left(\frac{F_{cy}}{1000\kappa}\right)^{1/2}\right)$	$D_c = \frac{B_c}{20}\left(\frac{6B_c}{E}\right)^{1/2}$	$C_c = \frac{2B_c}{3D_c}$
Uniform Compression in Flat Elements	$B_p = F_{cy}\left(1+\left(\frac{F_{cy}}{440\kappa}\right)^{1/3}\right)$	$D_p = \frac{B_p}{20}\left(\frac{6B_p}{E}\right)^{1/2}$	$C_p = \frac{2B_p}{3D_p}$
Uniform Compression in Curved Elements	$B_t = F_{cy}\left(1+\left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$	$D_t = \frac{B_t}{3.7}\left(\frac{B_t}{E}\right)^{1/3}$	$C_t = 0.76\left(\frac{E}{F_{cy}}\right)^{1/2}$
Flexural Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1+\left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$	$D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \frac{2B_{br}}{3D_{br}}$
Flexural Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1+\left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \frac{B_{tb}-B_t}{D_{tb}-D_t}$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\frac{F_{sy}}{240\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{20}\left(\frac{6B_s}{E}\right)^{1/2}$	$C_s = \frac{2B_s}{3D_s}$

κ = 1.0 ksi (6.895 MPa)

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Table B.4.2
BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH T5, T6, T7, T8, OR T9

TYPE OF STRESS AND MEMBER	INTERCEPT	SLOPE	INTERSECTION
Member Buckling	$B_c = F_{cy}\left(1+\left(\frac{F_{cy}}{2250\kappa}\right)^{1/2}\right)$	$D_c = \frac{B_c}{10}\left(\frac{B_c}{E}\right)^{1/2}$	$C_c = 0.41\frac{B_c}{D_c}$
Uniform Compression in Flat Elements	$B_p = F_{cy}\left(1+\left(\frac{F_{cy}}{1500\kappa}\right)^{1/3}\right)$	$D_p = \frac{B_p}{10}\left(\frac{B_p}{E}\right)^{1/2}$	$C_p = 0.41\frac{B_p}{D_p}$
Uniform Compression in Curved Elements	$B_t = F_{cy}\left(1+\left(\frac{F_{cy}}{50{,}000\kappa}\right)^{1/5}\right)$	$D_t = \frac{B_t}{4.5}\left(\frac{B_t}{E}\right)^{1/3}$	$C_t = 0.70\left(\frac{E}{F_{cy}}\right)^{1/2}$
Flexural Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1+\left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$	$D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \frac{2B_{br}}{3D_{br}}$
Flexural Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1+\left(\frac{F_{cy}}{50{,}000\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \frac{B_{tb}-B_t}{D_{tb}-D_t}$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\frac{F_{sy}}{800\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{10}\left(\frac{B_s}{E}\right)^{1/2}$	$C_s = 0.41\frac{B_s}{D_s}$

κ = 1.0 ksi (6.895 MPa)

Table B.4.3
POSTBUCKLING CONSTANTS

TYPE OF ELEMENT	k_1	k_2
Flat Elements in Uniform Compression for Temper Designations Beginning with O, H, T1, T2, T3, or T4, and weld-affected zones of all tempers	0.50	2.04
Flat Elements in Uniform Compression for Temper Designations Beginning with T5, T6, T7, T8, or T9	0.35	2.27
Flat Elements in Flexure	0.50	2.04

B.5 ELEMENTS

B.5.1 Width of Flat Elements and Stiffeners

For flat elements:

a) supported on one edge, the element width *b* is the distance from the element's unsupported edge to the toe of the fillet or bend at the element's supported edge (Figure B.5.1)

b) supported on both edges and flat elements supported on one edge and with a stiffener on the other edge, the element width *b* is the distance between the toes of the fillets or bends at the element's supported or stiffened edges (Figures B.5.2 and B.5.3).

c) supported on both edges and with an intermediate stiffener, the element width *b* is the largest distance between the toe of the fillet or bend at the element's supported edge and the toe of the fillet or bend at the intermediate stiffener (Figure B.5.4).

For all flat elements, if the inside corner radius exceeds 4 times the element thickness, the inside radius shall be assumed equal to 4 times the thickness in calculating *b*.

Dimensions and properties of stiffeners shall be determined in accordance with Figures B.5.3 and B.5.4.

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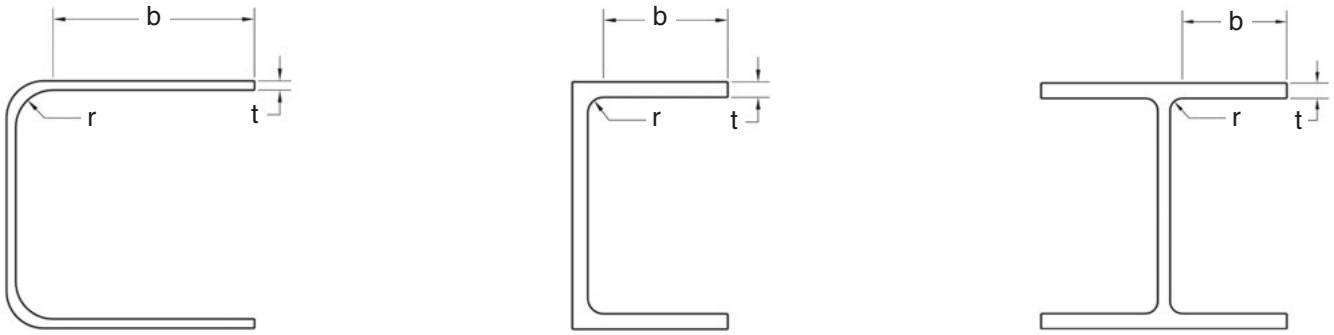

Figure B.5.1
FLAT ELEMENTS SUPPORTED ON ONE EDGE

Figure B.5.2
FLAT ELEMENTS SUPPORTED ON BOTH EDGES

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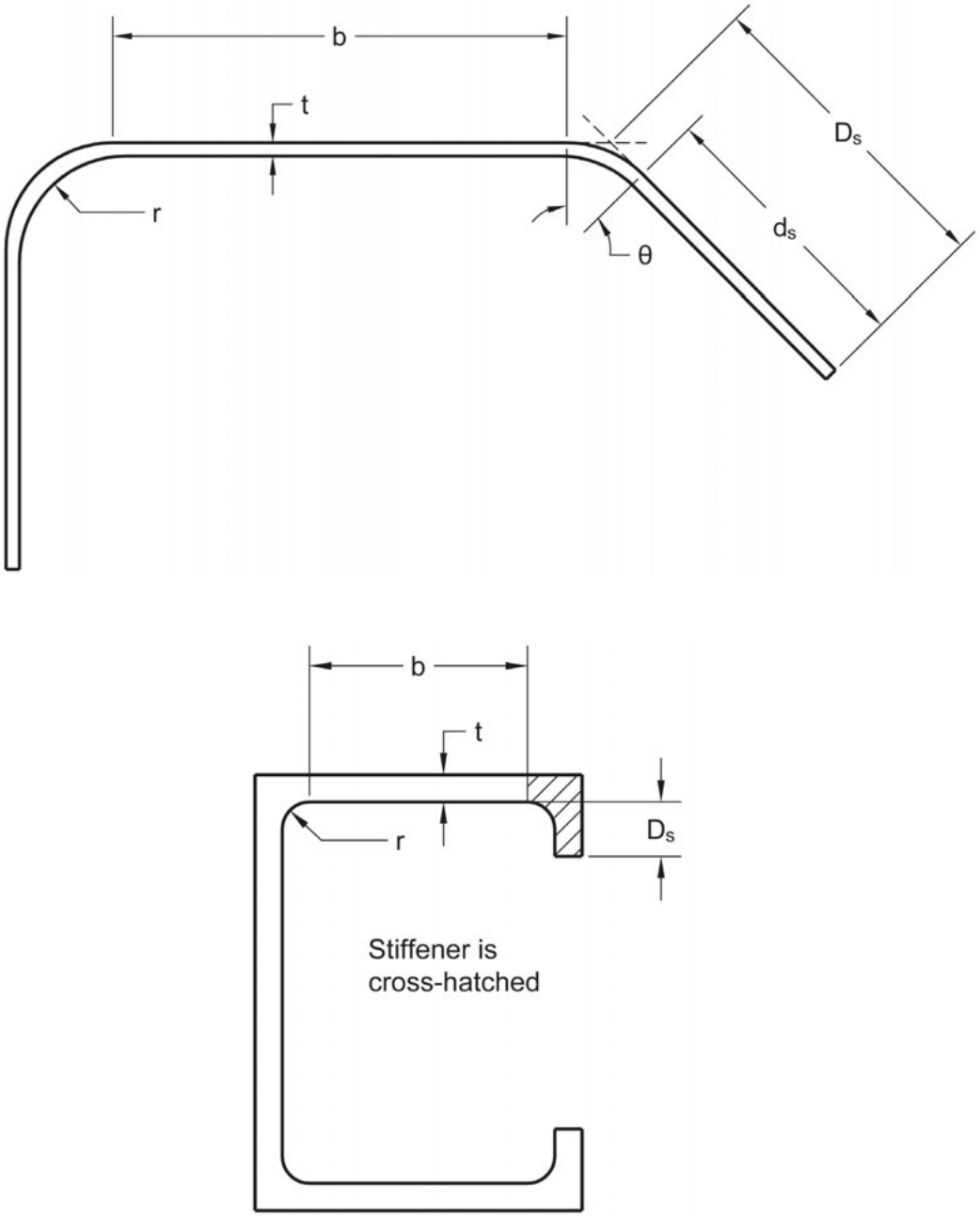

Figure B.5.3
EDGE STIFFENED ELEMENTS

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B.5.2 Radius of Curved Elements

The radius of curved elements R_b shall be taken at the mid-thickness of the element.

B.5.3 Thickness of Elements

For uniform compression on elements with linearly varying thickness with $\delta \le 2.0$:

a) For tapered thickness elements with the thick edge supported and the thin edge free, the slenderness is $(1 - 0.12\delta)(b/t_{avg})$.

b) For tapered thickness elements with the thin edge supported and the thick edge free, the slenderness is b/t_{avg}

c) For tapered thickness elements supported on both edges, the slenderness is b/t_{avg}.

where

b = element width

$$t_{avg} = \frac{t_{max} + t_{min}}{2} \qquad \text{(B.5-1)}$$

t_{avg} = average thickness of the element

t_{min} = minimum thickness of the tapered thickness element

t_{max} = maximum thickness of the tapered thickness element

$$\delta = \frac{t_{max} - t_{min}}{t_{min}} \qquad \text{(B.5-2)}$$

B.5.4 Strength of Elements in Uniform Compression

The stress F_c corresponding to the uniform compressive strength of elements is:

For unwelded elements:

$$F_c = F_{co} \qquad \text{(B.5-3)}$$

For welded elements:

$$F_c = F_{co}(1 - A_{wz}/A_g) + F_{cw} A_{wz}/A_g \qquad \text{(B.5-4)}$$

where

F_{co} = stress corresponding to the uniform compressive strength calculated using Sections B.5.4.1 through B.5.4.5 for an element if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and F_{cy}.

F_{cw} = stress corresponding to the uniform compressive strength calculated using Sections B.5.4.1 through B.5.4.5 for an element if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and F_{cyw}. For transversely welded elements with $b/t \le \lambda_1$, $F_{cw} = F_{co}$.

A_{wz} = cross sectional area of the weld-affected zone

A_g = gross cross sectional area of the element.

B.5.4.1 Flat Elements Supported on One Edge

The stress F_c corresponding to the uniform compressive strength of flat elements supported on one edge is:

LIMIT STATE	F_c	Slenderness b/t	Slenderness Limits
yielding	F_{cy}	$b/t \le \lambda_1$	$\lambda_1 = \frac{B_p - F_{cy}}{5.0 D_p}$
inelastic buckling	$B_p - 5.0 D_p\, b/t$	$\lambda_1 < b/t < \lambda_2$	
in columns whose buckling axis is not an axis of symmetry:			
elastic buckling	$\frac{\pi^2 E}{(5.0\, b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \frac{C_p}{5.0}$
in all other columns and all beams:			
post-buckling	$\frac{k_2\sqrt{B_p E}}{5.0 b/t}$	$b/t \ge \lambda_2$	$\lambda_2 = \frac{k_1 B_p}{5.0 D_p}$

B.5.4.2 Flat Elements Supported on Both Edges

The stress F_c corresponding to the uniform compressive strength of flat elements supported on both edges is:

LIMIT STATE	F_c	Slenderness b/t	Slenderness Limits
yielding	F_{cy}	$b/t \le \lambda_1$	$\lambda_1 = \frac{B_p - F_{cy}}{1.6 D_p}$
inelastic buckling	$B_p - 1.6 D_p\, b/t$	$\lambda_1 < b/t < \lambda_2$	
post-buckling	$\frac{k_2\sqrt{B_p E}}{1.6 b/t}$	$b/t \ge \lambda_2$	$\lambda_2 = \frac{k_1 B_p}{1.6 D_p}$

B.5.4.3 Flat Elements Supported on One Edge and with a Stiffener on the Other Edge

For flat elements

a) supported on one edge and with a stiffener on the other edge,

b) with a stiffener of depth $D_S \le 0.8b$, where D_S is defined in Figure B.5.3, and

c) with a thickness no greater than the stiffener's thickness, the stress F_c corresponding to the uniform compressive strength is

$$F_c = F_{UT} + (F_{ST} - F_{UT})\rho_{ST} \qquad \text{(B.5-5)}$$

where

F_{UT} is determined using Section B.5.4.1 and neglecting the stiffener

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F_{ST} is determined using Section B.5.4.2

ρ_{ST} = stiffener effectiveness ratio determined as follows:

a) $\rho_{ST} = 1.0$ for $b/t \le \lambda_e/3$ (B.5-6)

b) $$\rho_{ST} = \frac{r_s}{9t\left(\frac{b/t}{\lambda_e} - \frac{1}{3}\right)} \le 1.0 \quad \text{for } \lambda_e/3 < b/t \le \lambda_e \text{ (B.5-7)}$$

c) $$\rho_{ST} = \frac{r_s}{1.5t\left(\frac{b/t}{\lambda_e} + 3\right)} \le 1.0 \text{ for } \lambda_e < b/t < 2\lambda_e \text{ (B.5-8)}$$

r_s = the stiffener's radius of gyration about the stiffened element's mid-thickness.

For straight stiffeners of constant thickness (see Figure B.5.3)

$r_s = (d_s \sin\theta_s)/\sqrt{3}$

where

d_s = the stiffener's flat width and

θ_s = the angle between the stiffener and the stiffened element.

$$\lambda_e = 1.28\sqrt{E/F_{cy}} \quad \text{(B.5-9)}$$

F_c for the stiffened element determined using Section B.5.4.3 shall not exceed F_c for the stiffener determined using Section B.5.4.1.

For flat elements

a) supported on one edge and with a stiffener on the other edge, and

b) with a stiffener of depth $D_S > 0.8b$, where D_S is defined in Figure B.5.3, or with a thickness greater than the stiffener's thickness,

the stress F_c corresponding to the uniform compressive strength is $F_c = F_{UT}$.

B.5.4.4 Flat Elements Supported on Both Edges and with an Intermediate Stiffener

The stress F_c corresponding to the uniform compressive strength of flat elements supported on both edges and with an intermediate stiffener is:

LIMIT STATE	F_c	Slenderness λ_s	Slenderness Limits
yielding	F_{cy}	$\lambda_s \le \lambda_1$	$\lambda_1 = \frac{B_c - F_{cy}}{D_c}$
inelastic buckling	$B_c - D_c\lambda_s$	$\lambda_1 < \lambda_s < \lambda_2$	
elastic buckling	$\frac{\pi^2 E}{\lambda_s^2}$	$\lambda_s \ge \lambda_2$	$\lambda_2 = C_c$

where

$$\lambda_s = 4.62\ \frac{b}{t}\sqrt{\frac{1 + A_s/(bt)}{1 + \sqrt{1 + \frac{10.67 I_o}{bt^3}}}} \quad \text{(B.5-10)}$$

A_s = area of the stiffener only, not including any part of the element stiffened.

I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent sub-elements and the transition corners between them, taken about the centroidal axis (denoted as o-o in Figure B.5.4) of the section parallel to the stiffened element.

b = distance between stiffener and supporting element (see Figure B.5.4)

t = thickness of the flat element supported on both edges (see Figure B.5.4)

F_c shall not exceed F_c determined using Section B.5.4.2 for the sub-elements of the stiffened element, and shall not exceed F_c of the stiffener determined using Section B.5.4.1.

B.5.4.5 Round Hollow Elements and Curved Elements Supported on Both Edges

The stress F_c corresponding to the uniform compressive strength of round hollow elements and curved elements supported on both edges is:

LIMIT STATE	F_c	Slenderness λ	Slenderness Limits
yielding	F_{cy}	$\lambda \le \lambda_1$	$\lambda_1 = \frac{B_t - F_{cy}}{D_t}$
inelastic buckling	$B_t - D_t\lambda$	$\lambda_1 < \lambda < \lambda_2$	
elastic buckling	$\frac{\pi^2 E}{16\lambda^2\left(1 + \frac{\lambda}{35}\right)}$	$\lambda \ge \lambda_2$	$\lambda_2 = C_t$

$$\lambda = \sqrt{\frac{R_b}{t}}$$

For round hollow elements with transverse welds, use of Section B.5.4.5 is limited to elements with $R_b/t < 20$.

B.5.4.6 Direct Strength Method

As an alternate to Sections B.5.4.1 through B.5.4.4, the stress F_c corresponding to the uniform compressive strength of flat elements without welds may be determined as:

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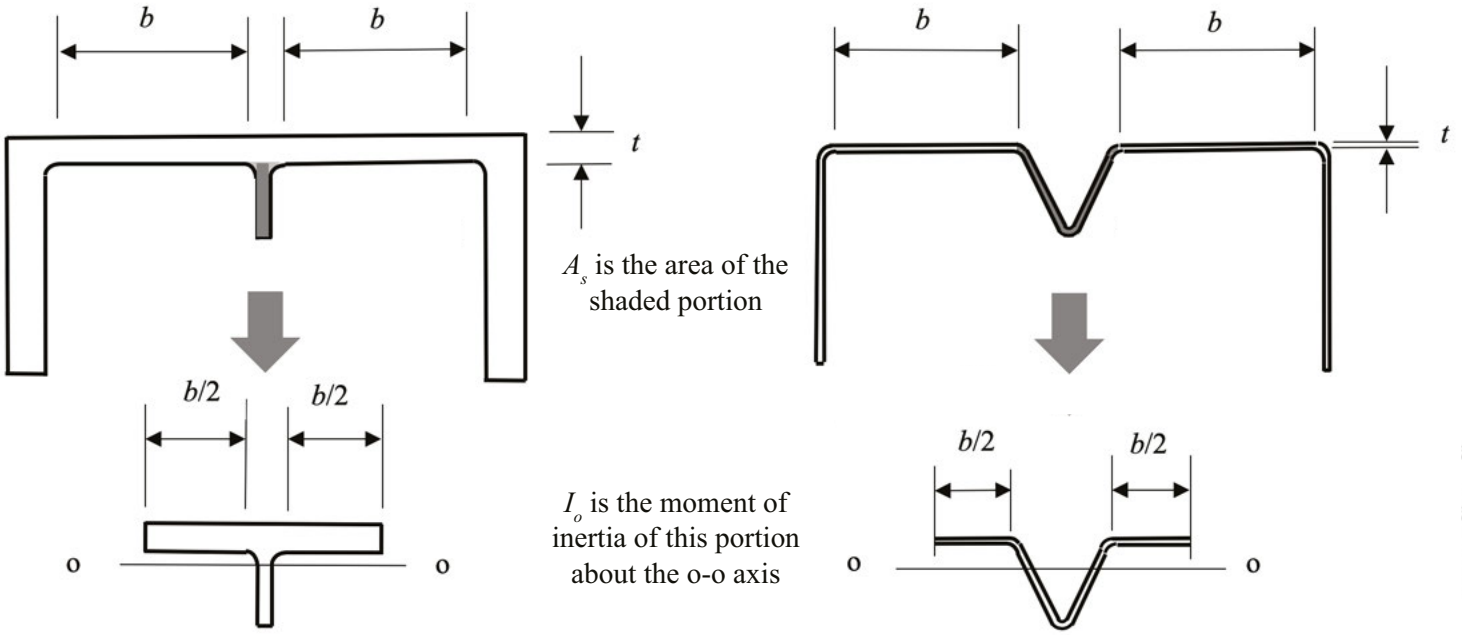

Figure B.5.4
FLAT ELEMENTS WITH AN INTERMEDIATE STIFFENER

LIMIT STATE	F_c	Slenderness λ_{eq}	Slenderness Limits
yielding	F_{cy}	$\lambda_{eq} \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{D_p}$
inelastic buckling	$B_p - D_p \lambda_{eq}$	$\lambda_1 < \lambda_{eq} < \lambda_2$	
elastic buckling	$\dfrac{k_2\sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$	$\lambda_2 = \dfrac{k_1 B_p}{D_p}$

$$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(B.5-11)}$$

F_e = the elastic local buckling stress of the cross section determined by analysis

B.5.5 Strength of Elements in Flexural Compression

The stress F_b corresponding to the flexural compressive strength of elements is:

For unwelded elements:

$$F_b = F_{bo} \qquad \text{(B.5-12)}$$

For welded elements:

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc} \qquad \text{(B.5-13)}$$

where

F_{bo} = stress corresponding to the flexural compressive strength calculated using Sections B.5.5.1 through B.5.5.3 for an element if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and F_{cy}.

F_{bw} = stress corresponding to the flexural compressive strength calculated using Sections B.5.5.1 through B.5.5.3 for an element if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and F_{cyw}.

A_{wzc} = cross sectional area of the weld-affected zone in compression

A_{gc} = gross cross sectional area of the element in compression.

B.5.5.1 Flat Elements Supported on Both Edges

The stress F_b corresponding to the flexural compressive strength of flat elements supported on both edges and flat elements supported on the compression edge with the tension edge free is:

LIMIT STATE	F_b	Slenderness b/t	Slenderness Limits
yielding	$1.5F_{cy}$	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_{br} - 1.5F_{cy}}{mD_{br}}$
inelastic buckling	$B_{br} - mD_{br}\, b/t$	$\lambda_1 < b/t < \lambda_2$	
post-buckling	$\dfrac{k_2\sqrt{B_{br}E}}{(mb/t)}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{k_1 B_{br}}{mD_{br}}$

m = $1.15 + c_o/(2c_c)$ for $-1 < c_o/c_c < 1$

m = $1.3/(1 - c_o/c_c)$ for $c_o/c_c \le -1$

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m = 0.65 for $c_c = -c_o$
c_c = distance from neutral axis to the element extreme fiber with the greatest compressive stress
c_o = distance from neutral to other extreme fiber of the element

Distances to compressive fibers are negative and distances to tensile fibers are positive.

B.5.5.2 Flat Elements Supported on Tension Edge, Compression Edge Free

The stress F_b corresponding to the flexural compressive strength of flat elements supported on the tension edge with the compression edge free is:

LIMIT STATE	F_b	Slenderness b/t	Slenderness Limits
yielding	$1.5F_{cy}$	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_{br} - 1.5F_{cy}}{3.5D_{br}}$
inelastic buckling	$B_{br} - 3.5D_{br}\, b/t$	$\lambda_1 < b/t < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E}{(3.5b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{C_{br}}{3.5}$

B.5.5.3 Flat Elements Supported on Both Edges and with a Longitudinal Stiffener

The stress F_b corresponding to the flexural compressive strength of flat elements supported on both edges and with a longitudinal stiffener located $0.4d_1$ from the supported edge that is in compression is:

LIMIT STATE	F_b	Slenderness b/t	Slenderness Limits
yielding	$1.5F_{cy}$	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_{br} - 1.5F_{cy}}{0.29D_{br}}$
inelastic buckling	$B_{br} - 0.29D_{br}\, b/t$	$\lambda_1 < b/t < \lambda_2$	
post-buckling	$\dfrac{k_2\sqrt{B_{br}E}}{(0.29b/t)}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{k_1 B_{br}}{0.29D_{br}}$

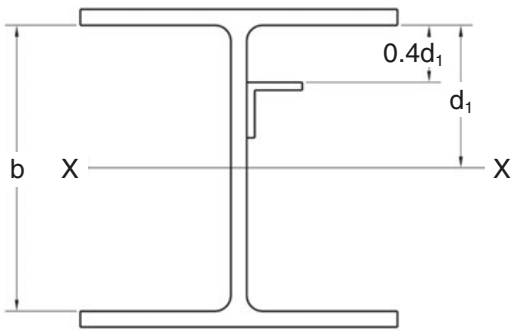

Figure B.5.5
FLAT ELEMENT WITH A LONGITUDINAL STIFFENER

The moment of inertia of the longitudinal stiffener I_L about the web of the beam shall equal or exceed

$$I_L = \frac{0.02\alpha_s f t b^3}{E}\left[\left(1 + \frac{6A_L}{bt}\right)\left(\frac{s}{b}\right)^2 + 0.4\right] \qquad \text{(B.5-14)}$$

where (see Figure B.5.5)
A_L = cross-sectional area of the longitudinal stiffener
d_1 = distance from the neutral axis to the compression flange
f = compressive stress at the toe of the flange
b = clear height of the web
s = distance between transverse stiffeners
t = web thickness
α_s = 1 for a stiffener consisting of equal members on both sides of the web
= 3.5 for a stiffener consisting of a member on only one side of the web

For a stiffener consisting of equal members on both sides of the web, the moment of inertia I_L shall be the sum of the moments of inertia about the centerline of the web. For a stiffener consisting of a member on one side of the web only, the moment of inertia I_L shall be taken about the face of the web in contact with the stiffener.

B.5.5.4 Pipes and Round Tubes

The stress F_b corresponding to the flexural compressive strength of pipes and round tubes is:

LIMIT STATE	F_b	Slenderness λ	Slenderness Limits
upper inelastic buckling	$B_{tb} - D_{tb}\,\lambda$	$\lambda \le \lambda_1$	$\lambda_1 = C_{tb}$
lower inelastic buckling	$B_t - D_t\,\lambda$	$\lambda_1 < \lambda < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E}{16\lambda^2\left(1 + \dfrac{\lambda}{35}\right)^2}$	$\lambda \ge \lambda_2$	$\lambda_2 = C_t$

$$\lambda = \sqrt{\frac{R_b}{t}}$$

B.5.5.5 Direct Strength Method

As an alternate to Sections B.5.5.1 through B.5.5.3 for flat elements in flexure without welds, the stress F_b corresponding to the flexural compressive strength may be determined as:

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Table B.5.1
ELASTIC BUCKLING STRESS F_e OF ELEMENTS

ELEMENT TYPE	ELEMENT STRESS	ELEMENT SUPPORT	F_e
flat	uniform compression	supported on both edges	$\frac{\pi^2 E}{(1.6b/t)^2}$
flat	uniform compression	supported on one edge	$\frac{\pi^2 E}{(5.0b/t)^2}$
flat	uniform compression	supported on one edge and with a stiffener on the other edge	$\left(1-\rho_{ST}\right)\frac{\pi^2 E}{(5.0b/t)^2}+\rho_{ST}\frac{\pi^2 E}{(1.6b/t)^2}$
flat	uniform compression	supported on both edges and with an intermediate stiffener	$\frac{\pi^2 E}{\lambda_s^2}$
curved	uniform compression	supported on both edges	$\frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1+\frac{\sqrt{R_b/t}}{35}\right)^2}$

λ_s is determined from equation B.5-10

LIMIT STATE	F_b	Slenderness λ_{eq}	Slenderness Limits
yielding	$1.5F_{cy}$	$\lambda_{eq} \le \lambda_1$	$\lambda_1 = \frac{B_{br}-1.5F_{cy}}{D_{br}}$
inelastic buckling	$B_{br}-D_{br}\lambda_{eq}$	$\lambda_1 < \lambda_{eq} < \lambda_2$	
post-buckling	$\frac{k_2\sqrt{B_{br}E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$	$\lambda_2 = k_1 B_{br}/D_{br}$

$$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(B.5-15)}$$

F_e = the elastic local buckling stress of the cross section determined by analysis

B.5.6 Elastic Buckling Stress of Elements

The elastic buckling stress of elements shall be determined using Table B.5.1.

B.6 FABRICATION AND ERECTION

Fabrication and erection shall meet the requirements in Chapter M.

B.7 QUALITY CONTROL AND QUALITY ASSURANCE

Quality control and quality assurance shall meet the requirements in Chapter N.

B.8 EVALUATION OF EXISTING STRUCTURES

Evaluation of existing structures shall meet the requirements in Appendix 5.

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Chapter C Design for Stability

This chapter addresses requirements for the analysis and design of structures for stability.

C.1 GENERAL STABILITY REQUIREMENTS

Stability shall be provided for the structure as a whole and for each of its components. The available strengths of members and connections determined in accordance with Section C.3 shall equal or exceed the required strengths determined in accordance with Section C.2.

C.2 CALCULATION OF REQUIRED STRENGTHS

The required strengths of members and connections of the structure shall be determined from an elastic analysis that considers the effects of each of the following:

a) Flexural, shear, and axial deformations, including all member and connection deformations that contribute to displacements of the structure;

b) Second-order effects including P-Δ effects (the effect of loads acting on the displaced location of joints or nodes in a structure) and P-δ effects (the effect of loads acting on the deflected shape of a member between joints or nodes);

c) Geometric imperfections. The effect of geometric imperfections on the stability of the structure shall be accounted for by analyzing the structure with the members' points of intersection displaced from their nominal locations by the tolerances specified in the contract documents. The displacements shall be placed to cause the greatest destabilizing effect.

d) Member stiffness reduction due to inelasticity. The effect of member stiffness reduction due to inelasticity on the stability of the structure shall be accounted for by using a reduced stiffness as follows:

A factor τ_b shall be applied to the flexural stiffnesses of all members whose flexural stiffnesses contribute to the stability of the structure, where

$\tau_b =$ 1.0 for $\alpha P_r / P_y \leq 0.5$
$\tau_b =$ $4(\alpha P_r / P_y)(1 - \alpha P_r / P_y)$ for $\alpha P_r / P_y > 0.5$
$P_r =$ required axial compressive strength using LRFD or ASD load combinations
$P_y =$ axial yield strength
$\alpha =$ 1.0 (LRFD); $\alpha = 1.6$ (ASD)

e) Uncertainty in stiffness and strength shall be addressed by applying a factor of 0.8 to all axial, shear, and flexural stiffnesses in the structure.

The analysis shall include all loads that affect the stability of the structure as a whole or of any of its components, including loads on members that do not provide stability. Analysis shall be conducted for either:

a) The LRFD load combinations with the results used directly to obtain the required strengths, or

b) 1.6 times the ASD load combinations with the results divided by 1.6 to obtain the required strengths.

C.3 CALCULATION OF AVAILABLE STRENGTHS

The available strengths of members and connections shall be determined in accordance with the provisions of Chapters D, E, F, G, H, and J. The effective length factor k of all members that provide stability of the structure as a whole or of any of its components shall be taken as 1. The effective length factor k of other members shall be taken as 1 unless a smaller value is justified by rational analysis.

Bracing intended to define the unbraced length of members shall have sufficient stiffness and strength to control member movement at the brace points.

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Chapter D Design of Members for Tension

This chapter addresses members subjected to axial tension through the centroidal axis.

D.1 GENERAL PROVISIONS

The available tensile strength of members is the lesser of the available strengths for the limit states of yielding and rupture. The available tensile strength, P_c, shall be determined in accordance with Chapter D, where $P_c = \phi_t P_{nt}$ for LRFD, $P_c = P_{nt}/\Omega_t$ for ASD, P_{nt} is nominal tensile strength and

LIMIT STATE	ϕ_t	Ω_t
tensile rupture	0.75	1.95
tensile yielding	0.90	1.65

D.2 TENSILE STRENGTH

The nominal tensile strength P_{nt} of tension members shall be determined as follows.

a) For tensile yielding in the gross section:

For unwelded members and members with transverse welds

$$P_{nt} = F_{ty} A_g \qquad \text{(D.2-1)}$$

For members with longitudinal welds

$$P_{nt} = F_{ty}(A_g - A_{wz}) + F_{tyw} A_{wz} \qquad \text{(D.2-2)}$$

b) For tensile rupture in the net section:

For unwelded members

$$P_{nt} = F_{tu} A_e / k_t \qquad \text{(D.2-3)}$$

For welded members

$$P_{nt} = F_{tu}(A_e - A_{ewz})/k_t + F_{tuw} A_{ewz} \qquad \text{(D.2-4)}$$

where

A_e = effective net area defined in Section D.3.2

A_{ewz} = effective net area in the weld-affected zone

Block shear rupture strength for the end connections of tension members is given in Section J.7.3.

D.3 AREA DETERMINATION

D.3.1 Net Area

The net area A_n of a member is the sum of the products of the thickness and the least net width of each element computed as follows:

The width of holes shall be taken as the nominal hole diameter for drilled or reamed holes and the nominal hole diameter plus 1/32 in. (0.8 mm) for punched holes.

For a chain of holes extending across a part in any diagonal or zigzag line, the net width of the part shall be obtained by deducting from the gross width the sum of the hole widths of all holes in the chain, and adding, for each gage space in the chain, the quantity $s^2/4g$ where

s = longitudinal center-to-center spacing (pitch) of any two consecutive holes

g = transverse center-to-center spacing (gage) between fastener gage lines

For angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angles less the thickness.

Weld metal in plug or slot welds shall not be included in the net area.

D.3.2 Effective Net Area

The effective net area A_e for angles, channels, tees, zees, rectangular tubes, and I-shaped sections shall be determined as follows:

a) If tension is transmitted directly to each of the cross-sectional elements of the member by fasteners or welds, the effective net area A_e is the net area.

b) If tension is transmitted by fasteners or welds through some but not all of the cross-sectional elements of the member, the effective net area A_e is:

$$A_e = A_n \left(1 - \frac{\overline{x}}{L_C}\right)\left(1 - \frac{\overline{y}}{L_C}\right) \qquad \text{(D.3-1)}$$

where

A_n = net area of the member at the connection

L_C = length of the connection in the direction of load, measured from the center of fasteners or the end of welds. If the length of the connection L_C is zero, the effective net area is the net area of the connected elements.

$\overline{x}$ = eccentricity of the connection in the x-axis direction

$\overline{y}$ = eccentricity of the connection in the y-axis direction

The effective net area of the section need not be less than the net area of the connected elements.

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This chapter addresses members subjected to axial compression through the centroidal axis.

E.1 GENERAL PROVISIONS

The available compressive strength of members is the least of the available strengths for the limit states of member buckling (E.2), local buckling (E.3), and the interaction between member buckling and local buckling (E.4). The available compressive strength, P_c, shall be determined in accordance with Chapter E, where $P_c = \phi_c P_{nc}$ for LRFD, $P_c = P_{nc}/\Omega_c$ for ASD, P_{nc} is the nominal compressive strength and

$\phi_c =$ 0.90 (LRFD)
$\Omega_c =$ 1.65 (ASD)

E.2 MEMBER BUCKLING

The nominal member buckling strength P_{nc} is

$$P_{nc} = F_c A_g \qquad \text{(E.2-1)}$$

where

LIMIT STATE	F_c	Slenderness Limits
yielding	F_{cy}	$\lambda \le \dfrac{B_c - F_{cy}}{D_c} = \lambda_1$
inelastic buckling	$\left(B_c - D_c\lambda\right)\left(0.85 + 0.15\dfrac{C_c - \lambda}{C_c - \lambda_1}\right)$	$\dfrac{B_c - F_{cy}}{D_c} < \lambda < C_c$
elastic buckling	$\dfrac{0.85\pi^2 E}{\lambda^2}$	$\lambda \ge C_c$

λ = greatest column slenderness determined from Sections E.2.1 and E.2.2.

For members without welds determine the nominal member buckling strength $P_{nc} = P_{no}$ using B_c, D_c, and C_c for unwelded material using Table B.4.1 or B.4.2 and F_{cy}.

For members that are fully weld-affected determine the nominal member buckling strength $P_{nc} = P_{nw}$ using B_c, D_c, and C_c for welded material using Table B.4.1 and F_{cyw}.

For members with transverse welds and:

a) supported at both ends with no transverse weld farther than 0.05L from the member ends, $P_{nc} = P_{no}$

b) supported at both ends with a transverse weld farther than 0.05L from the member ends or supported at only one end with a transverse weld $P_{nc} = P_{nw}$,

For members with longitudinal welds, the nominal member buckling strength is:

$$P_{nc} = P_{no}(1 - A_{wz}/A_g) + P_{nw}(A_{wz}/A_g) \qquad \text{(E.2-2)}$$

E.2.1 Flexural Buckling

For flexural buckling, λ is the largest slenderness kL/r of the column. The effective length factor k for calculating column slenderness kL/r shall be determined using Section C.3.

E.2.2 Torsional and Flexural-Torsional Buckling

For torsional or flexural-torsional buckling,

$$\lambda = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(E.2-3)}$$

where F_e is the elastic buckling stress determined by analysis or as follows:

a) For doubly symmetric members:

$$F_e = \left(\frac{\pi^2 E C_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y} \qquad \text{(E.2-4)}$$

b) For singly symmetric members where y is the axis of symmetry:

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H}\right)\left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}}\right] \qquad \text{(E.2-5)}$$

c) For unsymmetric members, F_e is the lowest root of the cubic equation:

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0 \qquad \text{(E.2-6)}$$

where

$$r_o^2 = x_0^2 + y_0^2 + \frac{I_x + I_y}{A_g} \qquad \text{(E.2-7)}$$

$$H = 1 - \frac{x_0^2 + y_0^2}{r_0^2} \qquad \text{(E.2-8)}$$

$$F_{ex} = \frac{\pi^2 E}{\left(\dfrac{k_x L_x}{r_x}\right)^2} \qquad \text{(E.2-9)}$$

$$F_{ey} = \frac{\pi^2 E}{\left(\dfrac{k_y L_y}{r_y}\right)^2} \qquad \text{(E.2-10)}$$

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) \qquad \text{(E.2-11)}$$

$I_x, I_y =$ moments of inertia about the principal axes
$x_o, y_o =$ coordinates of the shear center with respect to the centroid
$r_o =$ polar radius of gyration about the shear center
$r_x, r_y =$ radii of gyration about the centroidal principal axes

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E.3 LOCAL BUCKLING

For members without welds, the local buckling strength shall be determined in accordance with either Section E.3.1 or E.3.2. For members with welds, the local buckling strength shall be determined in accordance with Section E.3.1.

E.3.1 Weighted Average Method

The weighted average local buckling strength is

$$P_{nc} = \sum_{i=1}^{n} F_{ci} A_i + F_{cy} \left(A_g - \sum_{i=1}^{n} A_i \right) \qquad \text{(E.3-1)}$$

where

F_{ci} = local buckling stress of element i determined using Sections B.5.4.1 through B.5.4.5.

A_i = area of element i

E.3.2 Direct Strength Method

As an alternate to Section E.3.1, the local buckling strength of a shape composed of flat elements shall be determined as:

$$P_{nc} = F_c A_g \qquad \text{(E.3-2)}$$

where F_c is determined using Section B.5.4.6.

E.4 INTERACTION BETWEEN MEMBER BUCKLING AND LOCAL BUCKLING

If the elastic local buckling stress F_e is less than the member buckling stress F_c, the nominal compressive strength of the member shall not exceed

$$P_{nc} = \left[\frac{0.85\pi^2 E}{\lambda^2} \right]^{1/3} F_e^{2/3} A_g \qquad \text{(E.4-1)}$$

where λ = greatest column slenderness determined from Sections E.2.1 and E.2.2

If the local buckling strength is determined using Section E.3.1, F_e is the smallest elastic local buckling stress for all elements of the cross section determined by Table B.5.1.

If the local buckling strength is determined using Section E.3.2, F_e is the elastic local buckling stress of the cross section determined by analysis.

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This chapter addresses members subjected to flexure that are either

a) loaded in a plane parallel to a principal axis that passes through the shear center, or

b) restrained against rotation about their longitudinal axis at load points and supports.

F.1 GENERAL PROVISIONS

The available flexural strength of members is the least of the available strengths for the limit states of yielding, rupture, local buckling, and lateral-torsional buckling. The available flexural strength, M_c, shall be determined in accordance with Chapter F, where $M_c = \phi_b M_n$ for LRFD, $M_c = M_n/\Omega_b$ for ASD, M_n is the nominal flexural strength, and

LIMIT STATE	ϕ_b	Ω_b
rupture	0.75	1.95
other flexural limit states	0.90	1.65

For all shapes except single angles, determine the nominal flexural strength using Sections F.2, F.3, and F.4. For single angles, use Section F.5.

F.2 YIELDING AND RUPTURE

For the limit state of yielding, the nominal flexural strength $M_n = M_{np}$ where:

a) For wrought products, M_{np} is the least of $Z F_{cy}$, $1.5S_t F_{ty}$, and $1.5S_c F_{cy}$,

b) For cast products, M_{np} is the lesser of $S_t F_{ty}$ and $S_c F_{cy}$.

For the limit state of rupture, the nominal flexural strength $M_n = M_{nu}$ where

$$M_{nu} = Z F_{tu}/k_t \qquad \text{(F.2-1)}$$

where

Z = plastic modulus

S_t = section modulus on the tension side of the neutral axis

S_c = section modulus on the compression side of the neutral axis

F. 3 LOCAL BUCKLING

The nominal flexural strength for the limit state of local buckling $M_n = M_{nlb}$ shall be determined by Section F.3.1, F.3.2, or F.3.3. Local buckling is not a limit state for wire, rod, or bar.

F.3.1 Weighted Average Method

The nominal flexural strength for local buckling M_{nlb} shall be determined as

$$M_{nlb} = F_c I_f / c_{cf} + F_b I_w / c_{cw} \qquad \text{(F.3-1)}$$

where

F_c = stress corresponding to the strength of an element in uniform compression determined using Sections B.5.4.1 through B.5.4.6. The strength of stiffened elements shall not exceed the strength of an intermediate stiffener or an edge stiffener.

F_b = stress corresponding to the strength of an element in flexural compression determined using Sections B.5.5.1 through B.5.5.5.

c_{cf} = distance from the centerline of a uniform compression element to the cross section's neutral axis

c_{cw} = distance from a flexural compression element's extreme compression fiber to the cross section's neutral axis

I_f = moment of inertia of the uniform stress elements about the cross section's neutral axis. These elements include the elements in uniform compression and the elements in uniform tension and their edge or intermediate stiffeners.

I_w = moment of inertia of the flexural compression elements about the cross section's neutral axis. These elements include the elements in flexure and their intermediate stiffeners.

If there are stiffeners located farther than the compression flange from the cross section's neutral axis, the compressive flexural strength shall not exceed

$$F_{cy} I_f / c_{cs} + F_b I_w / c_{cw}$$

where

c_{cs} = distance from the cross section's neutral axis to the extreme fiber of uniform compression element

F.3.2 Direct Strength Method

The nominal flexural strength for local buckling M_{nlb} shall be determined as

LIMIT STATE	M_{nlb}	λ_{eq}	Slenderness Limits
yielding	M_{np}	$\lambda_{eq} \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{D_p}$
inelastic buckling	$M_{np} - \left(M_{np} - \dfrac{\pi^2 E S_{xc}}{C_p^2}\right)\dfrac{(\lambda_{eq} - \lambda_1)}{(C_p - \lambda_1)}$	$\lambda_1 < \lambda_{eq} < \lambda_2$	
post-buckling	$\dfrac{S_{xc} k_2 \sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$	$\lambda_2 = C_p$

where $\lambda_{eq} = \pi\sqrt{\dfrac{E}{F_e}}$ (F.3-2)

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F_e = the elastic local buckling stress of the cross section determined by analysis

F.3.3 Limiting Element Method

The nominal flexural strength for local buckling M_{nlb} shall be determined by limiting the stress in any element to the local buckling stress of that element, determined in accordance with Sections B.5.4.1 through B.5.4.5 and B.5.5.1 through B.5.5.4.

F.4 LATERAL-TORSIONAL BUCKLING

For the limit state of lateral-torsional buckling, the nominal flexural strength $M_n = M_{nmb}$ where:

LIMIT STATE	M_{nmb}	SLENDERNESS LIMITS
inelastic buckling	$M_{np}\left(1-\frac{\lambda}{C_c}\right)+\frac{\pi^2 E\lambda S_{xc}}{C_c^3}$	$\lambda < C_c$
elastic buckling	$\pi^2 E S_{xc}/\lambda^2$	$\lambda \geq C_c$

for lateral-torsional buckling about an axis designated as the *x*-axis.

To determine the lateral-torsional buckling slenderness λ use Sections F.4.2.1 through F.4.2.5. If more than one Section applies, any applicable Section shall be used.

For members without welds determine the lateral-torsional buckling strength $M_{nmb} = M_{nmbo}$ using C_c for unwelded material using Table B.4.1 or B.4.2 and F_{cy}.

For members that are fully weld-affected determine the lateral-torsional buckling strength $M_{nmb} = M_{nmbw}$ using C_c for welded material using Table B.4.1 and F_{cyw}.

For members with transverse welds and:

a) supported at both ends with no transverse weld farther than 0.05*L* from the member ends, $M_{nmb} = M_{nmbo}$

b) supported at both ends with a transverse weld farther than 0.05*L* from the member ends, or supported at only one end with a transverse weld $M_{nmb} = M_{nmbw}$

For members with longitudinal welds, the lateral-torsional buckling strength M_{nmb} is

$$M_{nmb} = M_{nmbo}(1 - A_{wz}/A_f) + M_{nmbw}(A_{wz}/A_f) \qquad \text{(F.4-1)}$$

where

A_f = area of the member farther than 2*c*/3 from the neutral axis, where *c* is the distance from the neutral axis to the extreme compression fiber.

A_{wz} = weld-affected area within A_f

F.4.1 Bending Coefficient C_b

F.4.1.1 Members Supported on Both Ends

For members subjected to uniform bending moment, the bending coefficient $C_b = 1$. For other members, C_b shall be taken as 1 or determined as follows.

For singly and doubly symmetric shapes between brace points

a) If $I_{yc}/I_y \leq 0.1$ or $I_{yc}/I_y \geq 0.9$, $C_b = 1$

b) If $0.1 < I_{yc}/I_y < 0.9$,

$$C_b = \frac{4M_{\max}}{\sqrt{M^2_{\max} + 4M^2_A + 7M^2_B + 4M^2_C}} R_m \leq 3.0 \qquad \text{(F.4-2)}$$

where

M_{max} = absolute value of the maximum moment in the unbraced segment

M_A = absolute value of the moment at the quarter point of the unbraced segment

M_B = absolute value of the moment at the midpoint of the unbraced segment

M_C = absolute value of the moment at the three-quarter point of the unbraced segment

R_m = 1.0 except for unbraced lengths of singly-symmetric members subjected to double-curvature bending from transverse loading,

$$R_m = 0.5 + 2\left(\frac{I_{yf}}{I_y}\right)^2$$

I_{yf} = moment of inertia of the flange on the negative side of the midheight (where the direction of the load is the positive direction) about the minor axis of the shape

I_y = minor axis moment of inertia of the shape

F.4.1.2 Cantilevers

For doubly symmetric shape cantilevers unbraced at the free end with loads applied at the centroid, for a concentrated load applied at the free end $C_b = 1.3$ and for uniform transverse load $C_b = 2.1$.

F.4.2 Slenderness for Lateral-Torsional Buckling

F.4.2.1 Shapes Symmetric About the Bending Axis

The slenderness for shapes symmetric about the bending axis is

$$\lambda = \frac{L_b}{r_{ye}\sqrt{C_b}} \qquad \text{(F.4-3)}$$

where r_{ye} is:

a) Between brace points of beams subjected to end moment only or to transverse loads applied at the beam's neutral axis, or at brace points:

$$r_{ye} = \sqrt{\frac{\sqrt{I_y}}{S_x}\sqrt{C_w + 0.038JL_b^2}} \qquad \text{(F.4-4)}$$

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b) Between brace points of beams subjected to transverse loads applied on the top or bottom fiber (where the load is free to move laterally with the beam if the beam buckles):

$$r_{ye} = \sqrt{\frac{I_y}{S_x}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{C_w}{I_y} + \frac{0.038JL_b^{\,2}}{I_y}}\right]} \qquad \text{(F.4-5)}$$

$d/4$ is negative when the load acts toward the shear center and positive when the load acts away from the shear center.

where

The y-axis is the principal axis in the plane of bending

I_y = moment of inertia about the y-axis

S_x = section modulus about the x-axis

d = depth of the beam

Alternately, for channels and I-shaped sections symmetric about the bending axis r_{ye} shall be taken as $r_y d/(2r_x)$ or $1.2r_y$.

F.4.2.2 Singly Symmetric Open Shapes Unsymmetric About the Bending Axis

For singly symmetric open shapes unsymmetric about the bending axis and with $I_{yc} \le I_{yt}$, determine the slenderness using Section F.4.2.1 where r_{ye} is calculated with I_y, S_x and J determined as though both flanges were the same as the compression flange with the overall depth d remaining the same.

F.4.2.3 Closed Shapes

For closed shapes, the slenderness is

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} \qquad \text{(F.4-6)}$$

F.4.2.4 Rectangular Bars

For rectangular bars, the slenderness is

$$\lambda = \frac{2.3}{t}\sqrt{\frac{dL_b}{C_b}} \qquad \text{(F.4-7)}$$

where

d = dimension of the bar in the plane of flexure

t = dimension of the bar perpendicular to the plane of flexure

F.4.2.5 Any Shape

For any shape symmetric or unsymmetric about the bending axis the slenderness is:

$$\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}} \qquad \text{(F.4-8)}$$

where M_e is the elastic lateral-torsional buckling moment for a laterally unbraced span subjected to uniform bending determined by analysis or as:

$$M_e = \frac{\pi^2 E I_y}{L_b^{\,2}}\left[U + \sqrt{U^2 + \frac{0.038JL_b^{\,2}}{I_y} + \frac{C_w}{I_y}}\right] \qquad \text{(F.4-9)}$$

where

The y-axis is the centroidal symmetry or principal axis such that the tension flange has a positive y coordinate and bending is about the x-axis. The origin of the coordinate system is the intersection of the principal axes.

$$U = C_1 g_o + C_2 \beta_x/2 \qquad \text{(F.4-10)}$$

C_1 and C_2:

a) If no transverse loads are applied between the ends of the unbraced segment $C_1 = 0$ and $C_2 = 1$.

b) If transverse loads are applied between the ends of the unbraced segment C_1 and C_2 shall be taken as 0.5 or determined by rational analysis.

g_0 = distance from the shear center to the point of application of the load; g_0 is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$.

$$\beta_x = \frac{1}{I_x}\left(\int_A y^3\,dA + \int_A yx^2\,dA\right) - 2y_o \qquad \text{(F.4-11)}$$

For singly symmetric I shapes, as an alternative to Equation F.4-11,

$$\beta_x = 0.9d_f\left(\frac{2I_{yc}}{I_y} - 1\right)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right] \qquad \text{(F.4-12)}$$

where

I_{yc} = moment of inertia of the compression flange about the y-axis

d_f = the distance between the flange centroids; for tees d_f is the distance between the flange centroid and the tip of the stem.

y_o = distance perpendicular to the bending axis from the cross-section's centroid to the shear center; positive in the direction of the load.

Alternately, for singly symmetric I shapes where the smaller flange area is not less than 80% of the larger flange area, β_x shall be taken as $-2y_o$.

F.4.3 Interaction Between Local Buckling and Lateral-Torsional Buckling

For open shapes:

a) whose flanges are flat elements in uniform compression supported on one edge and

b) for which the flange's elastic buckling stress F_e given in Section B.5.6 is less than the lateral-torsional buckling stress of the beam F_b determined in accordance with Section F.4, the lateral-torsional buckling strength shall not exceed

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$$M_{nmb} = \left[\frac{\pi^2 E}{\left(\frac{L_b}{r_{ye}\sqrt{C_b}}\right)^2}\right]^{1/3} F_e^{2/3} S_{xc} \qquad \text{(F.4-13)}$$

F.5 SINGLE ANGLES

For single angles, the nominal flexural strength M_n shall be determined as follows.

a) For the limit state of local buckling:

(1) If a leg tip is a point of maximum compression (Figure F.5.1):

Figure F.5. 1

LIMIT STATE	M_n	b/t	Slenderness Limits
yielding	$1.5F_{cy}S_c$	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_{br} - 1.5F_{cy}}{4.0D_{br}}$
inelastic buckling	$[B_{br} - 4.0D_{br}(b/t)]S_c$	$\lambda_1 < b/t < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E S_c}{(4.0b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{C_{br}}{4.0}$

Buckling constants B_{br}, D_{br}, and C_{br} are given in Tables B.4.1 and B.4.2.

(2) If a leg is in uniform compression (Figure F.5.2):

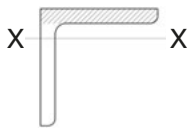


Figure F.5. 2

LIMIT STATE	M_n	b/t	Slenderness Limits
yielding	$F_{cy}S_c$	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{5.0D_p}$
inelastic buckling	$B_p - 5.0D_p(b/t)S_c$	$\lambda_1 < b/t < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E S_c}{(5.0b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{C_p}{5.0}$

Buckling constants B_p, D_p, and C_p are given in Tables B.4.1 and B.4.2.

b) For the limit state of yielding (Figure F.5.3):

Figure F.5. 3

$$M_n = 1.5M_y \qquad \text{(F.5-1)}$$

where M_y = yield moment about the axis of bending.

c) For the limit state of lateral-torsional buckling:

(1) for $M_e \le M_y$, $M_n = (0.92 - 0.17M_e/M_y)M_e$ (F.5-2)

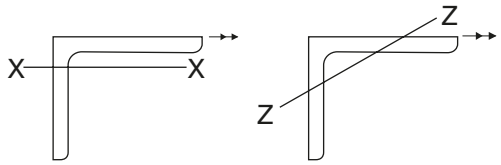
(2) for $M_e > M_y$, $M_n = (1.92 - 1.17\sqrt{M_y/M_e})M_y \le 1.3M_y$ (F.5-3)

where M_e = elastic lateral-torsional buckling moment from Section F.5.1 or F.5.2.

C_b between brace points shall be determined using Equation F.2-1 but shall not exceed 1.5.

F.5.1 Bending About Geometric Axes

Bending about a geometric axis is shown in Figure F.5.4. For combined axial compression and bending, resolve moments about principal axes and use Section F.5.2.



Subsections (a) and (b) Subsection (c)

Figure F.5. 4

a) *Angles with continuous lateral-torsional restraint:* M_n is the lesser of:

(1) local buckling strength determined by Section F.5a.
(2) yield strength determined by Section F.5b.

b) *Equal leg angles with lateral-torsional restraint only at the point of maximum moment*: Strengths shall be calculated with S_c being the geometric section modulus. M_n is the least of:

(1) local buckling strength determined by Section F.5a.
(2) yield strength determined by Section F.5b.
(3) If the leg tip is in compression, lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.73Eb^4tC_b}{L_b^2}\left[\sqrt{1 + 0.88(L_b t/b^2)^2} - 1\right] \qquad \text{(F.5-4)}$$

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If the leg tip is in tension, lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.73Eb^4tC_b}{L_b^2}\left[\sqrt{1+0.88(L_bt/b^2)^2}+1\right] \quad \text{(F.5-5)}$$

c) *Equal leg angles without lateral-torsional restraint*: Strengths shall be calculated with S_c equal to 0.80 of the geometric section modulus.

If the leg tip is in compression, M_n is the lesser of:

(1) local buckling strength determined by Section F.5a(1)

(2) lateral-torsional buckling strength determined by F.5c with

$$M_e = \frac{0.58Eb^4tC_b}{L_b^2}\left[\sqrt{1+0.88(L_bt/b^2)^2}-1\right] \quad \text{(F.5-6)}$$

If the leg tip is in tension, M_n is the lesser of:

(1) yield strength determined by Section F.5b

(2) lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.58Eb^4tC_b}{L_b^2}\left[\sqrt{1+0.88(L_bt/b^2)^2}+1\right] \quad \text{(F.5-7)}$$

d) *Unequal leg angles without lateral-torsional restraint*: moments about the geometric axes shall be resolved into moments about the principal axes and the angle shall be designed as an angle bent about a principal axis (Section F.5.2).

F.5.2 Bending About Principal Axes

Bending about principal axes is shown in Figure F.5.5.

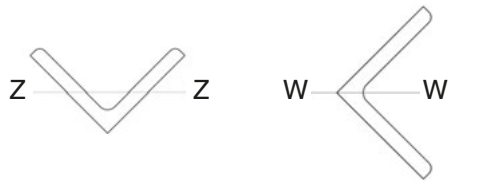

Figure F.5. 5

a) *Major axis bending*: M_n is the lesser of:

(1) local buckling strength determined by Section F.5a for the leg with its tip in compression

(2) lateral-torsional buckling strength determined by Section F.3c, with

$$M_e = \frac{9EAr_ztC_b}{L_b}\left(\sqrt{1+\left(4.4\frac{\beta_w r_z}{L_bt}\right)^2}+4.4\frac{\beta_w r_z}{L_bt}\right) \quad \text{(F.5-8)}$$

$$\beta_w = \left[\frac{1}{I_w}\int z\left(w^2+z^2\right)dA\right]-2z_o \quad \text{(F.5-9)}$$

β_w is the coefficient of monosymmetry about the major principal axis. β_w is positive when the short leg is in compression, negative when the long leg is in compression, and zero for equal-leg angles. (See the commentary for values for common angle sizes and equations for determining β_w.) If the long leg is in compression anywhere along the unbraced length of the angle, β_w shall be taken as negative.

z_o = coordinate along the z-axis of the shear center with respect to the centroid

I_w = moment of inertia about the major principal axis

b) *Minor axis bending*:

(1) If the leg tips are in compression, M_n is the lesser of the local buckling strength determined by Section F.5a(1) and the yield strength determined by Section F.5b.

(2) If the leg tips are in tension, M_n is the yield strength determined by Section F.5b.

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Chapter G Design of Members for Shear

This chapter addresses flat webs of members subjected to shear in the plane of the web, shear in pipes and round or oval tubes, and shear in rods.

G.1 GENERAL PROVISIONS

The available shear strength of members is the least of the available strengths for the limit states of buckling, yielding, and rupture. The available shear strength V_c, shall be determined in accordance with Chapter G, where $V_c = \phi_v V_n$ for LRFD, $V_c = V_n / \Omega_v$ for ASD, V_n is the nominal shear strength, and

LIMIT STATE	ϕ_v	Ω_v
shear rupture	0.75	1.95
other shear limit states	0.90	1.65

For the limit states of shear yielding and shear buckling, the nominal shear strength V_n is

For unwelded members:

$$V_n = F_{so} A_v \quad \text{(G.1-1)}$$

For welded members:

$$V_n = F_{so}(A_v - A_{wz}) + F_{sw} A_{wz} \quad \text{(G.1-2)}$$

where

F_{so} = shear stress F_s corresponding to the shear strength for an element determined using Section G.2, G.3, or G.4 if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and F_{sy}.

F_{sw} = shear stress F_s corresponding to the shear strength for an element determined using Section G.2, G.3, or G.4 if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and F_{syw}.

A_v = shear area as defined in Section G.2, G.3, G.4 or G.5

A_{wz} = weld-affected portion of the shear area

G.2 MEMBERS WITH FLAT WEBS SUPPORTED ON BOTH EDGES

The nominal shear strength V_n of flat webs supported on both edges is

For the limit state of shear rupture

For unwelded members

$$V_n = F_{su} A_n / k_t \quad \text{(G.2-1)}$$

For welded members

$$V_n = F_{su} (A_n - A_{wz})/k_t + F_{suw} A_{wz} \quad \text{(G.2-2)}$$

where

A_n = net area of the web

A_{wz} = weld-affected area of the web

For the limit states of shear yielding and shear buckling V_n is as defined in Section G.1 with

$$A_v = dt \quad \text{(G.2-3)}$$

and F_s determined from:

LIMIT STATE	F_s	b/t	Slenderness Limits
yielding	F_{sy}	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_s - F_{sy}}{1.25 D_s}$
inelastic buckling	$B_s - 1.25 D_s\, b/t$	$\lambda_1 < b/t < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E}{(1.25\, b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{C_s}{1.25}$

b = clear height of the web (see Figure G.2.1) for webs without transverse stiffeners and

$$b = \frac{a_1}{\sqrt{1 + 0.7\left(\dfrac{a_1}{a_2}\right)^2}} \quad \text{for webs with transverse stiffeners}$$

a_1 = the lesser of the clear height of the web and the distance between stiffeners

a_2 = the greater of the clear height of the web and the distance between stiffeners

t = web thickness

d = full depth of the section

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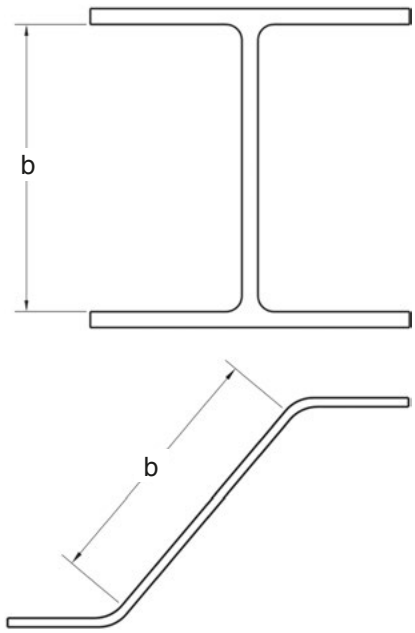

Figure G.2.1
FLAT WEBS IN SHEAR

Transverse stiffeners shall have a moment of inertia I_s not less than the following:

$$\frac{s}{b} \le 0.4, \qquad I_s = \frac{0.55Vb^2}{E}\left(\frac{s}{b}\right) \tag{G.2-4}$$

$$\frac{s}{b} > 0.4, \qquad I_s = \frac{0.088Vb^2}{E}\left(\frac{b}{s}\right) \tag{G.2-5}$$

where

b = clear height of the web regardless of whether or not a longitudinal stiffener is present

I_s = moment of inertia of the transverse stiffener. For a stiffener composed of members of equal size on each side of the web, the moment of inertia of the stiffener shall be computed about the centerline of the web. For a stiffener composed of a member on only one side of the web, the moment of inertia of the stiffener shall be computed about the face of the web in contact with the stiffener.

s = transverse stiffener spacing. For a stiffener composed of a pair of members, one on each side of the web, the stiffener spacing s is the clear distance between the pairs of stiffeners. For a stiffener composed of a member on only one side of the web, the stiffener spacing s is the distance between fastener lines or other connecting lines.

V = shear force on the web at the transverse stiffener

Stiffeners shall extend from flange to flange but need not be connected to either flange.

G.3 MEMBERS WITH FLAT WEBS SUPPORTED ON ONE EDGE

The nominal shear strength V_n of flat webs supported on one edge is

For the limit state of shear rupture

For unwelded members

$$V_n = F_{su}\, A_n / k_t \tag{G.3-1}$$

For welded members

$$V_n = F_{su}(A_n - A_{wz})/k_t + F_{suw}\, A_{wz} \tag{G.3-2}$$

where

A_n = net area of the web

A_{wz} = weld-affected area of the web

For the limit states of shear yielding and shear buckling V_n is as defined in Section G.1 with

$$A_v = bt \tag{G.3-3}$$

and F_s determined from:

LIMIT STATE	F_s	b/t	Slenderness Limits
yielding	F_{sy}	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_s - F_{sy}}{3.0D_s}$
inelastic buckling	$B_s - 3.0D_s\, b/t$	$\lambda_1 < b/t < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E}{(3.0b/t)^2}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{C_s}{3.0}$

b = distance from the unsupported edge to the mid-thickness of the supporting element

t = web thickness

G.4 PIPES AND ROUND OR OVAL TUBES

The nominal shear strength V_n of pipes and round or oval tubes is

For the limit state of shear rupture

For unwelded members

$$V_n = F_{su}\, A_n /(2k_t) \tag{G.4-1}$$

For welded members

$$V_n = F_{su}(A_n - A_{wz})/(2k_t) + F_{suw}\, A_{wz}/2 \tag{G.4-2}$$

where

A_n = net area of the pipe or tube

A_{wz} = weld-affected area of the pipe or tube

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For the limit states of shear yielding and shear buckling V_n is as defined in Section G.1 with

$$A_v = \pi(D_o^2 - D_i^2)/8 \qquad \text{(G.4-3)}$$

where

D_o = outside diameter of the pipe or tube
D_i = inside diameter of the pipe or tube

and F_s determined from:

LIMIT STATE	F_s	λ	Slenderness Limits
yielding	F_{sy}	$\lambda \le \lambda_1$	$\lambda_1 = \dfrac{1.3B_s - F_{sy}}{1.63D_s}$
inelastic	$1.3B_s - 1.63D_s\lambda$	$\lambda_1 < \lambda < \lambda_2$	
elastic buckling	$\dfrac{1.3\pi^2 E}{(1.25\lambda)^2}$	$\lambda \ge \lambda_2$	$\lambda_2 = \dfrac{C_s}{1.25}$

$$\lambda = 2.9\left(\frac{R_b}{t}\right)^{5/8}\left(\frac{L_v}{R_b}\right)^{1/4} \qquad \text{(G.4-4)}$$

R_b = mid-thickness radius of a pipe or round tube or maximum mid-thickness radius of an oval tube
t = wall thickness
L_v = length of pipe or tube from maximum to zero shear force

G.5 RODS

The nominal shear strength V_n of rods is

For the limit state of shear rupture

For unwelded members

$$V_n = F_{su} A_n / k_t \qquad \text{(G.5-1)}$$

For welded members

$$V_n = F_{su}(A_n - A_{wz})/k_t + F_{suw} A_{wz} \qquad \text{(G.5-2)}$$

where

A_n = net area of the rod
A_{wz} = weld-affected area of the rod

For the limit state of shear yielding, V_n is as defined in Section G.1 with

$$A_v = \pi D^2/4 \qquad \text{(G.5-3)}$$

where

D = diameter of the rod
$F_s = F_{sy}$ (G.5-4)

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This chapter addresses members subject to axial force and flexure about one or both axes, with or without torsion, and to members subject to torsion only.

H.1 MEMBERS SUBJECT TO FLEXURE AND AXIAL FORCE

For members subject to flexure and axial force,

$$\frac{P_r}{P_c} + \frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \le 1.0 \qquad \text{(H.1-1)}$$

where all terms are positive, and

x = subscript for major principal axis bending
y = subscript for minor principal axis bending
P_r = required axial strength
P_c = available axial strength determined in accordance with Chapter D for axial tension and Chapter E for axial compression
M_r = required flexural strength
M_c = available flexural strength determined in accordance with Chapter F

H.2 MEMBERS SUBJECT TO TORSION

The available torsional strength of members is the least of the available strengths for the limit states of rupture, yielding, and buckling. The available torsional strength ($\phi_T T_n$ for LRFD and T_n/Ω_T for ASD) shall be determined in accordance with this Section and Sections H.2.1, H.2.2, H.2.3, or H.2.4, where T_n is the nominal torsional strength and

LIMIT STATE	ϕ_T	Ω_T
torsional rupture	0.75	1.95
other torsional limit states	0.90	1.65

For the limit state of torsional rupture, the shear stress F_s corresponding to the torsional strength is

For unwelded members

$$F_s = F_{su}/k_t \qquad \text{(H.2-1)}$$

For welded members

$$F_s = F_{su}(1 - A_{wz}/A_g)/k_t + F_{suw} A_{wz}/A_g \qquad \text{(H.2-2)}$$

For the limit states of shear yielding and shear buckling, the shear stress F_s corresponding to the torsional strength is

For unwelded members

$$F_s = F_{so} \qquad \text{(H.2-3)}$$

For welded members

$$F_s = F_{so}(1 - A_{wz}/A_g) + F_{sw} A_{wz}/A_g \qquad \text{(H.2-4)}$$

where

F_{so} = shear stress corresponding to the torsional strength for an element determined using Section H.2 if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and F_{sy}.
F_{sw} = shear stress corresponding to the torsional strength for an element determined using Section H.2 if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and F_{syw}.
A_{wz} = cross sectional area of the weld-affected zone
A_g = gross cross sectional area of the element.

H.2.1 Pipes and Round or Oval Tubes

The nominal torsional strength T_n for pipes and round or oval tubes is

$$T_n = F_s J/R \qquad \text{(H.2-5)}$$

For the limit state of torsional rupture, the shear stress F_s corresponding to the torsional strength shall be determined in accordance with Section H.2.

For the limit state of torsional yielding and torsional buckling, the shear stress F_s corresponding to the shear strength is

LIMIT STATE	F_s	λ	Slenderness Limits
yielding	F_{sy}	$\lambda \le \lambda_1$	$\lambda_1 = \dfrac{B_s - F_{sy}}{1.25 D_s}$
inelastic buckling	$B_s - 1.25 D_s \lambda$	$\lambda_1 < \lambda < \lambda_2$	
elastic buckling	$\dfrac{\pi^2 E}{(1.25\lambda)^2}$	$\lambda \ge \lambda_2$	$\lambda_2 = \dfrac{C_s}{1.25}$

Buckling constants B_s, D_s, and C_s are given in Table B.4.1 or B.4.2.

$$\lambda = 2.9 \left(\frac{R_b}{t}\right)^{5/8} \left(\frac{L_s}{R_b}\right)^{1/4} \qquad \text{(H.2-6)}$$

R_b = mid-thickness radius of a pipe or round tube or the maximum mid-thickness radius of an oval tube
t = wall thickness

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L_s = length between transverse stiffeners, or overall length if no transverse stiffeners are present
R = outside radius of the pipe or tube
J = torsion constant of the pipe or tube

H.2.2 Rectangular Tubes

The nominal torsional strength T_n for rectangular tubes is

$$T_n = F_s C \quad \text{(H.2-7)}$$

where C is the torsional shear constant.

For the limit state of torsional rupture, the shear stress F_s corresponding to the torsional strength is determined in accordance with Section H.2.

For the limit state of torsional yielding and torsional buckling, F_s is determined in accordance with Section G.2 for the side with the larger slenderness.

H.2.3 Rods

The nominal torsional strength T_n for rods for the limit state of torsional yielding is

For unwelded members:

$$T_n = 0.196 F_{sy} D^3 \quad \text{(H.2-8)}$$

For welded members

$$T_n = 0.196 F_{syw} D^3 \quad \text{(H.2-9)}$$

The nominal torsional strength T_n for rods for the limit state of torsional rupture is

For unwelded members

$$T_n = 0.262 F_{su} D^3 / k_t \quad \text{(H.2-10)}$$

For welded members

$$T_n = 0.262 F_{suw} D^3 \quad \text{(H.2-11)}$$

where
D = diameter of the rod

H.2.4 Open Shapes

The nominal torsional strength T_n for open shapes is the lesser of:

a) the limit states of yielding, local buckling, and rupture due to normal stress determined in accordance with Chapter B, and

b) the limit states of yielding, local buckling, and rupture due to shear stress determined in accordance with Chapter G.

H.3 MEMBERS SUBJECT TO TORSION, FLEXURE, SHEAR, AND/OR AXIAL COMPRESSION

H.3.1 Flat Elements

Stresses in flat elements subject to torsion, flexure, shear, and/or axial compression shall satisfy the following:

$$f_c/(\phi F_c) + [f_b/(\phi F_b)]^2 + [f_s/(\phi F_s)]^2 \le 1.0 \quad \text{(H.3-1 LRFD)}$$

$$f_c/(F_c/\Omega) + [f_b/(F_b/\Omega)]^2 + [f_s/(F_s/\Omega)]^2 \le 1.0 \quad \text{(H.3-1 ASD)}$$

where
f_c = compressive stress due to axial compression
f_b = compressive stress due to flexure
f_s = shear stress due to shear and torsion
F_c = axial compressive stress corresponding to the nominal axial compressive strength
F_b = flexural compressive stress corresponding to the nominal flexural compressive strength
F_s = shear stress corresponding to the nominal shear strength

H.3.2 Curved Elements

Stresses in curved elements subject to torsion, flexure, shear, and/or axial compression shall satisfy the following:

$$f_c/(\phi F_c) + f_b/(\phi F_b) + [f_s/(\phi F_s)]^2 \le 1.0 \quad \text{(H.3-2 LRFD)}$$

$$f_c/(F_c/\Omega) + f_b/(F_b/\Omega) + [f_s/(F_s/\Omega)]^2 \le 1.0 \quad \text{(H.3-2 ASD)}$$

where
f_c = compressive stress due to axial compression
f_b = compressive stress due to flexure
f_s = shear stress due to shear and torsion
F_c = axial compressive stress corresponding to the nominal axial compressive strength
F_b = flexural compressive stress corresponding to the nominal flexural compressive strength
F_s = shear stress corresponding to the nominal shear strength

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This chapter addresses connecting elements and connectors.

J.1 GENERAL PROVISIONS

J.1.1 Design Basis

The design strength and the allowable strength of connections shall be determined in accordance with the provisions of this chapter and Chapter B.

If the longitudinal centroidal axes of connected axially loaded members do not intersect at one point, the connection and members shall be designed for the effects of eccentricity.

J.1.2 Fasteners in Combination with Welds

Fasteners shall not be considered to share load in combination with welds.

J.1.3 Maximum Spacing of Fasteners

The pitch and gage of fasteners joining components of tension members shall not exceed $(3 + 20t)$ in. [$(75 + 20t)$ mm] where t is the thickness of the outside component.

In outside components of compression members:

a) The component's strength shall satisfy the requirements of Section E.2 with an effective length $kL = s/2$, where s is the pitch, and

b) If multiple rows of fasteners are used, the component's strength shall satisfy the requirements of Section B.5.4.2 with a width $b = 0.8g$ where g is the gage. If only one line of fasteners is used, the component's strength shall satisfy the requirements of Section B.5.4.1 with a width b = the edge distance of the fastener.

J.2 WELDS

The design strength (ϕR_n for LRFD and R_n/Ω for ASD) of welds shall be determined using this Section where

ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

J.2.1 Groove Welds

J.2.1.1 Complete Joint Penetration and Partial Joint Penetration Groove Welds

The following types of groove welds are complete joint penetration welds:

a) Welds welded from both sides with the root of the first weld backgouged to sound metal before welding the second side.

b) Welds welded from one side using permanent or temporary backing.

c) Welds welded from one side using AC-GTAW root pass without backing

d) Welds welded from one side using PAW-VP in the keyhole mode.

All other groove welds are partial joint penetration welds.

J.2.1.2 Groove Weld Size

The size S_w of a complete joint penetration groove weld is the thickness of the thinner part joined.

The size S_w of a partial joint penetration groove weld is the depth of preparation for all J and U groove welds and for all V and bevel groove welds with an included angle greater than 45°.

J.2.1.3 Groove Weld Effective Length

A groove weld's effective length L_{we} for tension and compression is the length of the weld perpendicular to the direction of tensile or compressive stress. A groove weld's effective length for shear is the length of the weld parallel to the direction of shear stress.

J.2.2 Fillet Welds

J.2.2.1 Fillet Weld Size

The effective throat S_{we} is the shortest distance from the joint root to the face of the diagrammatic weld.

The size of fillet welds shall be not less than the size required to transmit calculated forces or the size shown in Table J.2.1. These requirements do not apply to fillet weld reinforcements of groove welds.

Table J.2.1
MINIMUM SIZE OF FILLET WELDS

Base Metal Thickness t of Thicker Part Joined in.	Minimum Size of Fillet Weld in.	Base Metal Thickness t of Thicker Part Joined mm	Minimum Size of Fillet Weld mm
$t \le$ ¼	1/8	$t \le 6$	3
¼ < $t \le$ ½	3/16	$6 < t \le 13$	5
½ < $t \le$ ¾	1/4	$13 < t \le 20$	6
$t >$ ¾	5/16	$t > 20$	8

The maximum size of fillet welds shall be:

a) Along edges of material less than ¼ in. (6 mm) thick, not greater than the thickness of the material.

b) Along edges of material ¼ in. (6 mm) or more in thickness, no greater than the thickness of the material minus 1/16 in. (2 mm), unless the weld is especially designated on the drawings to be built out to obtain full-throat thickness. In the as-welded condition, the distance between the edge

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of the base metal and the toe of the weld is permitted to be less than 1/16 in. (2 mm) provided the weld size is clearly verifiable.

J.2.2.2 Fillet Weld Effective Length

A fillet weld's effective length L_{we} is the overall length of the weld, including boxing. If the effective length is less than four times its nominal size S_w, the effective weld size shall be considered to be 25% of its effective length.

The length of any segment of intermittent fillet welds shall not be less than the greater of four times the weld size and 1½ in. (40 mm).

The maximum effective length of an end-loaded fillet weld is $100S_w$.

J.2.3 Plug and Slot Welds

The effective area A_{we} of plug or slot welds is the nominal area of the hole or slot in the plane of the faying surface. Slot lengths shall not exceed 10 times the slotted material's thickness.

J.2.4 Stud Welds

The base metal thickness for arc stud welding shall not be less than 50% of the stud diameter. The base metal thickness for capacitor discharge stud welding shall not be less than 25% of the stud diameter.

J.2.5 Strength

The nominal strength R_n of groove, fillet, plug, slot, and stud welded joints shall be the lesser of the base material strength for the limit states of tensile rupture and shear rupture and the weld metal strength for the limit state of rupture as follows:

a) For the base metal

$$R_n = F_{nBM} A_{BM} \qquad \text{(J.2-1)}$$

b) For the weld metal

$$R_n = F_{nw} A_{we} \qquad \text{(J.2-2)}$$

where

F_{nBM} = nominal stress of the base metal corresponding to its welded ultimate strength from Table A.4.3 or Table A.4.3M

F_{nw} = nominal stress of the weld metal corresponding to its ultimate strength from Table A.4.6

A_{BM} = cross-sectional area of the base metal

A_{we} = effective area of the weld

F_{nBM} , F_{nw} , A_{BM}, and A_{we} are given in Table J.2.2.

Table J.2.2
NOMINAL STRENGTH OF WELDED JOINTS

	Base Metal		Weld Metal	
Load Type and Direction Relative to Weld Axis	Nominal Stress F_{nBM}	Effective Area A_{BM}	Nominal Stress F_{nw}	Effective Area A_{we}
COMPLETE-JOINT PENETRATION GROOVE WELDS				
tension or compression normal to weld axis	F_{tuw}	S_wL_{we}	F_{tuw}	S_wL_{we}
tension or compression parallel to weld axis	tension or compression in parts parallel to a weld need not be considered in designing welds joining the parts			
shear	$0.6F_{tuw}$	S_wL_{we}	$0.6F_{tuw}$	S_wL_{we}
PARTIAL-JOINT PENETRATION GROOVE WELDS				
tension or compression normal to weld axis	F_{tuw}	S_wL_{we}	$0.6F_{tuw}$	S_wL_{we}
tension or compression parallel to weld axis	tension or compression in parts parallel to a weld need not be considered in designing welds joining the parts			
shear	$0.6F_{tuw}$	S_wL_{we}	$0.6F_{tuw}$	S_wL_{we}
FILLET WELDS				
shear	$0.6F_{tuw}$	S_wL_{we}	$0.6(0.85F_{tuw})$ (see note 1)	S_wL_{we}
tension or compression parallel to weld axis	tension or compression in parts parallel to a weld need not be considered in designing welds joining the parts			
PLUG AND SLOT WELDS				
shear parallel to faying surface	$0.6F_{tuw}$	see J.2.3	$0.6F_{tuw}$	see J.2.3
STUD WELDS				
shear	$0.6F_{tuw}$	$\pi D^2/4$	$0.6F_{tuw}$	$(\pi/4)(D - 1.191/n)^2$
tension	F_{tuw}	$\pi D^2/4$	F_{tuw}	$(\pi/4)(D - 1.191/n)^2$

① Alternately, the strength of fillet welds loaded transversely shall be taken as 1.36 times the strength given in Table J.2.2.

② F_{tuw} for base metal is listed in Tables A.4.3 and A.4.3M.

③ F_{tuw} for filler metal is listed in Table A.4.6.

J.2.6 Combination of Welds

If two or more of the types of welds (groove, fillet, plug, or slot) are combined in a single joint, the strength of each shall be separately computed with respect to the axis of the group in order to determine the strength of the combination.

J.2.7 Post-Weld Heat Treatment

The nominal strength of the weld-affected zone of post-weld-heat-treated base metal shall be taken as given in

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Table J.2.3. The tension coefficient k_t of the weld-affected zone after post-weld heat treatment for the alloys listed in Table J.2.3 shall be taken as the tension coefficient k_t of the non-weld-affected alloy.

Table J.2.3
NOMINAL STRENGTH OF THE WELD-AFFECTED ZONE OF POST-WELD-HEAT-TREATED BASE METAL

Alloy	Temper before welding	maximum nominal thickness (in.)	maximum nominal thickness (mm)	filler alloy	post-weld heat treat-ment	nominal post-weld heat treatment strength
6005A	T1	0.250	6.3	4043	T5	85% of unwelded T5
6061	T4	0.250	6.3	4043	T6	85% of unwelded T6
6063	T4	0.375	9.5	4043	T6	85% of unwelded T6

J.3 BOLTS

J.3.1 Holes and Slots for Bolts

The nominal diameter of holes for bolts shall not be more than 1/16 in. (2 mm) greater than the nominal diameter of the bolt unless slip-critical connections are used.

The nominal width of slots for bolts shall not be more than 1/16 in. (2 mm) greater than the nominal diameter of the bolt. If the nominal length of the slot exceeds 2.5D or the edge distance is less than 2D, where D is the nominal bolt diameter, the edge distance perpendicular to the slot length and slot length shall be sized to avoid overstressing the material along the slot. Unless slip-critical connections are used, the length shall be perpendicular to the direction of force.

J.3.2 Minimum Spacing of Bolts

The distance between bolt centers shall not be less than 2.5 times the nominal diameter of the bolt.

J.3.3 Minimum Edge Distance of Bolts

The distance from the center of a bolt to an edge of a part shall not be less than 1.5 times the nominal diameter of the bolt. See Section J.3.6 for the effect of edge distance on bearing strength.

J.3.4 Bolt Tension

The design tension strength (ϕR_n for LRFD and R_n/Ω for ASD) of aluminum bolts shall be determined for the limit state of tensile rupture as follows:

$\phi =$ 0.65 (LRFD)
$\Omega =$ 2.34 (ASD)

$$R_n = (\pi(D - 1.191/n)^2/4)F_{tu} \quad \text{(J.3-1)}$$

where

$F_{tu} =$ tensile ultimate strength of the bolt (Table A.4.7 or Table A.4.7M).

J.3.5 Bolt Shear

The available shear strength (ϕR_n for LRFD and R_n/Ω for ASD) of aluminum bolts shall be determined for the limit state of shear rupture as follows:

$\phi =$ 0.65 (LRFD)
$\Omega =$ 2.34 (ASD)

a) For bolts with threads in the shear plane,

$$R_n = (\pi(D - 1.191/n)^2/4)F_{su} \quad \text{(J.3-2)}$$

b) For bolts without threads in the shear plane,

$$R_n = (\pi D^2/4)F_{su} \quad \text{(J.3-3)}$$

where

$F_{su} =$ shear ultimate strength of the bolt (Table A.4.7 or Table A.4.7M).

If the grip (total thickness of parts being fastened) of an aluminum bolt exceeds 4.5D, the bolt's nominal shear strength shall be reduced by dividing by $1/2 + G_f/(9D)$ where G_f is the grip and D is the bolt's nominal diameter.

J.3.6 Bolt Bearing

The available bearing strength (ϕR_n for LRFD and R_n/Ω for ASD) of connected parts shall be determined for the limit state of bearing as follows:

$\phi =$ 0.75 (LRFD)
$\Omega =$ 1.95 (ASD)

a) For a bolt in a hole,

$$R_n = d_e t F_{tu} \le 2DtF_{tu} \quad \text{(J.3-4)}$$

b) For a bolt in a slot with the slot perpendicular to the direction of force:

$$R_n = 1.33DtF_{tu} \quad \text{(J.3-5)}$$

and the edge distance perpendicular to the slot length and slot length shall be sized to avoid overstressing the material between the slot and the edge of the part.

where

$d_e =$ distance from the center of the bolt to the edge of the part in the direction of force.
$t =$ for plain holes, thickness of the connected part; for countersunk holes, thickness of the connected part less ½ the countersink depth

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F_{tu} = tensile ultimate strength of the connected part
D = nominal diameter of the bolt

J.3.7 Slip-Critical Bolted Connections

J.3.7.1 General

Slip-critical connections between aluminum members or between aluminum and steel members shall comply with the Research Council on Structural Connections (RCSC) *Specification for Structural Joints Using High Strength Bolts* except as modified here. Slip-critical connections shall be designed for the limit states of shear rupture in accordance with Section J.3.7.4, bearing strength in accordance with Section J.3.6, and slip in accordance with Section J.3.7.5.

J.3.7.2 Material

Aluminum used in slip-critical connections shall have a tensile yield strength of at least 15 ksi (105 MPa). Bolts shall comply with ASTM F3125/F3125M Grades A325, A325M, nuts shall comply with ASTM A563 Grade DH or ASTM A194 Grade 2H, and washers shall comply with ASTM F436/F436M. Bolts, nuts, and washers shall be zinc coated by the hot-dip or mechanically deposited processes as specified in ASTM F3125/F3125M.

J.3.7.3 Holes

Holes shall be standard holes, oversize holes, short slotted holes, or long slotted holes. The nominal dimensions for each hole type shall not exceed those shown in the RCSC specification.

J.3.7.4 Bolt Tension and Shear

The available tensile or shear strength (ϕR_n for LRFD and the R_n/Ω for ASD) shall be determined for the limit state of rupture as follows:

ϕ = 0.75 (LRFD)
Ω = 2.0 (ASD)

$$R_n = F_n A_b \qquad \text{(J.3-6)}$$

where

F_n is F_{nt} or F_{nv} determined in accordance with the *Specification for Structural Steel Buildings (ANSI/AISC 360)*.

A_b = nominal cross sectional area (unthreaded body area) of the bolt

J.3.7.5 Slip Resistance

Slip-critical connections shall be designed for the limit state of slip in accordance with the *Specification for Structural Steel Buildings* with the following exceptions:

a) For standard size and short-slotted holes perpendicular to the direction of the load:
ϕ = 1.00 (LRFD)
Ω = 1.50 (ASD)

b) For oversized and short-slotted holes parallel to the direction of the load:
ϕ = 0.85 (LRFD)
Ω = 1.76 (ASD)

c) For long-slotted holes:
ϕ = 0.70 (LRFD)
Ω = 2.14 (ASD)

d) μ = mean slip coefficient = 0.50 for aluminum surfaces abrasion blasted with coal slag to SSPC SP-5 to an average substrate profile of 2.0 mils (0.05 mm) in contact with similar aluminum surfaces or zinc painted steel surfaces with a maximum dry film thickness of 4 mils (0.1 mm) (Class B surfaces). Determine slip coefficients for other surfaces in accordance with the RCSC specification Appendix A.

J.3.7.6 Washers

Washers shall be used under bolt heads and under nuts. At a long slotted hole in an outer ply, a galvanized steel plate washer or bar at least 5/16 in. (8 mm) thick with standard holes shall be used. The plate washer or bar shall completely cover the slot but need not be hardened. Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, a beveled washer shall be used.

J.3.8 Lockbolts

Lockbolts shall meet the requirements in this *Specification* for conventional bolts and be installed in conformance with the lockbolt manufacturer's specifications. The bearing areas under the head and collar shall not be less than those of a conventional bolt and nut.

J.4 RIVETS

J.4.1 Holes for Cold-Driven Rivets

The finished diameter of holes for cold-driven rivets shall not be more than 4% greater than the nominal diameter of the rivet.

J.4.2 Minimum Spacing of Rivets

The distance between rivet centers shall not be less than 3 times the nominal diameter of the rivet.

J.4.3 Minimum Edge Distance of Rivets

The distance from the center of a rivet to an edge of a part shall not be less than 1.5 times the nominal diameter of the rivet. See Section J.4.6 for the effect of edge distance on the bearing strength.

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J.4.4 Rivet Tension

Rivets shall not be used to resist loads acting parallel to the axis of the rivet.

J.4.5 Rivet Shear

The available shear strength (ϕR_n for LRFD and R_n/Ω for ASD) of aluminum rivets shall be determined for the limit state of shear rupture as follows:

ϕ = 0.65 (LRFD)
Ω = 2.34 (ASD)

$$R_n = \pi D_h^2 F_{su}/4 \qquad \text{(J.4-1)}$$

where

D_h = nominal diameter of the hole (See Section J.4.1 for hole size limits and Section J.4.8 for hollow-end rivets).

F_{su} = shear ultimate strength of the rivet (See Table A.4.8).

J.4.6 Rivet Bearing

The available bearing strength (ϕR_n for LRFD and R_n/Ω for ASD) shall be determined for the limit state of bearing as follows:

ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

$$R_n = d_e\, tF_{tu} \le 2D_h tF_{tu} \qquad \text{(J.4-2)}$$

where

d_e = distance from the center of the rivet to the edge of the part in the direction of force.

t = for plain holes, nominal thickness of the connected part; for countersunk holes, nominal thickness of the connected part less ½ the countersink depth

F_{tu} = tensile ultimate strength of the connected part

D_h = nominal diameter of the hole

J.4.7 Blind Rivets

Grip lengths and hole sizes for blind rivets shall comply with the manufacturer's specifications.

J.4.8 Hollow-End (Semi-Tubular) Rivets

The shear strength of hollow-end rivets with solid cross sections for a portion of the length shall be taken equal to the strength of solid rivets of the same material if the bottom of the cavity is at least 25% of the rivet diameter from the plane of shear.

J.5 TAPPING SCREWS

This section applies to tapping screws with a nominal diameter D from 0.164 in. (4.2 mm) (No. 8) through 0.25 in. (6.3 mm). Screws shall be thread-forming or thread-cutting, with or without a self-drilling point.

Screws shall be installed in accordance with the manufacturer's specifications.

J.5.1 Holes for Screws

The nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than 1/16 in. (1.6 mm).

The nominal diameter of holes to be subsequently tapped by screws shall not exceed that given in Tables J.5.1 and J.5.2.

Table J.5.1
HOLE DIAMETER D_h FOR TYPE AB, B, AND BP SCREWS

Screw Size	Metal Thickness in.	Hole Diameter in. ①	Drill Size
8	0.030	0.116	32
	0.036	0.120	31
	0.048	0.128	30
	0.060	0.136	29
	0.075	0.140	28
	0.105	0.147	26
	0.125	0.147	26
	0.135	0.149	25
	0.162 to 0.375	0.152	24
10	0.036	0.144	27
	0.048	0.144	27
	0.060	0.144	27
	0.075	0.147	26
	0.105	0.147	26
	0.125	0.154	23
	0.135	0.154	23
	0.164	0.159	21
	0.200 to 0.375	0.166	19
12	0.048	0.161	20
	0.060	0.166	19
	0.075	0.173	17
	0.105	0.180	15
	0.125	0.182	14
	0.135	0.182	14
	0.164	0.189	12
	0.200 to 0.375	0.196	9
¼	0.060	0.199	8
	0.075	0.201	7
	0.105	0.204	6
	0.125	0.209	4
	0.135	0.209	4
	0.164	0.213	3
	0.187	0.213	3
	0.194	0.221	2
	0.200 to 0.375	0.228	1

For material thicknesses not given, use the next smaller thickness.

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Table J.5.2
HOLE DIAMETER D_h FOR TYPE C, D, F, AND T SCREWS

screw size	Metal Thickness (in.) 0.050	0.060	0.083	0.109	0.125	0.140	3/16	1/4	5/16	3/8	1/2
	Hole Diameter (in.)										
8-32	0.1360	0.1360	0.1360	0.1405	0.1405	0.1440	0.1470	0.1495	0.1495		
10-24	0.1495	0.1520	0.1540	0.1570	0.1590	0.1610	0.1660	0.1719	0.1730	0.1730	
10-32	0.1610	0.1610	0.1610	0.1660	0.1660	0.1660	0.1719	0.1770	0.1770	0.1770	
12-24		0.1770	0.1800	0.1820	0.1850	0.1875	0.1910	0.1990	0.1990	0.1990	0.1990
¼-20			0.2055	0.2090	0.2130	0.2130	0.2210	0.2280	0.2280	0.2280	0.2280
¼-28			0.2188	0.2210	0.2210	0.2210	0.2280	0.2344	0.2344	0.2344	0.2344

For material thicknesses not given, use the next smaller thickness.

J.5.2 Minimum Spacing of Screws

The distance between screw centers shall not be less than 2.5 times the nominal diameter of the screw.

J.5.3 Minimum Edge Distance of Screws

The distance from the center of a screw to an edge of a part shall not be less than 1.5 times the nominal diameter of the screw. See Section J.5.5.1 for the effect of edge distance on the bearing strength.

J.5.4 Screwed Connection Tension

The tensile strength of a screwed connection is the least of the pull-out, pull-over, and screw tensile rupture strengths. The available tensile strength (ϕR_n for LRFD and R_n/Ω for ASD) shall be determined as follows:

$\phi = 0.50$ (LRFD)

$\Omega = 3.0$ (ASD)

The nominal strength R_n for the limit state of pull-out shall be determined in accordance with Section J.5.4.1.

The nominal strength R_n for the limit state of pull-over shall be determined in accordance with Section J.5.4.2.

The nominal strength R_n for the limit state of screw tensile rupture shall be determined in accordance with Section J.5.4.3.

For screws subjected to tension, the head of the screw or washer, if a washer is provided, shall have a nominal diameter not less than 5/16 in. (8 mm). Washers shall have a nominal thickness not less than 0.050 in. (1.3 mm).

J.5.4.1 Pull-Out

J.5.4.1.1 Screws in Holes

The nominal strength R_n for the limit state of pull-out of a screw in a hole is:

a) For UNC and UNF threads (screw types C, D, F, G, and T)

1) for 0.060 in. $\le L_e \le$ 0.125 in. (1.5 mm $\le L_e \le$ 3 mm)

$$R_n = K_s\, D\, L_e\, F_{ty2} \qquad \text{(J.5-1)}$$

where

$K_s = 1.01$ for 0.060 in. $\le L_e <$ 0.080 in. (1.5 mm $\le L_e <$ 2 mm)

$K_s = 1.20$ for 0.080 in. $\le L_e \le$ 0.125 in. (2 mm $\le L_e \le$ 3 mm)

F_{ty2} = tensile yield strength of member not in contact with the screw head or washer

D = nominal diameter of the screw

2) for 0.125 in. $< L_e <$ 0.25 in. (3 mm $< L_e <$ 6.3 mm)

$$R_n = 1.2DF_{ty2}(0.25 - L_e) + 1.16A_{sn}F_{tu2}(L_e - 0.125) \qquad \text{(J.5-2)}$$

where

A_{sn} = thread stripping area of internal thread per unit length of engagement

F_{tu2} = tensile ultimate strength of member not in contact with the screw head or washer

3) for 0.25 in. $\le L_e \le$ 0.375 in. (6.3 mm $\le L_e \le$ 10 mm)

$$R_n = 0.58\, A_{sn}\, L_e\, F_{tu2} \qquad \text{(J.5-3)}$$

b) For spaced threads (screw types AB, B, BP, BF, and BT)

1) for 0.038 in. $\le L_e \le 2/n$ (1 mm $\le L_e \le 2/n$)

$$R_n = K_s\, D\, L_e\, F_{ty2} \qquad \text{(J.5-4)}$$

where

$K_s = 1.01$ for 0.038 in. $\le L_e <$ 0.080 in. (1 mm $\le L_e <$ 2 mm)

$K_s = 1.20$ for 0.080 in. $< L_e < 2/n$ (2 mm $< L_e < 2/n$)

2) for $2/n < L_e < 4/n$

$$R_n = 1.2D\, F_{ty2}\, (4/n - L_e) + 3.26D\, F_{tu2}\, (L_e - 2/n) \qquad \text{(J.5-5)}$$

3) for $4/n \le L_e \le$ 0.375 in. ($4/n \le L_e \le$ 8 mm)

$$R_n = 1.63D\, L_e\, F_{tu2} \qquad \text{(J.5-6)}$$

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J.5.4.1.2 Screws in Screw Slots

The nominal strength R_n for the limit state of pull-out of a screw in a screw slot with the dimensions shown in Figure J.5.1 and Table J.5.3 is:

$$R_n = 0.29DL_e F_{tu} \quad \text{(J.5-7)}$$

where

D = nominal diameter of the screw

F_{tu} = tensile ultimate strength of the extrusion

The screw embedment length in the screw slot L_e shall not be less than $2D$.

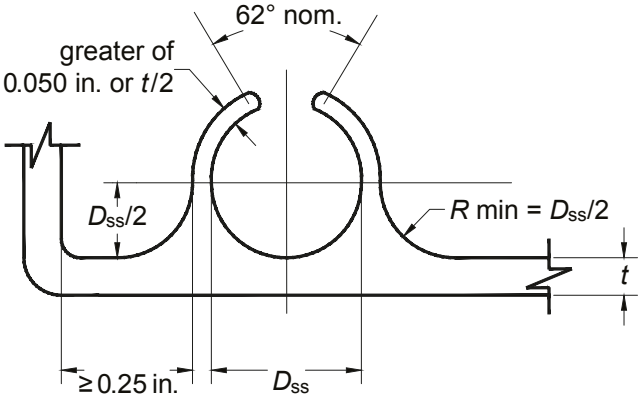

Figure J.5.1

Table J.5.3
SCREW SLOT DIMENSIONS

Screw Size	Screw Diameter D in.	D_{ss} in. +/- 0.007 in.
8	0.164	0.147
10	0.190	0.169
12	0.216	0.190
1/4	0.250	0.228

J.5.4.1.3 Screws (1/4 in. Diameter) in Screw Chases

The nominal strength R_n for the limit state of pull-out of a ¼ in. nominal diameter screw in a screw chase is:

$$R_n = K_{sc} L_e F_{tu} (n_o/n)^2/w_c \quad \text{(J.5-8)}$$

where

K_{sc} = 0.021 in^2

F_{tu} = tensile ultimate strength of the screw chase extrusion

n_o = 14 threads/in.

n = number of threads/in. of the screw

L_e = length of engagement of the screw's threads in the chase, calculated by deducting any chamfer at the top of the chase and the portion of the fastener at its point without full threads. The deduction for the point shall be: for AB screws, 0.250 in. for UNC screws, 0.050 in. and for F screws, 0.225 in.

w_c = nominal width of the chase, but no less than 0.180 in. and no greater than 0.220 in. For ribbed-wall chases, the nominal width is the inside width of the chase plus the height of one rib. The ribs' nominal height shall not exceed the depth of the screw thread used in the chase.

The nominal thickness of the chase walls shall not be less than 0.150 in. and the nominal depth of the chase shall not exceed 0.750 in.

J.5.4.2 Pull-Over

a) The nominal strength R_n for the limit state of pull-over for non-countersunk screws is:

$$R_n = C_{pov} t_1 F_{tu1} (D_{ws} - D_h) \quad \text{(J.5-9)}$$

where

C_{pov} = 1.0 for valley fastening and 0.7 for crown fastening

t_1 = nominal thickness of the part in contact with the screw head or washer

F_{tu1} = tensile ultimate strength of the part in contact with the screw head or washer

D_{ws} = larger of the nominal washer diameter and the screw head diameter, but no greater than 5/8 in. (16 mm). (See Section J.5.4 for the washer thickness requirement.)

D_h = nominal diameter of the hole in the material in contact with the screw head or washer

The nominal pull-over strength for non-countersunk screws need not be less than the nominal pull-over strength computed from Equation J.5-11 for countersunk screws.

Alternately, for parts with: 1) a nominal thickness of at least 0.040 in., 2) holes with the nominal diameters given in Table J.5.4, and 3) $t_1/D_{ws} \le 0.5$, the nominal strength R_n for the limit state of pull-over for non-countersunk screws with all-metal washers is:

$$R_n = (1.0 + 1.7t_1/D_{ws})D_{ws} t_1 F_{ty1} \quad \text{(J.5-10)}$$

where

F_{ty1} = tensile yield strength of the part in contact with the screw head or washer

D_{ws} = nominal diameter of the washer. The washer may be integral with the screw head.

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Table J.5.4
HOLE DIAMETER FOR EQUATION J.5-10

Screw Size	Screw Diameter D in.	Hole Diameter D_h in.	Drill Size
8	0.164	0.177	16
10	0.190	0.201	7
12	0.216	0.228	1
¼	0.250	0.266	H

b) The nominal strength R_n for the limit state of pull-over for countersunk screws with an 82° nominal angle head is:

$$R_n = (0.27 + 1.45t_1/D)\, D\, t_1 F_{ty1} \quad \text{(J.5-11)}$$

for 0.06 in. ≤ t_1 < 0.19 in. (1.5 mm ≤ t_1 < 5 mm) and $t_1/D \leq 1.1$. If $t_1/D > 1.1$, use $t_1/D = 1.1$

J.5.4.3 Screw Tension

The nominal strength R_n of an aluminum screw for the limit state of screw tensile rupture is:

$$R_n = A_r\, F_{tu}/1.25 \quad \text{(J.5-12)}$$

where
A_r = root area of the screw
F_{tu} = tensile ultimate strength of the screw
= 68 ksi (470 MPa) for 7075-T73 screws
= 62 ksi (430 MPa) for 2024-T4 screws

J.5.5 Screwed Connection Shear

The shear strength of a screwed connection is the least of the bearing, tilting, and screw shear rupture strengths. The available shear strength (ϕR_n for LRFD and R_n/Ω for ASD) shall be determined as follows:

ϕ = 0.50 (LRFD)
Ω = 3.0 (ASD)

The nominal strength R_n for the limit state of bearing shall be determined in accordance with Section J.5.5.1.

The nominal strength R_n for the limit state of tilting shall be determined in accordance with Section J.5.5.2.

The nominal strength R_n for the limit state of screw shear rupture shall be determined in accordance with Section J.5.5.3.

J.5.5.1 Screw Bearing

The nominal strength R_n for the limit state of bearing is

$$R_n = d_e\, t\, F_{tu} \leq 2DtF_{tu} \quad \text{(J.5-13)}$$

where
d_e = distance from the center of the screw to the edge of the part in the direction of force.
t = for plain holes, nominal thickness of the connected part; for countersunk holes, nominal thickness of the connected part less ½ the countersink depth.
F_{tu} = tensile ultimate strength of the connected part
D = nominal diameter of the screw

J.5.5.2 Screw Tilting

For $t_2 \leq t_1$, the nominal strength R_n for the limit state of tilting is:

$$R_n = 4.2(t_2^3 D)^{1/2} F_{tu2} \quad \text{(J.5-14)}$$

where
t_1 = nominal thickness of the part in contact with the screw head or washer
t_2 = nominal thickness of the part not in contact with the screw head or washer

For $t_2 > t_1$, tilting is not a limit state.

J.5.5.3 Screw Shear

The nominal strength R_n of an aluminum screw for the limit state of screw shear rupture is:

$$R_n = A_r\, F_{su}/1.25 \quad \text{(J.5-15)}$$

where
A_r = root area of the screw
F_{su} = shear ultimate strength of the screw
= 41 ksi (285 MPa) for 7075-T73 screws
= 37 ksi (255 MPa) for 2024-T4 screws

J.6 PINS

J.6.1 Holes for Pins

The nominal diameter of holes for pins shall not be more than 1/32 in. (1 mm) greater than the nominal diameter of the pin.

J.6.2 Minimum Edge Distance of Pins

The distance from the center of a pin to an edge of a part shall not be less than 1.5 times the nominal diameter of the pin. See Section J.6.5 for the effect of edge distance on bearing strength.

J.6.3 Pin Tension

Pins shall not be used to resist loads acting parallel to the axis of the pin.

J.6.4 Pin Shear and Flexure

The design strength (ϕR_n for LRFD and R_n/Ω for ASD) of an aluminum pin in shear or flexure shall be determined as follows:

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$\phi_y = 0.90, \phi_u = 0.65$ (LRFD)
$\Omega_y = 1.65, \Omega_u = 2.34$ (ASD)

a) Pin Shear
The available shear strength is

$$V_c = \phi V_n = \phi_y(\pi D^2 F_{sy}/4) \le \phi_u(\pi D^2 F_{su}/4) \quad \text{(J.6-1 LRFD)}$$

$$V_c = V_n/\Omega = (\pi D^2 F_{sy}/4)/\Omega_y \le (\pi D^2 F_{su}/4)/\Omega_u \quad \text{(J.6-1 ASD)}$$

b) Pin Flexure
The available flexural strength is

$$M_c = \phi M_n = \phi_y(\pi D^3 F_{ty}/21.3) \le \phi_u(\pi D^3 F_{tu}/(21.3 k_t)) \quad \text{(J.6-2 LRFD)}$$

$$M_c = M_n/\Omega = (\pi D^3 F_{ty}/21.3)/\Omega_y \le (\pi D^3 F_{tu}/(21.3 k_t))/\Omega_u \quad \text{(J.6-2 ASD)}$$

c) For pins subjected to shear and flexure,

$$\left(\frac{V_r}{V_c}\right)^3 + \left(\frac{M_r}{M_c}\right) \le 1.0 \quad \text{(J.6-3)}$$

V_r = required shear strength
V_c = available shear strength determined using Section J.6.4a
M_r = required flexural strength
M_c = available flexural strength determined using Section J.6.4b

J.6.5 Pin Bearing

The available bearing strength (ϕR_n for LRFD and R_n/Ω for ASD) of a part in contact with a pin shall be determined as follows:
ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

$$R_n = d_e\, t\, F_{tu}/1.5 \le 1.33 D t F_{tu} \quad \text{(J.6-4)}$$

where
D = nominal diameter of the pin
t = thickness of the connected part
d_e = distance from the center of a pin to the edge of a part, which shall not be less than $1.5D$

J.7 AFFECTED ELEMENTS OF MEMBERS AND CONNECTORS

This section applies to elements of members at connections and connectors such as plates, gussets, angles, and brackets.

J.7.1 Strength of Connectors in Tension

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) of connectors in tension shall be determined in accordance with Chapter D. For mechanically connected plates, $A_e = A_n \le 0.85 A_g$.

J.7.2 Strength of Connectors in Shear

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) of connectors in shear shall be the lesser value for the limit states of shear yielding and shear rupture.

a) For shear yielding of connectors:
$R_n = F_{sy} A_g$
ϕ = 1.00 (LRFD)
Ω = 1.50 (ASD)

b) For shear rupture of connectors:
$R_n = F_{su} A_{nv}/k_t$
ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

J.7.3 Block Shear Strength

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) shall be determined for the limit state of block shear rupture as follows:
ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

a) For mechanically fastened connections on a failure path with shear on some segments and tension on the other segments:

$$R_n = [F_{su}(A_{nv} + A_{gv})/2 + F_{tu} A_{nt}]/k_t \quad \text{(J.7-1)}$$

where
A_{gv} = gross area in shear
A_{nv} = net area in shear
A_{nt} = net area in tension

b) For welded connections on a failure path with shear on some segments and tension on the other segments:

$$R_n = F_{suw} A_{gvw} + F_{tuw} A_{gtw} + (F_{su} A_{gvo} + F_{tu} A_{gto})/k_t \quad \text{(J.7-2)}$$

where
A_{gvw} = gross weld-affected area in shear
A_{gvo} = gross area not weld-affected in shear
A_{gtw} = gross weld-affected area in tension
A_{gto} = gross area not weld-affected in tension

J.7.4 Strength of Connectors in Compression

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) of connectors in compression shall be determined in accordance with Chapter E.

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J.8 BEARING STRENGTH OF FLAT SURFACES

The available bearing strength (ϕR_n for LRFD and R_n/Ω for ASD) of flat surfaces in contact shall be determined as follows:

ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

$$R_n = 1.33\, F_{tu}\, A_b \qquad \text{(J.8-1)}$$

where A_b = bearing area

J.9 FLANGES AND WEBS WITH CONCENTRATED FORCES

When the required strength exceeds the available strength determined for the limit states given in this section, stiffeners and/or doublers shall be provided and shall be sized for the difference between the required strength and the available strength for the applicable limit state.

J.9.1 Flange Local Bending

This section applies to a tensile concentrated force applied as a line load transverse to the flange of an I-shaped section by a welded connection.

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) for the limit state of flange local bending shall be determined as:

$$R_n = 6.25\, F_{tyfw}\, t_f^2 \qquad \text{(J.9-1)}$$

ϕ = 0.90 (LRFD)
Ω = 1.65 (ASD)

where
F_{tyfw} = welded tensile yield strength of the flange
t_f = thickness of the loaded flange

When the concentrated force to be resisted is applied at a distance from the member end that is less than $10t_f$, R_n shall be reduced by 50%.

J.9.2 Web Local Yielding

This section applies to tensile and compressive concentrated forces applied to one flange of an I-shaped member at the cross section under consideration.

The available strength of members (ϕR_n for LRFD and R_n/Ω for ASD) for the limit state of web local yielding shall be determined as:

ϕ = 1.00 (LRFD)
Ω = 1.50 (ASD)

The nominal strength R_n shall be determined as follows:

a) When the concentrated force is applied at a distance greater than the depth of the member d from the member end

$$R_n = F_{yw} t_w \left(l_b + 2t_f \sqrt{\frac{F_{yf}}{F_{yw}} \frac{b_f}{t_w}} \right) \qquad \text{(J.9-2)}$$

b) When the concentrated force is applied at a distance less than or equal to the depth of the member d from the member end

$$R_n = F_{yw} t_w \left(l_b + t_f \sqrt{\frac{F_{yf}}{F_{yw}} \frac{b_f}{t_w}} \right) \qquad \text{(J.9-3)}$$

where
F_{yw} = tensile yield strength of the web (use the welded strength if the web is welded)
F_{yf} = tensile yield strength of the flange (use the welded strength if the flange is welded)
l_b = bearing length
t_w = web thickness
t_f = flange thickness
b_f = flange width

J.9.3 Web Crippling

The available strength (ϕR_n for LRFD and R_n/Ω for ASD) for the limit state of web crippling shall be determined using Section J.9.3.1 or Section J.9.3.2 as follows:

ϕ = 0.75 (LRFD)
Ω = 1.95 (ASD)

J.9.3.1 Web Crippling of Extruded Members

This section applies to compressive concentrated forces applied to one flange of an extruded I-shaped member at the cross section under consideration.

a) For concentrated forces applied at a distance from the member end that equals or exceeds $d/2$:

$$R_n = 0.80 t_w^2 \left(1 + 3 \left(\frac{l_b}{d} \right) \left(\frac{t_w}{t_f} \right)^{1.5} \right) \sqrt{\frac{EF_{yw} t_f}{t_w}} \qquad \text{(J.9-4)}$$

b) For concentrated forces applied at a distance from the member end that is less than $d/2$:
For $l_b/d \le 0.2$

$$R_n = 0.40 t_w^2 \left(1 + 3 \left(\frac{l_b}{d} \right) \left(\frac{t_w}{t_f} \right)^{1.5} \right) \sqrt{\frac{EF_{yw} t_f}{t_w}} \qquad \text{(J.9-5)}$$

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For $l_b/d > 0.2$

$$R_n = 0.40t_w^2\left(1+\left(\frac{4l_b}{d}-0.2\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right)\sqrt{\frac{EF_{yw}t_f}{t_w}} \quad \text{(J.9-6)}$$

J.9.3.2 Web Crippling of Formed Sheet Members

This section applies to compressive concentrated forces applied to formed sheet members.

a) For concentrated forces applied at a distance from the member end that equals or exceeds $d/2$:

$$R_n = \frac{C_{wa}(l_b + C_{w1})}{C_{wb}} \quad \text{(J.9-7)}$$

b) For concentrated forces applied at a distance from the member end that is less than $d/2$:

$$R_n = \frac{1.2C_{wa}(l_b + C_{w2})}{C_{wb}} \quad \text{(J.9-8)}$$

where

$$C_{wa} = t^2 \sin\theta_w (0.46F_{cy} + 0.02\sqrt{EF_{cy}}) \quad \text{(J.9-9)}$$

$$C_{wb} = C_{w3} + R_i(1-\cos\theta_w) \quad \text{(J.9-10)}$$

C_{w1} = 5.4 in. (140 mm)
C_{w2} = 1.3 in. (33 mm)
C_{w3} = 0.4 in. (10 mm)
d = member depth
l_b = length of the bearing at the concentrated force
R_i = inside bend radius at the juncture of the flange and web
t_w = web thickness
θ_w = angle between the plane of web and the plane of the bearing surface ($\theta_w \le 90^o$)

J.9.3.3 Combined Crippling and Flexure of Flat Webs

Combinations of flexure and concentrated forces applied at a distance of one-half or more of the member depth from the member end shall be limited by the following formula:

$$\left(\frac{R_r}{R_c}\right)^{1.5} + \left(\frac{M_r}{M_c}\right)^{1.5} \le 1.0 \quad \text{(J.9-11)}$$

where

R_r = required concentrated force
R_c = available strength to resist a concentrated force per Section J.9.3.1 or J.9.3.2
M_r = required flexural strength at the location of the concentrated force
M_c = available flexural strength determined in accordance with Chapter F at the location of the concentrated force

J.9.4 Supports for Flexural Members

A pair of transverse stiffeners, extending from the restrained flange to the toe of the web-flange fillet at the other flange, shall be provided at supports for flexural members which are not otherwise restrained at the support against rotation about their longitudinal axes.

J.9.5 Additional Stiffener Requirements for Concentrated Forces

Stiffeners required to resist tensile concentrated forces shall be designed in accordance with the requirements of Section J.7.1 and welded to the loaded flange and the web. The stiffener-to-flange welds shall be sized for the difference between the required strength and available strength of the member without the stiffener. The stiffener-to-web welds shall be sized to transfer to the web the algebraic difference in tensile force at the ends of the stiffener.

Stiffeners required to resist compressive concentrated forces applied at flanges shall:

a) Be designed in accordance with the requirements of Section J.7.4 and shall be connected to the web and either bear on or be connected to the loaded flange. Connections to the flange shall be sized for the difference between the required strength and the applicable limit state strength of the member without the stiffener. Connections to the web shall be sized to transfer to the web the algebraic difference in compression force at the ends of the stiffener. For stiffeners that bear on the loaded flange, the bearing stress shall comply with Section J.8.

b) For full depth stiffeners, be designed as axially compressed members in accordance with Chapter E. Stiffener properties shall be determined using an effective length of $0.75h$ and a cross section composed of two stiffeners and a strip of the web with a width of $25t_w$ at interior stiffeners and $12t_w$ at the ends of members. The connection attaching full depth stiffeners to the web shall be sized to transmit the difference between the available compressive force of the stiffener and the available compressive force of the member.

c) Comply with the following additional requirements:

(1) The width of each stiffener plus one-half the thickness of the web shall not be less than one-third of the flange or moment connection plate width delivering the concentrated force.

(2) The stiffener thickness shall not be less than one-half the thickness of the flange or moment connection plate delivering the concentrated load, nor less than the width divided by $\frac{56}{\sqrt{F_{ty}}}$

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(3) Transverse stiffeners shall extend a minimum of one-half the depth of the member.

J.9.6 Additional Doubler Plate Requirements for Concentrated Forces

Doubler plates required for compression shall be designed in accordance with Chapter E.

Doubler plates required for tension shall be designed in accordance with Chapter D.

Doubler plates required for shear shall be designed in accordance with Chapter G.

Doubler plates shall also comply with the following requirements:

a) The thickness and extent of the doubler plate shall provide the additional material necessary to equal or exceed the strength requirements.

b) The available strength of the connection of the doubler plate to the member shall equal or exceed the force transmitted to the doubler plate. Doubler plates shall be welded to the member.

J.10 ROOFING AND SIDING CONNECTIONS

J.10.1 Endlaps

Minimum endlaps shall be those given in Table J.10.1.

Table J.10.1
MINIMUM ENDLAPS

Depth of section *d*	Roofing slope > 2 on 12, < 3 on 12	Roofing slope ≥ 3 on 12	Siding
$d \leq 1$ in. (25 mm)	–	6 in. (150 mm)	4 in. (100 mm)
1 in. (25 mm) $< d <$ 2 in. (50 mm)	9 in. (230 mm)	6 in. (150 mm)	4 in. (100 mm)
$d \geq 2$ in. (50 mm)	9 in. (230 mm)	6 in. (150 mm)	6 in. (150 mm)

J.10.2 Sidelaps

For sinusoidal corrugated sheet, the minimum sidelap width for roofing shall equal the pitch of the corrugations, and the minimum sidelap width for siding shall equal half the pitch.

For trapezoidal sheet with a depth greater than 1 in. (25 mm) the minimum sidelap for both roofing and siding shall have a developed width equal to the width of the narrowest flat plus 2 in. (50 mm). Trapezoidal sheet with a depth of 1 in. (25 mm) or less shall have a sidelap of proven design with an anti-siphoning feature.

J.10.3 Fasteners in Laps

The minimum size of fasteners used in end laps and side laps shall be #12 (5.5 mm) for screws and 3/16 in. (5 mm) diameter for rivets. The maximum spacing for sidelap fasteners shall be 12 in. (300 mm). Endlap fasteners shall be no more than 2 in. (50 mm) from the end of the overlapping sheet.

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Chapter L Design for Serviceability

L.1 GENERAL PROVISIONS

Serviceability is the preservation of a structure's function under service load combinations.

L.2 CAMBER

If camber is required, its magnitude, direction, and location shall be shown on the structural drawings.

L.3 DEFLECTIONS

Deflections caused by service load combinations shall not impair serviceability.

For shapes with elements addressed by Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, or B.5.5.3 with $f_a > F_e$, effective widths shall be used to determine the moment of inertia used to calculate deflections.

The effective width b_e of such elements in compression is:

$$\text{If } f_a \le F_e,\ b_e = b \qquad \text{(L.3-1)}$$

$$\text{If } f_a > F_e,\ b_e = b\sqrt{F_e / f_a} \qquad \text{(L.3-2)}$$

where

b_e = element's effective width
b = element's width
F_e = element's elastic local buckling stress determined using Section B.5.6
f_a = maximum compressive stress in the element from service load combinations

The effective width of elements subjected to flexure shall be placed next to the compression flange.

Bending deflections shall be calculated using the modulus of elasticity given in Table A.4.1.

L.4 VIBRATION

Vibration caused by service load combinations shall not impair serviceability.

L.5 WIND-INDUCED MOTION

Wind-induced motion caused by service load combinations shall not impair serviceability.

L.6 EXPANSION AND CONTRACTION

Thermal expansion and contraction shall not impair serviceability.

L.7 CONNECTION SLIP

Connection slip under service load combinations shall be precluded if it would impair serviceability.

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M.1 LAYOUT

A temperature correction shall be applied where necessary in the layout of dimensions. The coefficient of thermal expansion used shall be per Section A.4.1.

M.2 CUTTING

M.2.1 Methods

Cutting shall be by shearing, sawing, nibbling, routing, arc cutting, laser, or abrasive water jet. Edges which have been arc or laser cut shall be planed to remove edge cracks. Oxygen cutting is prohibited.

M.2.2 Edge Quality

The surface roughness profile of edges, including holes, shall not exceed 1,000 μin. (25μm) as defined in ASME B46.1.

M.2.3 Re-entrant Corners

Re-entrant corners shall be filleted.

M.3 HEATING

Base metal alloys 535.0, 5083, 5086, 5154, and 5456 and weldments made with filler metal alloys 5183, 5356, 5556, or 5654 shall not be held at temperatures from 150°F (66°C) to 450°F (230°C). To hot form such alloys, they shall be

1) rapidly heated to a temperature not to exceed 550°F (290°C),

2) formed before the metal cools below 450°F (230°C),

3) rapidly cooled from 450°F to 150°F, and

4) designed using O temper strength.

For other alloys heated above 200°F (93°C) during fabrication other than welding, time at temperature shall be limited as specified in Section A.4.1.1.

M.4 HOLES

M.4.1 Fabrication Methods

The diameter of punched holes shall equal or exceed the metal thickness. The amount by which the diameter of a sub-punched hole is less than that of the finished hole shall be at least ¼ the thickness of the piece but not less than 1/32 in. (0.8 mm). Punching shall not be used for castings.

M.4.2 Hole Alignment

Holes shall not be drifted in a manner that distorts the metal. All chips and foreign matter between connected parts shall be removed before assembly.

M.5 BENDING

Bend radii shall be large enough to avoid cracking.

M.6 FINISHES

M.6.1 Where Protective Coating Is Required

Aluminum shall be provided with a protective coating when:

a) alloy 2014 is in the presence of moisture,

b) aluminum would otherwise be in contact with or fastened to dissimilar materials as described in Section M.7,

c) aluminum is exposed to corrosive conditions.

M.6.2 Surface Preparation

Surfaces to be painted shall be prepared immediately before painting by:

a) Chemical cleaning (such as a solution of phosphoric acid and organic solvents), or

b) Abrasion blasting, or

c) Unsealed anodizing, or

d) Chemical conversion coating, or

e) Using a procedure specified by the coating supplier.

M.6.3 Abrasion Blasting

Abrasion blasting shall not be used if it distorts, perforates, or significantly reduces the thickness of the material blasted.

M.7 CONTACT WITH DISSIMILAR MATERIALS

As an alternative to the requirements of Sections M.7.1 through M.7.3, aluminum shall be separated from the materials of this Section by a nonporous isolator compatible with the aluminum and the dissimilar material.

M.7.1 Metals

Where 1) aluminum contacts other metals except 300 series stainless steel, zinc, or cadmium and 2) the faying surfaces are exposed to moisture, the other metal shall be painted or coated with zinc, cadmium, or aluminum. Uncoated aluminum shall not be exposed to moisture or runoff that has come in contact with other uncoated metals except 300 series stainless steel, zinc, or cadmium.

Steel fasteners with a specified minimum tensile ultimate strength greater than 120 ksi in the load bearing portion of the shank shall not be used in contact with aluminum.

M.7.2 Wood, Fiberboard, or Other Porous Materials

Aluminum surfaces to be placed in contact with wood, fiberboard, or other porous material that absorbs water shall be painted.

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M.7.3 Concrete or Masonry

Aluminum surfaces shall be painted if they are to be placed in contact with concrete or masonry unless the concrete or masonry remains dry after curing and no corrosive additives such as chlorides are used. Aluminum shall not be embedded in concrete with corrosive additives such as chlorides if the aluminum is electrically connected to steel.

M.8 FABRICATION TOLERANCES

Dimensional tolerances shall comply with the *Code of Standard Practice for Fabricating and Erecting Structural Aluminum*.

M.9 WELDING

Welding shall comply with the AWS D1.2 *Structural Welding Code – Aluminum*. Filler alloys shall be selected from Tables M.9.1 and M.9.2.

The contract documents shall specify if visual inspection is required to be performed by AWS certified welding inspectors. When inspection other than visual inspection is required, the contract documents shall state the method, extent, inspector qualifications, and acceptance criteria for such inspection.

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Table M.9.1
WELD FILLERS FOR WROUGHT ALLOYS

Base Metal / Base Metal	1060, 1100, 3003, Alclad 3003	2219	3004, Alclad 3004	5005, 5050	5052	5083, 5456	5086	5154	5454	6005, 6005A, 6061, 6063, 6082, 6351	7005
7005	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183, 5356)
6005, 6005A, 6061, 6063, 6082, 6351	4043 (4047)	4145	5356 (4043, 4047, 5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (4043, 4047, 5183, 5556)	
5454	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5654 (5183, 5356, 5556)	5554 (5183, 5356, 5556)		
5154	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5654 (5183, 5356, 5556)			
5086	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)				
5083, 5456	5356 (5183, 5556)	DNW		5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183)					
5052	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)						
5005, 5050	4043 (1100, 4047)	DNW	5356 (4043, 4047, 5183, 5556)	5356 (4043, 4047, 5183, 5556)							
3004, Alclad 3004	4043 (4047, 5183, 5356, 5556)	DNW	5356 (5183, 5556)								
2219	4145	2319 (4145)									
1060, 1100, 3003, Alclad 3003	4043 (1100, 4047)										

① This table is for structural applications subjected to normal atmospheric conditions using GTAW or GMAW.
② DNW = Do Not Weld
③ Fillers in parentheses are acceptable alternates.

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Table M.9.2
WELD FILLERS FOR CAST ALLOYS

BASE METAL	BASE METAL		
	535.0	356.0, A356.0, A357.0, 359.0	354.0, C355.0
1060, 1100, 3003, Alclad 3003	5356	4043 (4047)	4145
2219	DNW	4145	4145
3004, Alclad 3004	5356	4043 (4047)	4145 (4043, 4047)
5005, 5050	5356	4043 (4047)	4145 (4043, 4047)
5052	5356	4043 (4047)	4043 (4047)
5083, 5456	5356	5356	DNW
5086	5356	5356	DNW
5154	5356	4043	DNW
5454	5356	4043 (4047)	4043
6005, 6005A, 6061, 6063, 6082, 6351	5356	4043 (4047, 4145, 4643)	4145 (4043, 4047)
7005	5356	4043 (4047)	4145 (4043, 4047)
354.0, C355.0	DNW	4145	4145 ①
356.0, A356.0, A357.0, 359.0	5356	4043 ①	
535.0	5356		

① To weld C355.0 to itself, 4009 may be used; to weld A356.0 to itself, 4010 may be used; to weld A357.0 to itself, 4011 may be used.
② DNW = Do Not Weld
③ Fillers in parentheses are acceptable alternates.

M.10 BOLT INSTALLATION

Unless the joint is a slip-critical connection, bolts need only be installed snug tight, the tightness that exists when all plies in a joint are in firm but not necessarily continuous contact. Slip-critical connections shall be tightened and inspected in accordance with the RCSC *Specification for Structural Joints Using ASTM A325 or A490 Bolts*.

M.11 RIVET INSTALLATION

M.11.1 Driven Head

The driven head of aluminum rivets shall be flat or cone-point, with dimensions as follows:

a) Flat heads shall have a diameter at least 1.4 times the nominal diameter of the rivet and a height at least 0.4 times the nominal diameter of the rivet.

b) Cone-point heads shall have a diameter at least 1.4 times the nominal diameter of the rivet and a height to the apex of the cone at least 0.65 times the nominal diameter of the rivet. The nominal included angle at the apex of the cone shall be 127°.

M.11.2 Hole Filling

Rivets shall fill holes completely. Rivet heads shall be concentric with the rivet holes and shall be in continuous contact with the surface of the part joined.

M.11.3 Defective Rivets

Defective rivets shall be removed by drilling. The drill bit diameter shall not exceed the diameter of the replacement rivet.

M.12 ERECTION TOLERANCES

Erection tolerances shall comply with the *Code of Standard Practice for Fabricating and Erecting Structural Aluminum*.

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Chapter N Quality Control and Quality Assurance

N.1 SCOPE

Quality control (QC) specified in this chapter shall be the responsibility of the fabricator and erector. Quality assurance (QA) specified in this chapter and nondestructive testing shall be the responsibility of others when required by the contract documents.

N.2 FABRICATOR QUALITY CONTROL PROGRAM

The fabricator shall establish and maintain a quality control program that ensures that the work complies with this *Specification*. The quality control program shall include:

a) Procedures for identifying the specification, alloy, and temper of all aluminum supplied by the fabricator
b) Inspection procedures
c) Procedures to address nonconformance

For work performed by the fabricator, the fabricator shall obtain the following documents prior to fabrication. The fabricator shall submit these documents for review by the EOR when requested by the EOR.

a) Fabrication drawings
b) Quality control program
c) QC inspector qualifications
d) Weld procedure specifications (WPSs)
e) Procedure qualification records (PQRs) for the WPSs
f) Welding personnel performance qualification records (WPQRs)

For material furnished by the fabricator, the fabricator shall obtain the following documents prior to fabrication. The fabricator shall submit these documents for review by the EOR when requested by the EOR.

a) For wrought products, certification by the supplier that the material complies with Section A.4.2
b) For castings, certification by the supplier that the material complies with Section A.4.3
c) For weld filler metal, certification by the supplier that the material complies with Section A.4.4
d) For bolts and nuts, certification by the supplier that the material complies with Section A.4.5
e) For rivets, certification by the supplier that the material complies with Section A.4.6
f) For screws, certification by the supplier that the material complies with Section A.4.7

N.3 ERECTOR QUALITY CONTROL PROGRAM

The erector shall establish and maintain a quality control program that ensures that the work complies with this *Specification*. The quality control program shall include:

a) Procedures for identifying the specification, alloy, and temper of all aluminum supplied by the erector
b) Inspection procedures
c) Procedures to address nonconformance

For work performed by the erector, the erector shall obtain the following documents prior to erection. The erector shall submit these documents for review by the EOR when requested by the EOR.

a) Erection drawings
b) Quality control program
c) QC inspector qualifications
d) Weld procedure specifications (WPSs)
e) Procedure qualification records (PQRs) for the WPSs
f) Welding personnel performance qualification records (WPQRs)

For material furnished by the erector, the erector shall obtain the following documents prior to erection. The erector shall submit these documents for review by the EOR when requested by the EOR.

a) For wrought products, certification by the supplier that the material complies with Section A.4.2
b) For castings, certification by the supplier that the material complies with Section A.4.3
c) For weld filler metal, certification by the supplier that the material complies with Section A.4.4
d) For bolts and nuts, certification by the supplier that the material complies with Section A.4.5
e) For rivets, certification by the supplier that the material complies with Section A.4.6
f) For screws, certification by the supplier that the material complies with Section A.4.7

N.4 INSPECTION AND NONDESTRUCTIVE TESTING PERSONNEL

Quality control and quality assurance welding inspection personnel shall be welding inspectors or higher as defined in AWS B5.1, *Specification for the Qualification of Welding Inspectors*.

Nondestructive testing personnel shall be qualified in accordance with the American Society for Nondestructive Testing (ASNT) ASNT CP-189, *Standard for the Qualification and Certification of Nondestructive Testing Personnel*.

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N.5 INSPECTION REQUIREMENTS

The fabricator's quality control inspector (QCI) shall inspect:

a) Shop cut surfaces in accordance with Section M.2
b) Shop fabricated holes in accordance with Section M.4
c) Shop fabricated bends in accordance with Section M.5
d) Fabrication tolerances in accordance with Section M.8
e) Shop welding in accordance with Section M.9
f) Bolt installation in accordance with Section M.10
g) Rivet installation in accordance with Section M.11
h) Fabrication in accordance with the fabrication drawings

The erector's quality control inspector (QCI) shall inspect:

a) Field cut surfaces in accordance with Section M.2
b) Field fabricated holes in accordance with Section M.4
c) Field fabricated bends in accordance with Section M.5
d) Field welding in accordance with Section M.9
e) Bolt installation in accordance with Section M.10
f) Rivet installation in accordance with Section M.11
g) Erection tolerances in accordance with Section M.12
h) Erection in accordance with the erection drawings

The acceptance criteria for ultrasonic testing (UT) shall be as required by AWS D1.2 for radiographic testing (RT). Inspectors shall submit inspection reports and nondestructive testing reports to the EOR and to the fabricator or erector that performed the work.

N.6 NONCONFORMANCE

The party responsible for QC or QA shall report nonconformance to the engineer of record (EOR) and to the fabricator or erector that performed the work. Nonconforming work or material shall be brought into conformance or made suitable for its intended purpose as determined by the EOR.

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Appendix 1 Testing

1.1 GENERAL PROVISIONS

Testing is an acceptable method for determining the available strengths of aluminum members, assemblies, or connections when such strengths cannot be determined in accordance with this *Specification*'s provisions other than with Appendix 1. Tests shall be conducted by a testing laboratory accredited by a nationally recognized accreditation service.

1.2 TEST CONDITIONS

Test conditions, including loading, supports, material, dimensions, tolerances, QA/QC, and configuration, shall be the same as nominal conditions in service.

In tests that require measurement of deflection, a preload that is 20% of the design load shall be applied to set the specimen before testing. During testing, deflections shall be measured at the supports as well as at the point of maximum deflection, and the difference shall be taken as the specimen deflection.

As an alternative, the structural performance of exterior aluminum fenestration products such as windows, curtain walls, and doors shall be determined in accordance with ASTM E330.

1.3 DESIGN BASED ON TESTING

Design based on testing shall be performed in accordance with Section 1.3.1 or Section 1.3.2.

1.3.1 Method 1

The nominal strength R_n determined from testing and used with the resistance and safety factors given in this *Specification* shall be calculated as follows:

$$R_n = R_{tm} - K\sigma_x \qquad (1.3\text{-}1)$$

where

R_n = nominal strength
R_{tm} = mean strength of all tests
σ_x = standard deviation of the test strengths
K = statistical coefficient based on the number of tests n.

K is a one-sided factor for 99% of the population exceeding X_a with a confidence of 95%. Values of K for the following values of n are:

Table 1.3.1
STATISTICAL COEFFICIENT *K*

n	*K*	*n*	*K*
3	10.55	18	3.370
4	7.042	19	3.331
5	5.741	20	3.295
6	5.062	21	3.262
7	4.641	22	3.233
8	4.353	23	3.206
9	4.143	24	3.181
10	3.981	25	3.158
11	3.852	30	3.064
12	3.747	35	2.994
13	3.659	40	2.941
14	3.585	45	2.897
15	3.520	50	2.863
16	3.463	100	2.684
17	3.415		

1.3.2 Method 2

The resistance and safety factors used with the average of test strengths shall be determined in accordance with this Section. Resistance factors determined using this Section shall not be greater than the resistance factors given in the *Specification*. Safety factors determined using this Section shall not be less than the safety factors given in the *Specification*.

No fewer than four identical specimens shall be tested. If any individual result deviates from the average result by more than 10%, at least three more tests shall be performed.

For LRFD of building-type structures, the design strength shall be the average of all test results multiplied by the resistance factor ϕ determined as follows:

$$\phi = 1.5 M_m F_m e^{-\beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}} \qquad (1.3\text{-}2\ \text{LRFD})$$

For ASD of building-type structures, the allowable strength shall be the average of all test results divided by the safety factor Ω determined as follows:

$$\Omega = \frac{1.05\alpha + 1}{M_m F_m (\alpha + 1)} e^{\beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}} \qquad (1.3\text{-}2\ \text{ASD})$$

where

C_n = correction factor = $\dfrac{n^2 - 1}{n^2 - 3n}$

D_n = nominal dead load
e = base for natural logarithms ≈ 2.72
F_m = mean value of the fabrication factor, the ratio of the specimen's relevant geometric property to its nominal value
L_n = nominal live load

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M_m = mean value of the material factor, the ratio of the specimen's relevant material strength to the specified minimum strength. The relevant material strength shall be determined by conducting tensile tests in accordance with ASTM B557 on specimens taken from the component tested.

n = number of tests

R_{ti} = strength of ith test

R_{tm} = mean strength of all tests $= \dfrac{\sum_{i=1}^{n} R_{ti}}{n}$

V_F = coefficient of variation of the fabrication factor

V_M = coefficient of variation of the material factor

V_P = coefficient of variation of the ratio of the test strengths divided by the average value of all the test strengths

$$= \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{R_{ti}}{R_{tm}}\right)^2 - \frac{\left(\sum_{i=1}^{n}\frac{R_{ti}}{R_{tm}}\right)^2}{n}}{n-1}}$$

V_Q = coefficient of variation of the loads

$$= \frac{\sqrt{(0.105\alpha)^2 + 0.25^2}}{1.05\alpha + 1};$$

in lieu of calculation by the above formula, $V_Q = 0.21$

$\alpha = D_n / L_n$; in lieu of calculation, $\alpha = 0.2$

βo = the target reliability index

= 2.5 for columns, beams and beam-columns,

= 3.0 for tension members, and

= 3.5 for connections.

The following values shall be used when data established from a sufficient number of results on material properties do not exist for the member or connection:

M_m = 1.10 for behavior governed by yield

= 1.00 for behavior governed by rupture

F_m = 1.00

V_M = 0.06

V_F = 0.05 for structural members and mechanically fastened connections

= 0.15 for welded connections

1.4 TESTING ROOFING AND SIDING

The flexural strength of roofing and siding shall be established from tests when any of the following conditions apply.

a) Web angles are asymmetrical about the centerline of a valley, rib, flute, crimp, or other corrugation;

b) Web angles are less than 45°;

c) Aluminum panels are alternated with panels composed of any material having significantly different strengths or deflection characteristics;

d) Flats spanning from rib to rib or other corrugation in the transverse direction have a width to thickness ratio greater than either of the following

(1) $\dfrac{1230}{\sqrt[3]{q}}$ where q is the design load in psf ($\dfrac{447}{\sqrt[3]{q}}$ where q is the design load in kN/m^2)

(2) $435\sqrt{\dfrac{F_{ty}}{q}}$ where F_{ty} is in ksi and q is in psf ($37\sqrt{\dfrac{F_{ty}}{q}}$ where F_{ty} is in MPa and q is in kN/m^2);

e) Panel ribs, valleys, crimps, or other corrugations are of unequal depths;

f) Specifications prescribe less than one fastener per rib to resist negative or uplift loading at each purlin, girt, or other transverse supporting member; or

g) Panels are attached to supporting members by profile interlocking straps or clips.

1.4.1 Test Method

Tests shall be conducted in accordance with ASTM E 1592.

1.4.2 Different Thicknesses

Only the thinnest and thickest specimens manufactured are required to be tested when panels are of like configuration, differing only in material thickness. Where the failure of the test specimens is from flexural stress, the flexural strength for intermediate thicknesses shall be interpolated as follows:

$$\log M_i = \log M_1 + \left(\frac{\log t_i - \log t_{\min}}{\log t_{\max} - \log t_{\min}}\right)\left(\log M_2 - \log M_1\right) \qquad (1.4\text{-}1)$$

where

M_i = flexural strength of member of intermediate thickness t_i

M_1 = flexural strength of member of thinnest material

M_2 = flexural strength of member of thickest material

t_i = thickness of intermediate thickness material

t_{min} = thickness of thinnest material tested

t_{max} = thickness of thickest material tested

1.4.3 Available Strengths

Available strengths shall be determined using the resistance factors for LRFD and safety factors for ASD given in Chapter F for flexure and those in Chapter J applied to the minimum test strength achieved for fasteners.

1.4.4 Deflections

Deflections shall meet the requirements of Section L.3.

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Appendix 3 Design for Fatigue

3.1 GENERAL PROVISIONS

Welded details, mechanically fastened joints, and wrought material subjected to 100,000 or more stress cycles shall meet the static requirements of this *Specification* and the requirements of this Appendix. Fatigue design of castings shall be made by testing in accordance with Appendix 1.

Categories of details for fatigue design shall be chosen from Figure 3.1 and Table 3.1.

The applied stress range is the algebraic difference between the maximum and minimum nominal service load stresses perpendicular to the expected plane of cracking determined by elastic methods. Stresses shall not be amplified by stress concentration factors for geometrical discontinuities.

The provisions of this Appendix do not apply to structures subjected to temperatures exceeding 200°F (93°C).

3.2 CONSTANT AMPLITUDE LOADING

For constant amplitude loading

$$S_{ra} \le S_{rd} \tag{3.2-1}$$

where

S_{ra} = applied stress range
S_{rd} = design stress range

$$S_{rd} = C_f N^{-1/m} \tag{3.2-2}$$

C_f, m = constants from Table 3.2
N = number of stress cycles

If the applied stress range S_{ra} is less than the constant amplitude fatigue limit given in Table 3.2, no further fatigue assessment is required. The design stress range S_{rd} shall not be less than the value from Equation 3.2-2 when $N = 5 \times 10^6$ cycles and shall not be greater than the value from Equation 3.2-2 when $N = 100{,}000$ cycles.

3.3 VARIABLE AMPLITUDE LOADING

For variable amplitude loading:

$$S_{re} \le S_{rd} \tag{3.3-1}$$

where

S_{re} = equivalent applied stress range

$$S_{re} = \left(\sum_{i=1}^{N_s} \alpha_i S_{ri}^{\ m} \right)^{1/m} \tag{3.3-2}$$

S_{rd} = design stress range

$$S_{rd} = C_f N^{-1/m} \tag{3.3-3}$$

α_i = number of stress cycles in the spectrum of the ith applied stress range divided by the total number of stress cycles
S_{ri} = ith applied stress range in the spectrum
C_f, m = constants from Table 3.2
N_S = number of stress ranges in the spectrum
N = number of stress cycles

The design stress range S_{rd} shall not exceed the value from Equation 3.3-3 when $N = 100{,}000$ cycles.

If the maximum stress range in the spectrum is less than the constant amplitude fatigue limit, no further fatigue assessment is required.

3.4 FABRICATION AND ERECTION REQUIREMENTS

Permanent backing bars for longitudinal welds shall be continuous. Splices in backing bars shall be complete joint penetration welds with the reinforcement ground flush in the long direction of the bar and shall be made before making the longitudinal weld. Backing bars shall be attached with continuous fillet welds. Permanent backing bars shall not be used for transverse welds subject to tension.

A reinforcing fillet weld shall be added to transverse tee and corner joints. The fillet weld size shall equal or exceed one quarter of the minimum thickness of the parts joined but shall not be less than 3/16 in. (5 mm).

Re-entrant corners shall have a radius of at least 3/4 in. (20 mm).

Fillet welds on outstanding elements shall be returned around the end of the element for a distance of at least twice the nominal weld size.

Punched or scribed layout marks shall not remain on parts.

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Table 3.1
STRESS CATEGORY

GENERAL CONDITION	DETAIL	Detail Category	Fatigue Design Details ①
Plain Material	Base metal with rolled, extruded, drawn, or cold finished surfaces; cut or sheared surfaces with ANSI/ASME B46.1 surface roughness ≤ 1000 μin. (25μmm)	A	1, 2
Built-up Members	Base metal and weld metal in members without attachments and built up of plates or shapes connected by continuous full or partial penetration groove welds or continuous fillet welds parallel to the direction of applied stress.	B	3, 4, 5
	Flexural stress in base metal at the toe of welds on girder webs or flanges adjacent to welded transverse stiffeners.	C	6, 21
	Base metal at the end of partial-length welded cover plates with square or tapered ends, with or without welds across the ends.	E	5
Mechanically Fastened Connections	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration does not result in out-of-plane bending in the connected material and the stress ratio (the ratio of minimum stress to maximum stress) R_S is ②		
	$R_S \leq 0$	B	7
	$0 < R_S < 0.5$	D	7
	$0.5 \leq R_S$	E	7
	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration results in out-of-plane bending in connected material.	E	8
Fillet Welds	Base metal at intermittent fillet welds	E	
	Base metal at the junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the members so as to balance weld stresses.	E	15, 17
	Shear stress in weld metal of continuous or intermittent longitudinal or transverse fillet welds.	F	5, 15, 18
Groove Welds	Base metal and weld metal at full-penetration groove welded splices of parts of similar cross section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection.	B	9, 10
	Base metal and weld metal at full-penetration groove welded splices at transitions in width or thickness, with welds ground to slopes ≤ 1: 2.5, with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection.	B	11. 12
	Base metal and weld metal at full-penetration groove welded splices with or without transitions with slopes ≤ 1: 2.5, when reinforcement is not removed and/or weld soundness is not established by radiographic or ultrasonic inspection.	C	9,10, 11, 12
	Base metal and weld metal at full-penetration groove welds with permanent backing.	E	22
Attachments	Base metal detail of any length attached by groove welds subject to transverse and/or longitudinal loading, with a transition radius $R \geq 2$ in. (50 mm) and with the weld termination ground smooth:		
	$R \geq 24$ in. (610 mm)	B	13
	24 in. > $R \geq 6$ in. (150 mm)	C	13
	6 in. > $R \geq 2$ in. (50 mm)	D	13
	Base metal at a detail attached by groove welds or fillet welds with a detail dimension parallel to the direction of stress $a < 2$ in. (50 mm)	C	19
	Base metal at a detail attached by groove welds or fillet welds subject to longitudinal loading, with a transition radius, if any, < 2 in. (50 mm):		
	2 in. (50 mm) ≤ $a \leq 12b$ or 4 in. (100 mm)		
	$a > 12b$ or 4 in. (100 mm)		
	Base metal at a detail of any length attached by fillet welds or partial-penetration groove welds in the direction parallel to the stress, with a transition radius $R \geq 2$ in. (50 mm), and the weld termination is ground smooth:	D E	14 14, 19, 20
	$R \geq 24$ in. (610 mm)	B	16
	24 in. > $R \geq 6$ in. (150 mm)	C	16
	6 in. > $R \geq 2$ in. (50 mm)	D	16
Luminaire Base Welds	Base metal and filler metal at a pair of circumferential fillet welds at least 0.48D apart in a tube's longitudinal direction, where D = the outside diameter of the tube. Fillet welds shall be sufficient to develop the static bending strength of the tube and be placed in the following order: weld the top of the base and the tube, then weld the end of the tube and the bottom of the base. The base shall be for a top mounted luminaire or as a support for a short arm, defined as that producing no more than 5 ksi (35 MPa) tensile dead load stress in the tube at top of the base.	F1	23

① See Figure 3.1. These examples are provided as guidelines and are not intended to exclude other similar details.
② Tensile stresses are considered to be positive and compressive stresses are considered to be negative.

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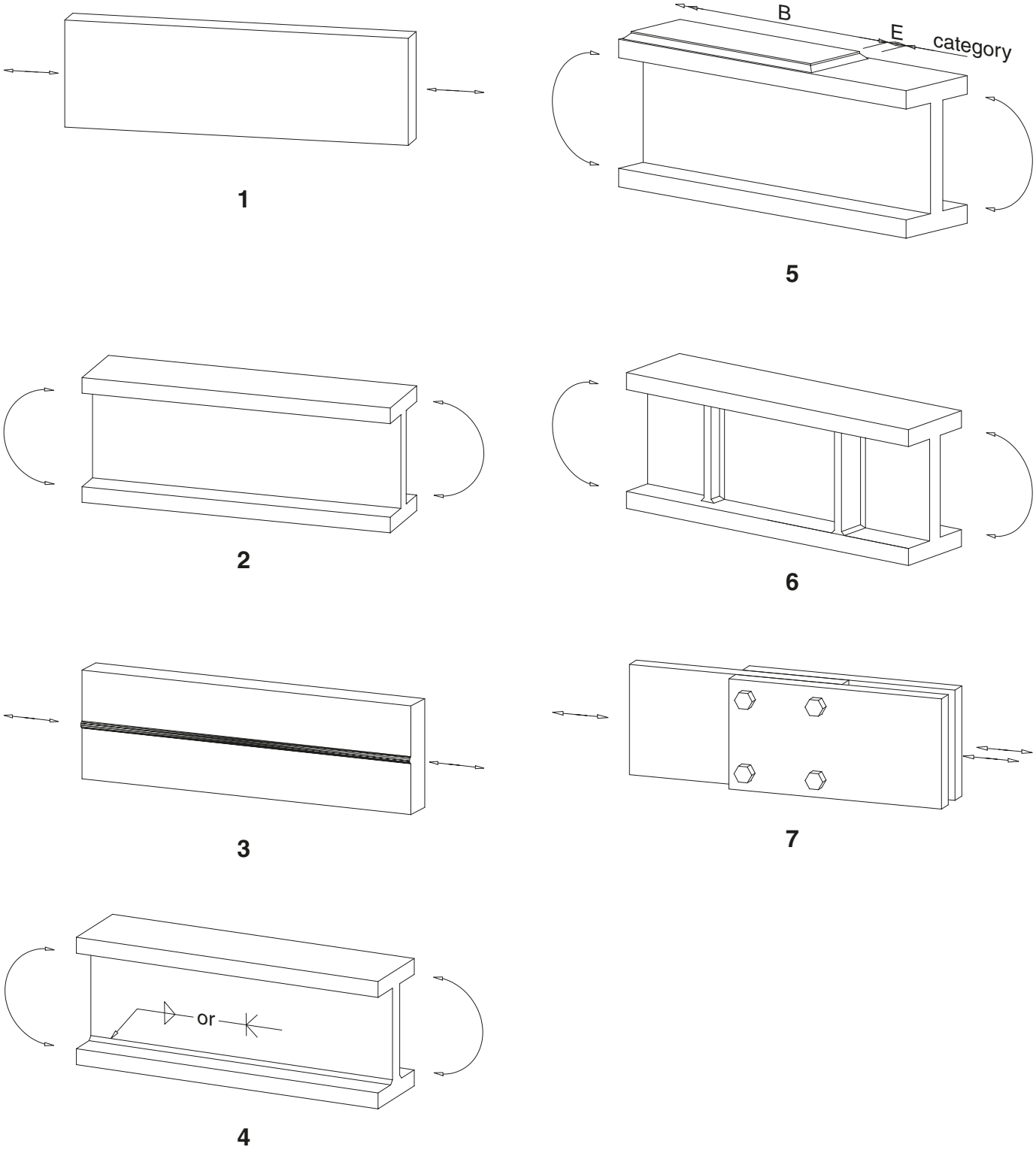

Figure 3.1
FATIGUE DESIGN DETAILS

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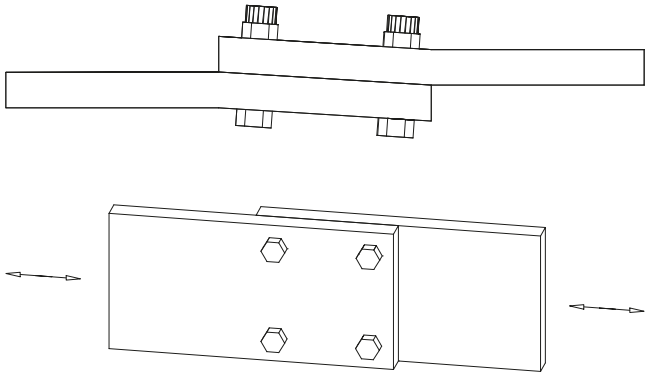

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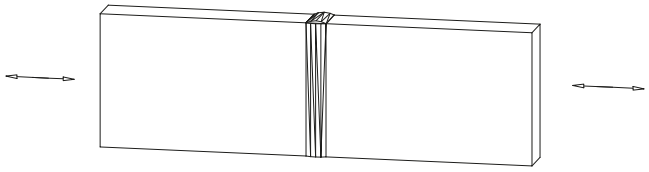

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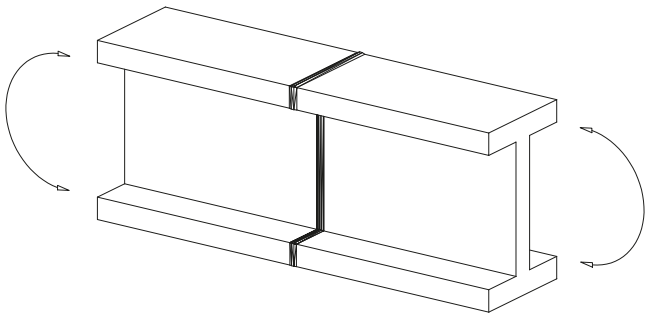

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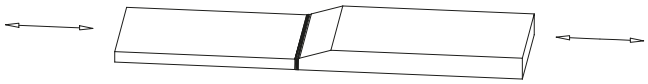

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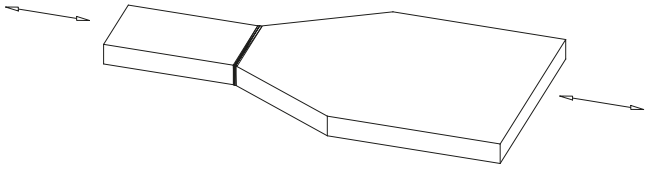

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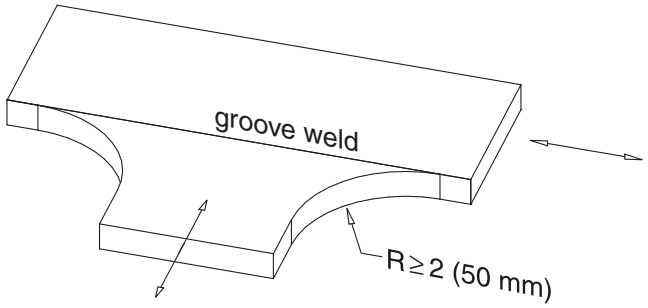

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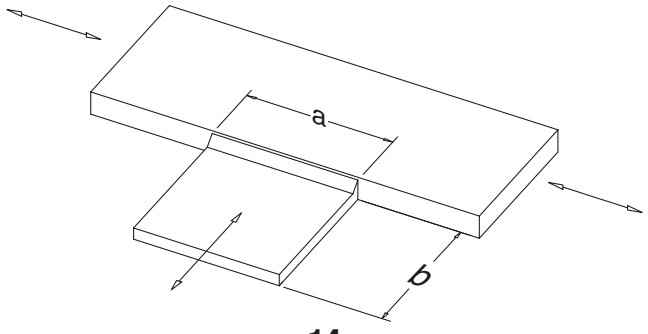

Figure 3.1
FATIGUE DESIGN DETAILS

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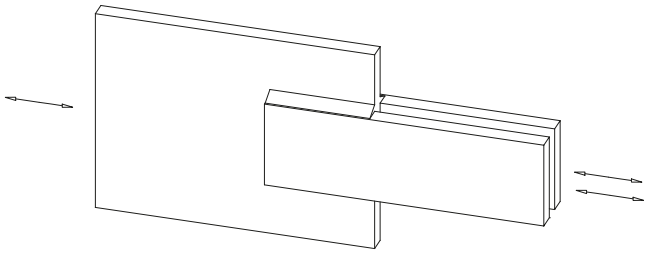

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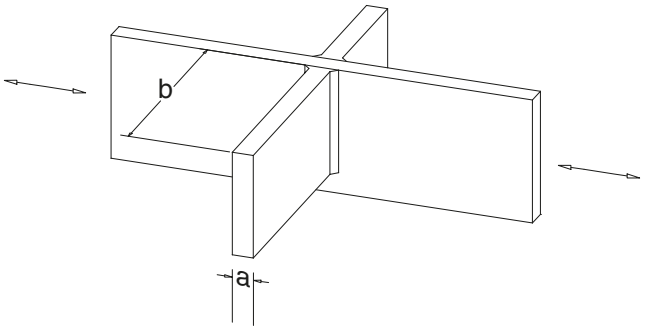

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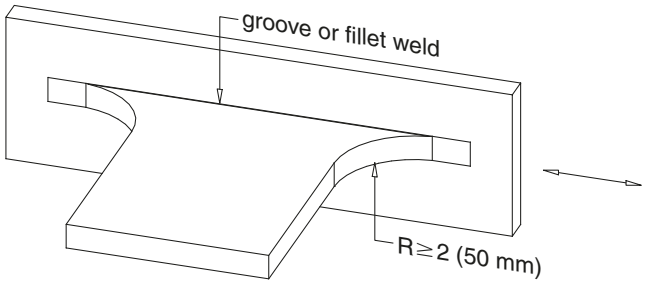

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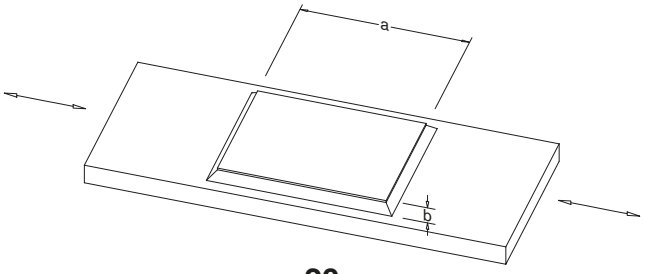

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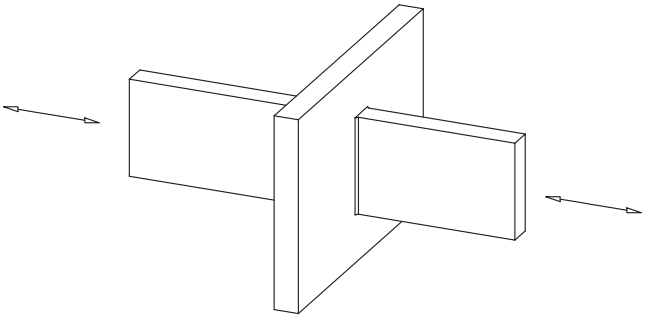

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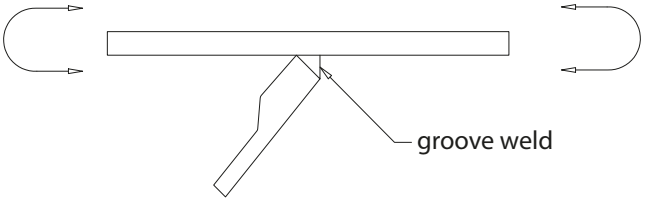

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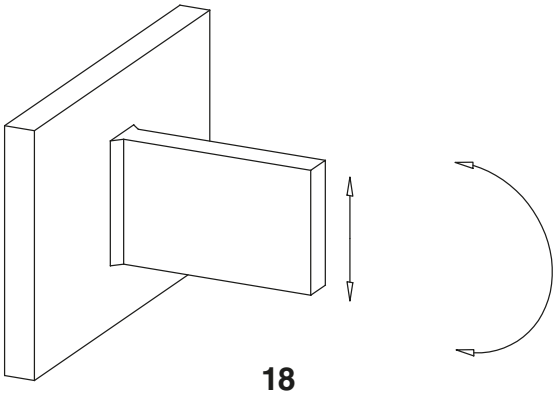

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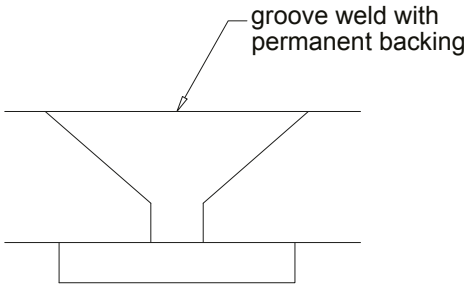

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Figure 3.1
FATIGUE DESIGN DETAILS

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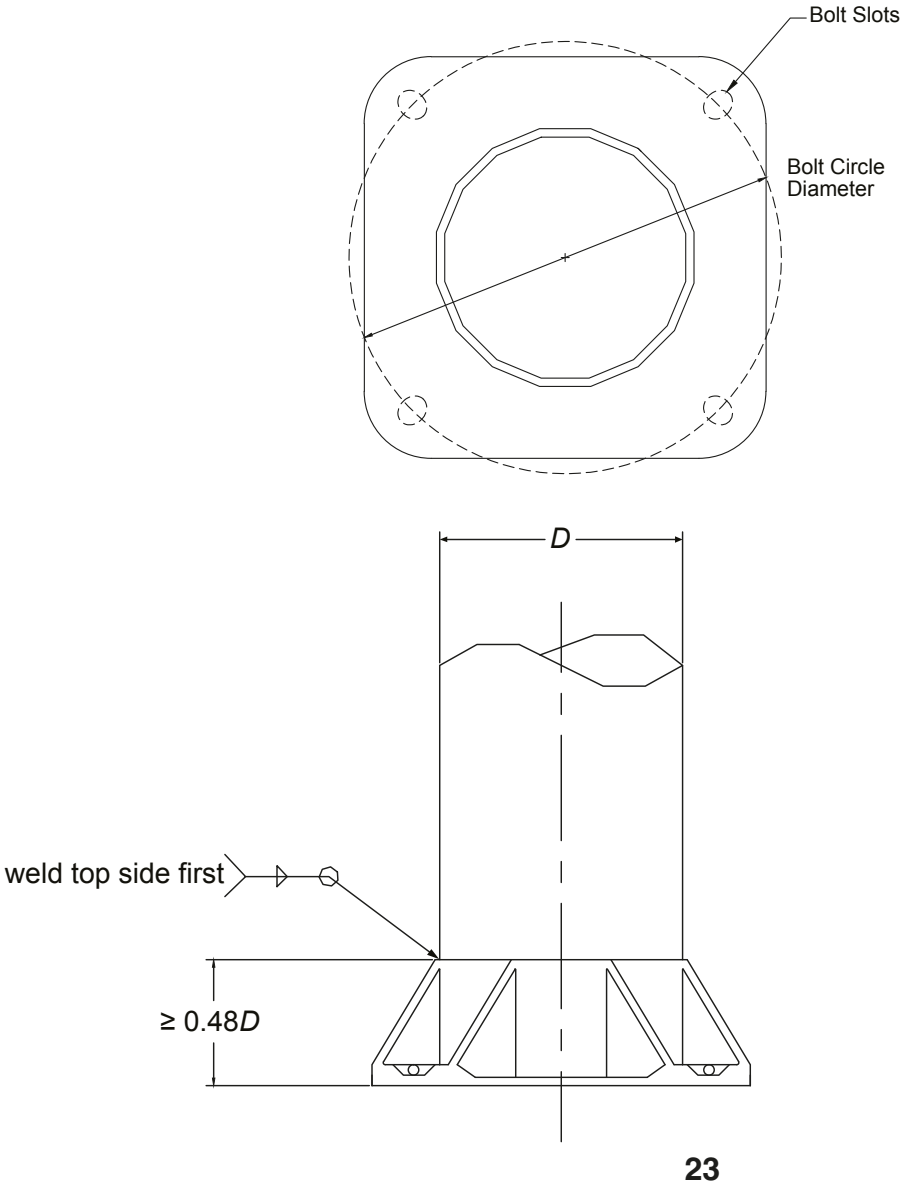

Table 3.1
FATIGUE DESIGN DETAILS

Table 3.2
CONSTANTS FOR S-N CURVES

Detail Category	C_f		m	Constant Amplitude Fatigue Limit	
	ksi	MPa		ksi	MPa
A	96.5	665	6.85	10.2	70
B	130	900	4.84	5.4	37
C	278	1920	3.64	4.0	28
D	157	1080	3.73	2.5	17
E	160	1100	3.45	1.8	13
F	174	1200	3.42	1.9	13
F1	29.0	200	7.31	3.2	22

Constant amplitude fatigue limit is based on $N = 5 \times 10^6$ except for detail category F1 where $N = 10 \times 10^6$.

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Appendix 4 Design for Fire Conditions

This appendix addresses the design and evaluation of aluminum structures exposed to fire. It includes criteria for determining heat input, thermal expansion, and reduction in mechanical properties of aluminum at elevated temperatures.

4.1 GENERAL PROVISIONS

Design for fire conditions shall comply with the requirements for design by engineering analysis given in Section 4.2 or the requirements for design by qualification testing given in Section 4.3. The analysis methods in Section 4.2 document the anticipated performance of aluminum structures when subjected to design-basis fires, and provide evidence of compliance with the performance objectives of Section 4.1.2. The qualification testing methods in Section 4.3 document the fire resistance of aluminum structures subject to the standardized fire testing protocols required by building codes.

4.1.1 Definitions

This appendix uses the following terms as defined below:

active fire protection: structural materials and systems activated by a fire to mitigate adverse effects or notify people to take action to mitigate adverse effects.

compartmentation: the enclosure of a structure's space with elements that have a specific fire endurance.

design-basis fire: a set of conditions that define the development of a fire and the spread of combustion products in a structure.

elevated temperatures: temperatures in excess of the anticipated ambient temperature, experienced by structural elements as a result of fire.

fire: destructive burning, as manifested by any or all of the following: light, flame, heat, or smoke.

fire barrier: an element of construction formed of fire-resisting materials and tested in accordance with ASTM E119 or other approved standard fire-resistance test to demonstrate compliance with the building code.

fire endurance: a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance.

fire resistance: the property of assemblies that prevents or retards the passage of excessive heat, hot gases, or flames under conditions of use and enables them to continue to perform a stipulated function.

flashover: the transition to a state of total surface involvement in a fire of combustible materials within an enclosure.

heat flux: radiant energy per unit surface area.

heat release rate: the rate at which thermal energy is generated by a burning material.

restrained construction: floor and roof assemblies and individual beams in buildings where the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures.

unrestrained construction: floor and roof assemblies and individual beams in buildings that are assumed to be free to rotate and expand throughout the range of anticipated elevated temperatures.

4.1.2 Performance Objectives

Structural components, members, and frame systems shall be designed to maintain their load-bearing function during the design-basis fire and to satisfy other performance requirements specified for the building occupancy.

Deformation criteria shall be applied where the means of providing structural fire resistance or the design criteria for fire barriers requires consideration of the deformation of the load-carrying structure.

Forces and deformations from the design-basis fire shall not cause a horizontal or vertical breach of the compartment of fire origin.

4.1.3 Load Combinations and Required Strength

The required strength of the structure and its elements shall be determined using load and resistance factor design for the following gravity load combination:

$$[0.9 \text{ or } 1.2]D_n + T + 0.5L_n + 0.2S_n \quad (4\text{-}1)$$

where

D_n = nominal dead load
L_n = nominal live load
S_n = nominal snow load
T = nominal forces and deformations due to the design-basis fire defined in Section 4.2.1.

D_n, L_n, and S_n shall be the nominal loads specified in ASCE 7.

4.2 DESIGN FOR FIRE CONDITIONS BY ANALYSIS

4.2.1 Design-Basis Fire

A design-basis fire shall be defined that describes heating conditions for the structure. These heating conditions shall relate to the fuel commodities and compartment characteristics present in the assumed fire area. The fuel load density based on the occupancy of the space shall be considered when determining the total fuel load. Heating conditions shall be specified in terms of a heat flux or temperature of the upper gas layer created by the fire. The variation of the heating conditions with time shall be determined for the duration of the fire.

When the analysis methods in Section 4.2 are used to demonstrate an equivalency as an alternative material or method as permitted by a building code, the design-basis fire shall be determined in accordance with ASTM E119.

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4.2.1.1 Localized Fire

Where the heat release rate from the fire is insufficient to cause flashover, a localized fire exposure shall be assumed. In such cases, the fuel composition, arrangement of the fuel, and area occupied by the fuel shall be used to determine the radiant heat flux from the flame and smoke plume to the structure.

4.2.1.2 Post-Flashover Compartment Fires

Where the heat release rate from the fire is sufficient to cause flashover, a post-flashover compartment fire shall be assumed. The determination of the temperature versus time profile resulting from the fire shall include fuel load, ventilation characteristics to the space (natural and mechanical), compartment dimensions, and thermal characteristics of the compartment boundary.

4.2.1.3 Exterior Fires

The exposure of exterior structure to flames projecting from wall openings as a result of a post-flashover compartment fire shall be considered along with the radiation from the interior fire through the opening. The shape and length of the flame projection and distance between the flame and the exterior structure shall be used to determine the heat flux to the aluminum. The method in Section 4.2.1.2 shall be used to define the interior compartment fire characteristics.

4.2.1.4 Fire Duration

The fire duration in a particular area shall be determined by considering the total combustible mass, the available fuel in the space. In the case of a localized fire or a post-flashover fire, the time duration shall be determined as the total combustible mass divided by the mass loss rate, except where determined from Section 4.2.1.2.

4.2.1.5 Active Fire Protection Systems

The effects of active fire protection systems shall be considered when defining the design-basis fire.

Where automatic smoke and heat vents are installed in non-sprinklered spaces, the resulting smoke temperature shall be determined from calculation.

4.2.2 Temperatures in Structural Systems under Fire Conditions

Temperatures within structural members, components, and frames due to heating conditions posed by the design-basis fire shall be determined by a heat transfer analysis.

4.2.3 Material Properties at Elevated Temperatures

4.2.3.1 Mechanical Properties

The deterioration in strength and stiffness of structural members shall be accounted for in the structural analysis. The modulus of elasticity at elevated temperatures E_m shall be determined from test data or Table 4.1. Yield strengths F_{tym} and ultimate strengths F_{tum} at elevated temperatures shall be determined from test data or Table 4.2.

Table 4.1
MODULUS OF ELASTICITY AT ELEVATED TEMPERATURES

ALUMINUM TEMPERATURE °F	ALUMINUM TEMPERATURE °C	E_m /E 6XXX ALLOYS
75	24	1.00
200	93	1.00
212	100	0.96
300	149	0.92
350	177	0.90
400	204	0.87
450	232	0.84
500	260	0.80
600	316	0.69
700	371	0.56
1000	538	0.00

Interpolate for temperatures between those given in the table.

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Table 4.2
STRENGTHS AT ELEVATED TEMPERATURES

Aluminum Temperature		6061-T6		6063-T5		6063-T6	
°F	°C	F_{tym}/F_{ty}	F_{tum}/F_{tu}	F_{tym}/F_{ty}	F_{tum}/F_{tu}	F_{tym}/F_{ty}	F_{tum}/F_{tu}
75	24	1.00	1.00	1.00	1.00	1.00	1.00
200	93	1.00	1.00	1.00	1.00	1.00	1.00
212	100	0.95	0.91	0.93	0.91	0.90	0.89
300	149	0.90	0.84	0.89	0.84	0.84	0.80
350	177	0.88	0.80	0.89	0.84	0.77	0.71
400	204	0.75	0.67	0.68	0.63	0.58	0.57
450	232	0.58	0.53	0.50	0.50	0.42	0.43
500	260	0.40	0.40	0.36	0.38	0.29	0.29
600	316	0.20	0.20	0.20	0.20	0.11	0.11
700	371	0.08	0.08	0.08	0.08	0.06	0.07
1000	538	0.00	0.00	0.00	0.00	0.00	0.00

Interpolate for temperatures between those given in the table.

4.2.3.2 Thermal Expansion

Thermal expansion for temperatures between 70°F and 600°F (20°C and 300°C) shall be determined using a coefficient of thermal expansion for aluminum of 14.2×10^{-6}/°F (25.6×10^{-6}/°C).

4.2.3.3 Specific Heat

The specific heat of aluminum alloys is 0.23 Btu/lb/°F (960 J/kg/°C) at 212°F (100°C).

4.2.4 Structural Design Requirements

4.2.4.1 General Structural Integrity

Structures shall provide adequate strength and deformation capacity to withstand the conditions developed during the design-basis fire within the prescribed limits of deformation. The structural system shall be designed to sustain local damage with the structural system as a whole remaining stable.

Continuous load paths shall be provided to transfer all forces from the region exposed to fire to the final point of resistance. The foundation shall be designed to resist the forces and to accommodate the deformations developed during the design-basis fire.

4.2.4.2 Strength Requirements and Deformation Limits

Conformance of the structural system to these requirements shall be demonstrated by constructing a mathematical model of the structure based on principles of structural mechanics and evaluating this model for the internal forces and deformations in the members of the structure developed by the temperatures of the design-basis fire.

Individual members shall be provided with adequate strength to resist the shears, axial forces, and moments determined by this analysis.

Connections shall develop the strength of the connected members or the forces indicated above. Where the means of providing the fire resistance requires the consideration of deformation criteria, the deformation of the structural system or members thereof under the design-basis fire shall not exceed the prescribed limits.

4.2.4.3 Methods of Analysis

4.2.4.3.1 Advanced Methods of Analysis

The methods of analysis in this section are permitted for the design of all aluminum structures for fire conditions. The design-basis fire exposure shall be that determined in Section 4.2.1. The analysis shall include both a thermal response and the mechanical response to the design-basis fire.

The thermal response shall produce a temperature field in each structural element as a result of the design-basis fire and shall incorporate temperature-dependent thermal properties of the structural elements and fire-resistive materials in accordance with Section 4.2.2.

The mechanical response results in forces and deformations in the structural system subjected to the thermal response calculated from the design-basis fire. The mechanical response shall explicitly account for the deterioration in strength and stiffness with increasing temperature, the effect of thermal expansion, and large deformations. Boundary conditions and connection fixity in the analysis shall be representative of the proposed structural design. Material properties shall be as given in Section 4.2.3.

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The resulting analysis shall consider all relevant limit states, such as excessive deflections, connection fractures, and overall and local buckling.

4.2.4.3.2 Simple Methods of Analysis

The methods of analysis in this section apply to evaluating the performance of individual members at elevated temperatures during exposure to fire.

Support and restraint conditions (forces, moments, and boundary conditions) at normal temperatures may be assumed to remain unchanged throughout the fire exposure.

a) Tension members

It is permitted to model the thermal response of a tension member using a one-dimensional heat transfer equation with heat input from the design-basis fire defined in Section 4.2.1.

The design strength of a tension member shall be determined using the provisions of Chapter D with aluminum properties as given in Section 4.2.3 and assuming a uniform temperature over the cross section using the temperature equal to the maximum aluminum temperature.

b) Compression members

It is permitted to model the thermal response of a compression member using a one-dimensional heat transfer equation with heat input from the design-basis fire defined in Section 4.2.1.

The design strength of a compression member shall be determined using the provisions of Chapter E with aluminum properties as given in Section 4.2.3.

c) Flexural members

It is permitted to model the thermal response of a flexural member using a one-dimensional heat transfer equation to calculate bottom flange temperature and to assume that this bottom flange temperature is constant over the depth of the member. Heat input shall be determined from the design-basis fire defined in Section 4.2.1.

The design strength of a flexural member shall be determined using the provisions of Chapter F with aluminum properties as given in Section 4.2.3.

4.2.4.4 Design Strength

The design strength shall be determined in accordance with Section B.3. The nominal strength R_n shall be determined using the material properties given in Section 4.2.3 at the temperature developed during the design-basis fire.

4.3 DESIGN BY QUALIFICATION TESTING

4.3.1 Qualification Standards

Structural members and components in aluminum structures shall be qualified for the rating period in conformance with ASTM E119.

4.3.2 Restrained Construction

A restrained condition exists when the surrounding or supporting structure is capable of resisting actions caused by thermal expansion throughout the range of anticipated elevated temperatures.

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Appendix 5 Evaluation of Existing Structures

5.1 GENERAL PROVISIONS

These provisions apply to evaluating the strength or serviceability of existing members, connections, or structures. These provisions shall be applicable when the evaluation of an existing aluminum structure is specified for (a) verification of a specific set of load effects or (b) determination of the available strength of a load-resisting member, connection, or structure. Evaluations shall be based on structural analysis or both structural analysis and load testing.

5.2 MATERIAL PROPERTIES

5.2.1 Wrought and Cast Products

Unless the aluminum alloy and temper used in the structure are identified from records, specimens shall be cut from the structure and both:

a) Chemical composition tests shall be conducted to determine the alloy, and

b) Tensile tests shall be conducted in accordance with ASTM B557 to determine the tensile yield strength, tensile ultimate strength, and elongation to determine the temper.

Mechanical properties given in the appropriate ASTM material specification for the alloy, temper, and product that were determined to have been used in the structure shall be used in the structural analysis.

5.2.2 Welds

Where structural performance depends on existing welds:

a) The filler metals used in the structure shall be identified from records or chemical analysis of representative samples of weld metal.

b) If welds do not meet the visual inspection criteria of AWS D1.2, additional inspection shall be conducted to determine their strength.

5.2.3 Bolts and Rivets

Unless bolt or rivet strength can be determined from records or markings, representative samples shall be removed and tested to determine tensile strength in accordance with ASTM F606/F606M.

5.3 EVALUATION BY STRUCTURAL ANALYSIS

5.3.1 Dimensions

Dimensions and the condition of structural members and connections shall be determined from records and/or from a field survey.

5.3.2 Strength Evaluation

Loads shall be determined in accordance with Section B.2 or the maximum load that can be withstood shall be determined. Load effects in the structure shall be determined by structural analysis. The available strength of members and connections shall be determined using the *Specification for Aluminum Structures*.

5.3.3 Serviceability Evaluation

Deformations shall be calculated at service loads.

5.4 EVALUATION BY LOAD TESTING

The structure shall be analyzed and a written testing plan prepared before testing.

Test loads shall be applied incrementally in accordance with the written testing plan. The tested strength of the structure is the maximum applied test load plus the dead load. The live load rating L of the structure shall be calculated by setting the tested strength equal to $1.2D_n + 1.6L$, where D_n is the nominal dead load. For roof structures, the live load rating L shall represent L_r, S_n or R

where

L_r = nominal roof live load
R = nominal load due to rainwater or snow, exclusive of the ponding contribution
S_n = nominal snow load

More severe load combinations shall be used where required by the applicable building codes.

The structure shall be visually inspected for signs of distress or imminent failure at each load increment. Deformations shall be recorded at each load increment and one hour and 24 hours after the removal of the load. The test load shall not exceed a value that produces deformations that exceed material, fabrication, or erection dimensional tolerances for the structure tested.

5.5 EVALUATION REPORT

The evaluation shall be documented by a written report that includes:

a) whether the evaluation was based on structural analysis or a combination of structural analysis and load testing;

b) when testing was performed, the loads and load combinations used and the load-deformation and time-deformation relationships observed;

c) information obtained from records and material testing;

d) either: i) the adequacy of the members, connections, or structure to withstand the load effects, or ii) the available strength of the member, connection, or structure;

e) the date the evaluation was performed.

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Appendix 6 Member Stability Bracing

This appendix addresses the strength and stiffness necessary to provide a braced point in a column, beam, or beam-column.

6.1 GENERAL PROVISIONS

Bracing systems shall have the strength and stiffness specified in this Appendix. Where such a system braces more than one member, the strength and stiffness of the bracing shall be the sum of the required strengths of all members being braced. The evaluation of the stiffness furnished by the bracing shall include the effects of connections and anchoring details.

The available strength and stiffness of the bracing members and connections shall equal or exceed the required strength and stiffness, respectively, unless analysis justifies smaller values.

Columns, beams, and beam-columns with end and intermediate braced points designed to meet the requirements in Sections 6.2, 6.3, and 6.4 are permitted to be designed based on lengths kL and L_b, as defined in Chapters E and F, taken equal to the distance between the braced points.

In lieu of the requirements of Sections 6.2, 6.3, and 6.4:

a) The required brace strength and stiffness can be obtained using a second order analysis that satisfies the provisions of Chapter C and includes brace points displaced from their nominal locations in a pattern that provides for the greatest demand on the bracing.

b) The required bracing stiffness can be obtained as $2/\phi$ (LRFD) or 2Ω (ASD) times the ideal bracing stiffness determined from a buckling analysis. The required brace strength can be determined using the provisions of Sections 6.2, 6.3, and 6.4.

c) For either of the above analysis methods, members with end or intermediate braced points meeting these requirements may be designed based on effective lengths, kL and L_b, less than the distance between braced points.

6.2 COLUMN BRACING

6.2.1 Panel Bracing

The panel bracing system shall have the strength and stiffness specified in this section. The connection of the bracing system to the column shall have the strength specified in Section 6.2.2 for a point brace at that location.

The required shear strength of the bracing system in the direction perpendicular to the longitudinal axis of the column is

$$V_{br} = 0.005P_r \qquad (6\text{-}1)$$

The required shear stiffness of the bracing system is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{2P_r}{L_b}\right) \qquad (6\text{-}2 \text{ LRFD})$$

$$\beta_{br} = \Omega\left(\frac{2P_r}{L_b}\right) \qquad (6\text{-}2 \text{ ASD})$$

where

ϕ = 0.75 (LRFD); Ω = 2.00 (ASD)
L_{br} = unbraced length within the panel under consideration
P_r = required axial strength of the column within the panel under consideration

6.2.2 Point Bracing

The required strength of end and intermediate point braces in the direction perpendicular to the longitudinal axis of the column is

$$P_{br} = 0.01P_r \qquad (6\text{-}3)$$

The required stiffness of the brace is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{8P_r}{L_b}\right) \qquad (6\text{-}4 \text{ LRFD})$$

$$\beta_{br} = \Omega\left(\frac{8P_r}{L_b}\right) \qquad (6\text{-}4 \text{ ASD})$$

where

ϕ = 0.75 (LRFD)
Ω = 2.00 (ASD)
L_{br} = unbraced length adjacent to the point brace
P_r = largest of the required axial strengths of the column within the unbraced lengths adjacent to the point brace

When the unbraced lengths adjacent to a point brace have different P_r/L_{br} values, the larger value shall be used to determine the required brace stiffness.

For intermediate point bracing of an individual column, L_{br} in Equation 6-4 need not be taken less than the maximum effective length, kL, permitted for the column based on the required axial strength P_r.

6.3 BEAM BRACING

Beams shall be restrained against rotation about their longitudinal axis at points of support. When a braced point is assumed in the design between points of support, lateral bracing, torsional bracing, or a combination of the two shall be provided to prevent the relative displacement of the top and bottom flanges (i.e., to prevent twist). In members subject to double curvature bending, the inflection point shall not be considered a braced point unless bracing is provided at that location.

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The requirements of this section apply to bracing of doubly- and singly symmetric I-shaped members subjected to flexure within a plane of symmetry and zero net axial force.

6.3.1 Lateral Bracing

Lateral bracing shall be attached at or near the beam compression flange, except as follows

a) At the free end of a cantilevered beam, lateral bracing shall be attached at or near the tension flange.

b) For braced beams subjected to double curvature bending, bracing shall be attached at or near both flanges at the braced point nearest the inflection point.

It is permitted to use either panel or point bracing to provide lateral bracing for beams.

6.3.1.1 Panel Bracing

Panel bracing systems shall have the strength and stiffness specified in this section. The connection of the bracing system to the member shall have the strength specified in Section 6.3.1.2 for a point brace at that location.

The required shear strength of the bracing system is

$$V_{br} = 0.01 M_r C_d / h_o \qquad (6\text{-}5)$$

The required stiffness of the bracing system is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{4 M_r C_d}{L_{br} h_o}\right) \qquad (6\text{-}6 \text{ LRFD})$$

$$\beta_{br} = \Omega\left(\frac{4 M_r C_d}{L_{br} h_o}\right) \qquad (6\text{-}6 \text{ ASD})$$

where

ϕ = 0.75 (LRFD)
Ω = 2.00 (ASD)
h_o = distance between flange centroids
C_d = 1.0 except C_d = 2.0 for the brace closest to the inflection point in a beam subjected to double curvature
L_{br} = unbraced length within the panel under consideration
M_r = required flexural strength of the beam in the panel under consideration

6.3.1.2 Point Bracing

The required strength of end and intermediate point braces in the direction perpendicular to the longitudinal axis of the beam is

$$P_{br} = 0.02 M_r C_d / h_o \qquad (6\text{-}7)$$

The required stiffness of the brace is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{10 M_r C_d}{L_{br} h_o}\right) \qquad (6\text{-}8 \text{ LRFD})$$

$$\beta_{br} = \Omega\left(\frac{10 M_r C_d}{L_{br} h_o}\right) \qquad (6\text{-}8 \text{ ASD})$$

where

ϕ = 0.75 (LRFD)
Ω = 2.00 (ASD)
h_o = distance between flange centroids
C_d = 1.0 except C_d = 2.0 for the brace closest to the inflection point in a beam subject to double curvature
L_{br} = unbraced length adjacent to the point brace
M_r = largest of the required flexural strengths of the beam within the unbraced lengths adjacent to the point brace

When the unbraced lengths adjacent to a point brace have different M_r/L_{br} values, the larger value shall be used to determine the required brace stiffness.

For intermediate point bracing of an individual beam, L_{br} in Equation 6-8 need not be taken less than the maximum effective length, L_b, permitted for the beam based on the required flexural strength, M_r.

6.3.2 Torsional Bracing

Torsional bracing shall be attached at any cross-section location, and need not be attached near the compression flange.

6.3.2.1 Point Bracing

The required flexural strength of the brace about the longitudinal axis of the beam is

$$M_{br} = 0.02 M_{br} \qquad (6\text{-}9)$$

The required flexural stiffness of the brace is

$$\beta_{br} = \frac{\beta_T}{\left(1 - \frac{\beta_T}{\beta_{sec}}\right)} \qquad (6\text{-}10)$$

where

$$\beta_T = \frac{1}{\phi}\left(\frac{2.4 L M_r^{\,2}}{n E I_{yeff} C_b^{\,2}}\right) \qquad (6\text{-}11 \text{ LRFD})$$

$$\beta_T = \Omega\left(\frac{2.4 L M_r^{\,2}}{n E I_{yeff} C_b^{\,2}}\right) \qquad (6\text{-}11 \text{ ASD})$$

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$$\beta_{sec} = \frac{3.3E}{h_o}\left(\frac{1.5h_o t_w^{\,3}}{12} + \frac{t_{st} b_s^{\,3}}{12}\right) \qquad (6\text{-}12)$$

where

ϕ = 0.75 (LRFD)
Ω = 3.00 (ASD)
I_{yeff} = effective out-of-plane moment of inertia = $I_{yc} + (t/c)I_{yt}$
I_{yc} = moment of inertia of the compression flange about the *y*-axis
I_{yt} = moment of inertia of the tension flange about the *y*-axis
L = span length
n = number of braced points within the span
M_r/C_b = maximum value of the required flexural strength of the beam divided by the moment gradient factor, within the unbraced lengths adjacent to the point brace
t_w = beam web thickness
t_{st} = beam web stiffener thickness
c = distance from the neutral axis to the extreme compressive fibers
t = distance from the neutral axis to the extreme tensile fibers
b_s = stiffener width for one-sided stiffeners (use twice the individual width for pairs of stiffeners)
β_T = overall brace system required stiffness
β_{sec} = web distortional stiffness, including the effect of web transverse stiffeners, if any
M_r = largest of the required flexural strengths of the beam within the unbraced lengths adjacent to the point brace

Web stiffeners shall extend the full depth of the braced member and shall be attached to the flange if the torsional brace is also attached to the flange. Web stiffeners are permitted to stop short of the beam flange by a distance equal to $4t_w$ if the torsional brace is not attached to the flange.

6.3.2.2 Continuous Bracing

For continuous torsional bracing:

a) The brace strength per unit length along the beam shall be $0.02M_r$ divided by the maximum unbraced length permitted for the beam based on the required flexural strength, M_r. The required flexural strength, M_r, is the maximum value throughout the beam span.

b) The brace stiffness per unit length shall be given by Equations 6-10 and 6-11 with $L/n = 1.0$.

c) The web distortional stiffness shall be taken as:

$$\beta_{sec} = \frac{3.3Et_w^{\,3}}{12h_o} \qquad (6\text{-}13)$$

6.4 BEAM-COLUMN BRACING

For bracing of beam-columns, the required strength and stiffness for the axial force shall be determined as specified in Section 6.2, and the required strength and stiffness for the flexure shall be determined as specified in Section 6.3. The values so determined shall be combined as follows:

a) When panel bracing is used, the required strength is the sum of the values determined using Equations 6-1 and 6-5, and the required stiffness is the sum of the values determined using Equations 6-2 and 6-6.

b) When point bracing is used, the required strength is the sum of the values determined using Equations 6-3 and 6-7, and the required stiffness is the sum of the values determined using Equations 6-4 and 6-8. In Equations 6-4 and 6-8, L_b for beam-columns shall be taken as the actual unbraced length; the provisions in Sections 6.2.2 and 6.3.1.2 that L_b need not be taken less than the maximum permitted effective length based on P_r and M_r shall not be applied.

c) When torsional bracing is provided for flexure in combination with panel or point bracing for the axial force, the required strength and stiffness shall be combined or distributed in a manner that is consistent with the resistance provided by the element(s) of the actual bracing details.

d) When the combined stress effect from axial force and flexure results in compression to both flanges, either lateral bracing shall be added to both flanges or both flanges shall be laterally restrained by a combination of lateral and torsional bracing.

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PART II

COMMENTARY ON THE SPECIFICATION FOR ALUMINUM STRUCTURES

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

PART II

Commentary on the Specification for Aluminum Structures

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Chapter A General Provisions

A.1 SCOPE

This *Specification* replaces the 2015 *Specification for Aluminum Structures* and its organization is similar to the 2016 AISC *Specification for Structural Steel Buildings*.

This *Specification* provides the nominal strength of aluminum structures, members, and connections. The nominal strength is usually defined as a force or moment, but in some cases as a stress.

This *Specification* provides two methods of design for strength limit states of building-type structures:

1) Load and Resistance Factor Design (LRFD): The nominal strength multiplied by a resistance factor must equal or exceed the required strength determined by analysis for the appropriate LRFD load combinations.

2) Allowable Strength Design (ASD): The nominal strength divided by a safety factor must equal or exceed the required strength determined by analysis for the appropriate ASD load combinations.

Strength limit states for non-building-type structures can be addressed using the nominal strengths provided by this *Specification* in conjunction with loads, load combinations, load factors, and safety or resistance factors provided by codes that apply to those structures.

A.2 REFERENCED DOCUMENTS

This section lists the referenced documents and establishes the editions of the documents to be used with this *Specification*.

A.3 UNITS

Due to rounding, SI and US Customary units quantities in the *Specification* are not equal. The *Specification* prohibits using one set of units with a more favorable magnitude for one parameter and the other set of units for another parameter.

A.4 MATERIAL

A.4.1 General Provisions

Modulus of Elasticity: The modulus of elasticity E given in Table A.4.1 is a typical value for compression. The tensile modulus of elasticity is approximately 2% less than the compressive modulus. ASTM test method E111 is used to measure the modulus. While the modulus varies slightly among aluminum alloys, for all but 2014, the difference between 10,100 ksi (70,000 MPa) and a more accurate modulus is 5% or less, and zero for most alloys. This variation is small compared to typical engineering accuracy. More precise moduli are given in *Aluminum Standards and Data 2017* Table 2.1.

Coefficient of Thermal Expansion: More precise coefficients of thermal expansion than those given in this Section are given in the *Aluminum Design Manual* Part IV Table 3 and in *Aluminum Standards and Data*.

Density: More precise densities than those given in this Section are given in the *Aluminum Design Manual* Part IV Table 4 and in *Aluminum Standards and Data*.

Shear Yield Strength: The shear yield strength F_{sy} is based on the von Mises yield criterion that

$$F_{sy} = \frac{F_{ty}}{\sqrt{3}}\ , \text{approximated as } F_{sy} = 0.6\ F_{ty}.$$

Prior to the 2015 edition of the *Specification for Aluminum Structures*, the compressive yield strength F_{cy} and shear ultimate strength F_{su} were provided for each alloy-temper-product addressed by the *Specification*. In the 2015 edition the compressive yield strength was changed to a function of tensile yield strength and shear ultimate strength was changed to a function of tensile ultimate strength. The tensile yield strength F_{ty} and tensile ultimate strength F_{tu} are the minimum strengths from material specifications such as ASTM B221 for extrusions.

The compressive yield strengths F_{cy} and shear ultimate strengths F_{su} previously listed in the *Specification* were from unpublished data generated prior to the first edition of the *Specification* (1967) and of limited extent. The commentary on this data read:

> "Table A.4.3 compressive yield strengths F_{cy} and shear ultimate strengths F_{su} are expected strengths that 99% of the population is expected, but not guaranteed, to equal or exceed. Material should not be accepted or rejected based on these strengths. These strengths are derived strengths established by multiplying strengths from tests of representative lots of material by the ratio of the specified tensile yield or ultimate strength to the tensile yield or ultimate strength of the lot tested. Effort is made to base these strengths on test results for at least 5 lots of each alloy, temper, and product, but there are instances where insufficient data are available and the strengths are based on data for similar products."

Shear Ultimate Strength: The table below shows the relationship between F_{su} and F_{tu} for the alloy-temper and products in the 2010 *Specification*. $F_{su} = 0.6F_{tu}$ with a coefficient of variation of 4.4%. This equation gives a larger F_{su} than the 2010 Table A.4.3 by a maximum of 12% (in the case of 5154-H34 sheet). The *Specification* uses the same relationship for shear yielding: $F_{sy} = 0.6F_{ty}$.

	F_{su}/F_{tu}
average	0.60
minimum	0.53
maximum	0.65
standard deviation	0.026
coefficient of variation	0.044

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Compressive Yield Strength: The table below shows the relationship between F_{cy} and F_{ty} for the alloy-temper and products in the 2010 *Specification*.

a) For non-cold-worked tempers, $F_{cy} = F_{ty}$ with a coefficient of variation of 1.0%. This equation gives a larger F_{cy} than the 2010 Table A.4.3 by a maximum of 4% (in the case of 2014-T6 rod and bar).

b) For cold-worked tempers, $F_{cy} = 0.9F_{ty}$ with a coefficient of variation of 6.6%. This equation gives a larger F_{cy} than the 2010 Table A.4.3 by a maximum of 11% (in the case of 5456-H116, H32, and H321 plate).

	F_{cy}/F_{ty}
Cold-worked tempers	
average	0.90
minimum	0.81
maximum	1.08
standard deviation	0.060
coefficient of variation	0.066
Non-cold-worked tempers	
average	1.00
minimum	0.96
maximum	1.02
standard deviation	0.010

The Canadian Standards Association CAN3-S157-M83 *Strength Design in Aluminum* Section 1.2.3 used $F_{cy} = 0.9F_{ty}$ for non-heat treatable alloys. The commentary to the 2005 edition of S157 read:

> "In compression, the yield strength is taken to be equal to that in tension for fully heat treated plate alloys and extruded products. As a consequence of the Bauschinger effect, the yield strength of rolled products in work-hardened alloys may be lower in compression, but this is not expected to influence significantly the level of safety."

A.4.1.1 Properties at Elevated Temperatures

For the alloy-tempers included in this *Specification*, properties are negligibly affected at temperatures up to 200°F. Because the reduction in strength will not exceed 5% for the alloys, tempers, times, and temperatures given in Table A.4.2, it is unnecessary to account for this reduction in design within these limits.

Aluminum Standards and Data and Kaufman (1999) provide typical mechanical properties for many aluminum products at elevated temperatures. The reduction in strength varies with alloy, temper, temperature, and time of exposure.

A.4.1.2 Temperature Limits

See the commentary to Section M.3.

A.4.2 Wrought Products

This *Specification* applies to material that complies with the ASTM material specifications cited in Section A.4.2. These ASTM specifications include dimensional tolerances given in ANSI H35.2. Dimensional tolerances in ANSI H35.2 are very similar to dimensional tolerances given in *Aluminum Standards and Data*.

Table A.4.3 tensile ultimate strengths F_{tu} and tensile yield strengths F_{ty} are specified minimum strengths. Specified minimum strengths are established after sufficient test data have been accumulated to determine the form of the frequency distribution curve and to provide a reliable estimate of the population mean and standard deviation. In most instances the distribution is normal and strengths are based on the results of at least 100 tests from at least 10 different lots of material. Tensile strengths are established at levels at which 99% of the material is expected to conform at a 0.95 confidence level.

Test methods used to determine mechanical properties are summarized below:

Type of Stress	ASTM Test Method
Tension	B 557
Compression	E 9
Shear	B 769

Typical strengths for many wrought products are given in *Aluminum Standards and Data*.

Aluminum alloys gain strength by heat treatment or strain hardening. Welding causes local annealing in a zone around the weld, reducing the strength within the zone. The resulting variation in mechanical properties in the vicinity of a weld is illustrated by the typical distribution in Figure CA.4.1. Moore, et al. (1971) discussed the effect of welding heat on aluminum mechanical properties.

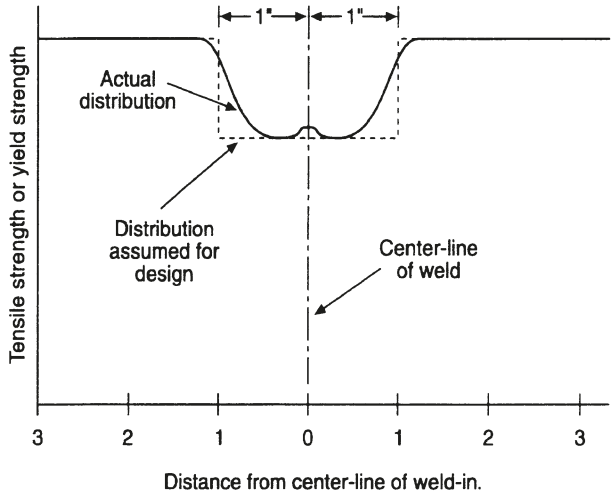

Figure CA.4.1
DISTRIBUTION OF MECHANICAL PROPERTIES NEAR A WELD

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The size of the weld-affected zone (WAZ) is used to determine the strength of welded members. It is approximated as extending 1 in. [25 mm] from the centerline of a groove weld or the heel of a fillet weld (Aluminum Association (2002) and Hill, et al. (1962)). The actual size of the WAZ is a function of many factors, including part thickness, weld size, travel speed, welding process, number of passes, and preheat. Approximating the WAZ size is a reasonable convenience because the strength of typical welded members is not strongly dependent on the WAZ size. Furthermore, there is no sharply defined boundary for the WAZ. For large welds in thick parts, the WAZ may be larger than prescribed by the *Specification*.

For non-heat treatable alloys, the welded tensile ultimate strengths F_{tuw} and welded tensile yield strengths F_{tyw} match the strengths for the annealed temper (O) of the alloy, and for heat treatable alloys, the welded tensile ultimate and tensile yield strengths are slightly less than the solution heat treated (T4 temper) strengths (Nelson and Howell (1952)).

Table A.4.3 gives the welded strengths for welds produced in accordance with AWS D1.2. The welded tensile ultimate strengths F_{tuw} are the weld procedure qualification strengths required by AWS D1.2 for groove welds, and are from specimens loaded transverse to the weld.

Tests of welded yield strengths are not routinely required by welding codes or product specifications. Welded yield strengths F_{tyw} are for 0.2% offset in a 2 in. (50 mm) gauge length, the same criteria used for determining the yield strength of unwelded material. The welded yield strengths for heat treatable alloys are based on Canadian standards S157 and W47.2 and considering T1 and T4 temper strengths. The yield strength of the weld-affected zone from weld-affected specimens loaded longitudinally (parallel to the weld) is more useful than specimens loaded transverse to the weld. This is because the welded yield strength is only used for member design, and the longitudinal direction is the direction of the stress of interest for member design. The longitudinal welded yield strength is the average of the welded yield strength of the base metal in the weld-affected zone and the welded yield strength of the filler.

The notch strength is the tensile ultimate strength of a standard notched specimen. Kaufman (2001) documented the notch strength of a number of aluminum alloy-tempers and suggested ASTM tests for determining notch strength.

Alloy-tempers with notch-strength-to-yield-strength ratios less than 1 are considered to be notch sensitive, since they will rupture at a notch before yielding. Such alloy-tempers require a reduction in the tensile ultimate strength

Table CA.4.1
RATIO R_t OF NOTCHED SPECIMEN TENSILE ULTIMATE STRENGTH TO SMOOTH SPECIMEN TENSILE YIELD STRENGTH

Table	thk	width	E or C	L or T	*R*	6061-T6	5456-H34	*7075-T73**	2014-T6	*7075-T6**
5.1(a)	0.063	0.5	E	L	0.001	1.18			1.03	*1.06*
5.1(b)	0.063	0.5	E	T	0.001	1.18			1.03	*1.02*
5.2(a)	0.063	1.000	E	L	0.001	1.08		*1.10*	0.93	*0.95*
5.2(a)	0.125	1.000	E	L	0.001	1.12	1.05	*1.03*	0.99	*0.86*
5.2(b)	0.063	1.000	E	T	0.001	1.12		*0.98*	0.89	*0.90*
5.2(b)	0.125	1.000	E	T	0.001	1.20	1.09	*1.02*	0.88	*0.81*
5.3(a)	0.063	3.000	E	L	0.0005			*0.93*		*0.78*
5.3(a)	0.125	3.000	E	L	0.0005		0.97		0.82	*0.71*
5.3(a)	0.250	3.000	E	L	0.0005				0.71	*0.57*
5.3(b)	0.063	3.000	E	T	0.0005			*0.88*		*0.78*
5.3(b)	0.125	3.000	E	T	0.0005		0.97		0.76	*0.62*
5.3(b)	0.250	3.000	E	T	0.0005	1.11	0.90	*0.85*	0.65	*0.47*
5.4(a)	0.125	3.000	C	L	0.063				0.84	*0.75*
5.4(a)	0.125	3.000	C	L	0.063				0.77	*0.53*
5.4(b)	0.063	3.000	C	T	0.063			*0.89*		*0.77*
5.4(b)	0.125	3.000	C	T	0.063				0.77	*0.64*
5.4(b)	0.250	3.000	C	T	0.063			*0.85*	0.63	*0.50*
					average	1.14	1.00	*0.95*	0.84	*0.75*
					$1/R_t$		1.00	*1.06*	1.20	*1.34*
					k_t	1	1	*1.1*	1.25	*1.35*

* 7075-T6 and 7075-T73 are not included in the *Specification*.

Notes:

1) E = edge notched specimen; C = center slot specimen

2) L = longitudinal yield strength used; T = transverse yield strength used

3) *R* = radius of notch or slot (in.)

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used for design. This reduction is made by dividing the tensile ultimate strength by the tension coefficient k_t, a coefficient greater than or equal to 1.

The k_t factor of 1.25 for 2014-T6 has been used since publication of ASCE (1956).

The k_t factor of 1.25 for 6005-T5 and 6105-T5 is based on the fact that Kaufman (2001) shows that the unit propagation energy for 6005-T5 is no greater than that for 2014-T6.

Tension coefficients are based on the ratio R_t of notched specimen tensile ultimate strength to smooth specimen tensile yield strength. Data given by Kaufman (2001) is summarized in Table CA.4.1. To determine the tension coefficient k_t, $1/R_t$ is rounded up to the nearest 0.05. The resulting tension coefficient is consistent with the tension coefficients historically used for 6061-T6, 5456-H34, and 2014-T6 in the *Specification*. 7075-T6 and 7075-T73 are not included in the *Specification* because their data are too limited in plate thicknesses, but are shown here for comparison.

A.4.3 Castings

ASTM B26 and B108 do not specify tensile yield strengths for some of the cast alloy-tempers they include (for example, sand cast 356.0-T7). These alloy-tempers are not included in Table A.4.4 (and therefore are excluded from the scope of this *Specification*) since design usually uses the yield strength. There are also other alloy-tempers in B26 or B108 that are not included in Table A.4.4 and therefore not included in this *Specification*.

ASTM B26 and B108 do not require conformance with dimensional standards (tolerances) as do ASTM specifications for wrought products (for example, B209). Therefore, dimensional standards for castings are established in this *Specification* as those in the Aluminum Association *Standards for Aluminum Sand and Permanent Mold Castings*. *Standards for Aluminum Sand and Permanent Mold Castings* also provides strengths for separately cast coupons of cast alloy-tempers not included in the *Specification*.

Castings are more prone to discontinuities than wrought products. Therefore, this *Specification* includes discontinuity standards for castings in order for them to be designed to the same *Specification* provisions as wrought products. The quality standards are based on the following:

ASTM B26 and B108 (section 20) both include options for liquid penetrant and radiographic inspection that may be specified by the purchaser. Liquid penetrant inspection detects only surface flaws, so it is insufficient. ASTM B26 and B108 only require radiographic inspection be performed if the purchaser specifies such inspection. If such inspection is specified, the purchaser must also specify which of four quality grades (A, B, C, or D) must be met. Grade A allows no discontinuities at all; this is more stringent than wrought product quality levels and so it is unwarranted. When Grade D is specified, no tensile tests of coupons cut from castings are required. Therefore, only grade B or C are suitable for the type of structural components addressed by this *Specification*. Grade C is used, since Grade C allows gas holes no larger than approximately 1/8 in. (3 mm) and this is the same as the ultrasonic inspection Grade B flaw size limit for wrought plate in *Aluminum Standards and Data 2017* (Table 6.3).

Once the acceptance criteria for an individual casting are determined, the number of castings from a given lot to be radiographed and the acceptance criteria for the lot must be established. *Standards for Aluminum Sand and Permanent Mold Castings* establishes four frequency levels for inspection, Level 1 requiring the most frequent inspection (radiographing every casting). Inspection Level 2 requires a statistically determined frequency of sampling and is used in this *Specification*. Level 3 leaves the inspection frequency up to the foundry and Level 4 requires no radiographs; therefore, neither requires inspection.

Strengths given in Table A.4.4 are taken from ASTM B108 for permanent mold castings. For certain alloy-tempers, B108 allows the purchaser to specify either 1) that all locations in the casting shall have certain B108-specified tensile strengths, or 2) purchaser-designated locations in the casting that shall have certain B108-specified tensile strengths. The strengths for case 2 are usually greater than those for case 1. For both cases 1 and 2, the strengths in Table A.4.4 are the B108-specified strengths without any factors.

The strengths specified in ASTM B26 Table 2 for sand castings are for separately cast test bars and not for the castings themselves. Section 11.3 of ASTM B26 states "When specified, the tensile strength, yield strength, and elongation values of specimens cut from castings shall not be less than 75% of the tensile and yield strength values and not less than 25% of the elongation values specified in Table 2." Therefore, the strengths given in Table A.4.4 for sand castings are 75% of the ASTM B26 Table 2 strengths to represent what a purchaser would expect to receive if he requires testing of the actual castings.

Kaufman (2001) Figure 5.4 provides notch-strength-to-yield-strength ratios for various sand and permanent mold alloy/temper products. The alloy/temper products in this *Specification* have notch-yield ratios ≥ 1.0, so no reduction in tensile rupture strength is required for notch sensitivity for these alloy-tempers and the tension coefficient k_t is 1.0.

A.4.4 Filler Metal for Welding

This *Specification* and AWS D1.2 require that weld filler metal comply with AWS A5.10. Tables M.9.1 and M.9.2 show the appropriate filler alloy for various base metal combinations.

For 1100 and 5000 series filler alloys, tensile strengths are based on the tensile strengths of annealed alloys with chemical compositions similar to the filler alloy. For 2319 filler alloy, tensile strengths are those for welded 2219. For 4043 filler alloy, the tensile ultimate strength is based on the AWS D1.2:2014 weld qualification tensile strength for 6061. The tensile yield strength matches the welded yield strength of 6061 previously given in the *Specification* for weldments 3/8" thick or less when welded with 4043 which was based on unpublished test data. For 4047 filler alloy,

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Table CA.4.2
SOURCES OF TENSILE STRENGTH FOR FILLERS

FILLER	TENSILE STRENGTH SOURCE	NOTES
1100	1100-O	1100 filler and 1100 base metal have the same chemical composition
2319	2219 weld qualification strength	2219 and 2319 have identical chemical composition except Ti content: 2219 has 0.02 to 0.10% and 2319 has 0.10 to 0.20%
4043	6061 weld qualification strength	
4047	fillet weld shear strength	Menzemer and Iasconne (2002)
5183	5083-O	5083 and 5183 have identical chemical composition except Mg content: 5083 has 4.0 to 4.9% and 5183 has 4.3 to 5.2%, and Mn content: 5083 has 0.40 to 1.0% and 5183 has 0.50 to 1.0%
5356	5086-O	
5554	5454-O	5454 and 5554 have identical chemical composition except Ti content: 5454 has 0 to 0.20% and 5554 has 0.05 to 0.20%
5556	5456-O	5456 and 5556 have identical chemical composition except Ti content: 5456 has 0 to 0.20% and 5556 has 0.05 to 0.20%
5654	5254-O	5254 and 5654 have identical chemical composition except Ti content: 5254 has 0 to 0.05% and 5654 has 0.05 to 0.15%

the tensile ultimate strength is calculated from the shear strength determined by Menzemer and Iasconne (2002) using the relationship between the shear strength of fillet welds and the tensile strength given in Section J.2.5.

Table CA.4.2 lists the sources of filler tensile strengths. For 2319, 5454, 5556, and 5654, the only difference in the chemical composition of the filler and the base metal on which the filler strength is based is titanium (Ti). Titanium's principal purpose in fillers is as a grain refiner to enhance the formation of fine grains as the weld meta solidifies rather than the otherwise occurring more natural, larger casting-like grain structure. Finer grain structure improves strength.

The strength of other filler alloys can be established by testing as described below and conducted in accordance with Appendix 1. Calculate minimum strengths using *Specification* Section 1.3.1. To prepare the test weldments:

- Comply with AWS D1.2 and use its requirements for statically loaded, non-tubular structures,
- Limit interpass temperatures to 250°F with unassisted cooling,
- Use base metal that complies with this *Specification* and for which the filler is intended, and
- Use filler metal that complies with AWS A5.10.

a) Determine the tensile ultimate strength, tensile yield strength, and elongation of longitudinal specimens taken from groove welds (Figure CA.4.2) in accordance with AWS B4.0 (*Standard Methods for Mechanical Testing of Welds*) with a standard 0.500 in. (12.5 mm) round test specimen with 2 in. (50 mm) gage length. Test at least 10 specimens from each of 5 different lots (as defined by AWS A5.01 Lot Class S1) of filler material.

b) Determine the shear ultimate strength of longitudinal fillet welds in accordance with the AWS B4.0 fillet weld shear test method. Test at least 12 specimens from each of 4 different thicknesses. Determine the effective throat of fillets by measuring a macroetched specimen from each fillet weld.

For each test, report:

- The alloy and chemical composition of each filler lot
- The time elapsed between welding and testing
- The times and temperatures of any post-weld heat treatment
- Material certifications for the filler alloy and base metals
- Base metal alloys, temper before welding, and product specification
- A procedure qualification record (PQR) and welding

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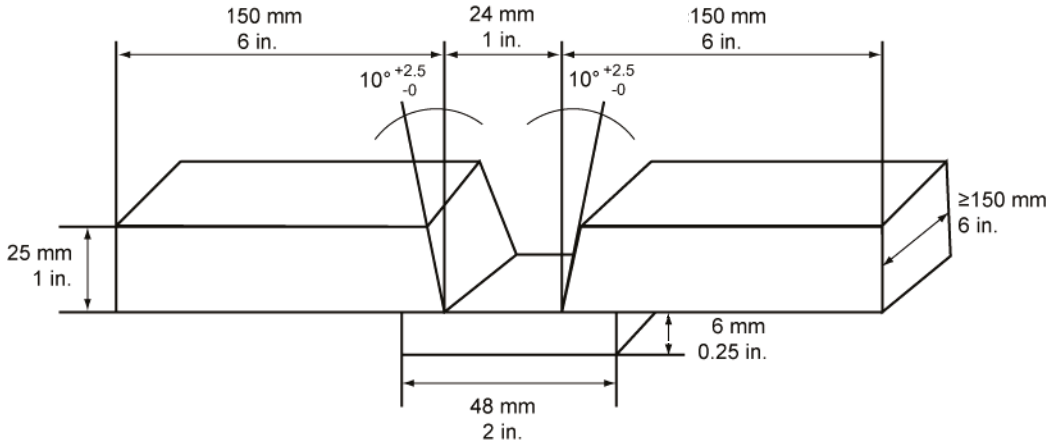

Figure CA.4.2

procedure specification (WPS) for each WPS used
- A welder performance qualification record (WPQR) for each welder or welding operator. Use at least two welders or welding operators.
- The individual test results
- The location of rupture

A.4.5 Bolts, Washers, and Nuts

This *Specification* addresses aluminum bolts, washers, and nuts only. ASTM F468, *Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use*, includes 2024-T4, 6061-T6, and 7075-T73 aluminum bolts. The strengths given in Table A.4.7 are the F468 stresses corresponding to strength of machined specimens. Section J.3.4 requires that these stresses be multiplied by the root area to determine the tensile strength of a bolt. F468 gives lesser tensile stresses corresponding to the strength of full-size bolts and requires that these stresses be multiplied by the tensile stress area to determine the strength of a bolt. The tensile stress area is greater than the root area. However, for $1/4" \le D \le 1"$, bolt tensile strengths determined by multiplying the machined specimen stresses corresponding to strength by the root area are 0 to 7% greater than bolt tensile strengths determined by multiplying the full-size bolt stresses corresponding to strength by the tensile stress area. This difference is considered sufficiently small to be acceptable for design purposes. Bolt dimensions are given in Part VI, Table 5-4. ASTM F467, *Nonferrous Nuts for General Use*, includes 2024-T4, 6061-T6, and 6262-T9 aluminum nuts. Nut dimensions are given in Part VI, Table 5-5.

Steel (uncoated or coated with zinc or other coatings) and stainless steel bolts are often used to connect aluminum parts. The AISC *Specification for Structural Steel Buildings* includes design rules for ASTM A307, A325, and A449 steel bolts. ASCE 8-02, *Specification for the Design of Cold-Formed Stainless Steel Structural Members*, provides design rules for fasteners meeting ASTM F593, *Stainless Steel Bolts, Hex Cap Screws, and Studs*. Steel fasteners with a specified minimum tensile strength greater than 120 ksi (those with a Rockwell hardness greater than or equal to C35) may suffer hydrogen-assisted stress corrosion cracking (HASCC) when exposed to certain dissimilar materials (including aluminum), moisture, and tensile stress due to installation or loading. Examples of fasteners that are not to be used in contact with aluminum are A490 bolts and Grade 8 (SAE J429) bolts or screws, all of which have a specified minimum tensile strength of 150 ksi. Each of the maximum hardness values (C38 for A490 and C39 for Grade 8) exceeds C34.

A.4.6 Rivets

This *Specification* addresses aluminum rivets only. ASTM B316, *Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*, provides the strengths that are used in Table A.4.8.

Carbon steel rivets should not be used unless a) the aluminum is joined to carbon steel (see Section M.7.1) and corrosion resistance of the structure is not required, or b) the structure is protected against corrosion.

A.4.7 Screws

This *Specification* addresses aluminum screws only. There are no ASTM specifications for aluminum screws.

The material for screws used to connect aluminum parts is selected to meet strength and corrosion resistance considerations. Steel screws with a Rockwell hardness of C35 or greater may suffer hydrogen-assisted stress corrosion cracking (HASCC) where exposed to certain dissimilar metals, moisture, and tensile stress due to installation or loading. Aluminum and austenitic stainless steel screws do not experience HASCC. When fasteners will not be exposed to contact with liquid water or humidity near the dew point, certain other steels, with appropriate hardness, and appropriately coated and/or plated are often used. An example is 430 stainless steel, which has a nominal composition of 16% chromium. The AISI S100 *North American Specification for the Design of Cold-Formed Steel Structural Members* provides design rules for steel screws, and AISI S904 provides test methods for determining the tensile and shear strengths of steel screws.

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B.1 SECTION PROPERTIES

Section properties for many shapes are given in this *Manual* in Part V. Formulas for calculating section properties are also given in Part V.

Nominal (rather than minimum) dimensions are used to calculate section properties. This is because safety or resistance factors account for the fact that actual dimensions may be less than nominal dimensions, within the tolerances prescribed by the material specifications required by Section A.4.

The torsion constant J may be determined as follows:

a) For open shapes $J = \Sigma\,(1/3 - 0.2t/b)bt^3$ for the rectangles comprising the shape where b is the larger dimension and t is the smaller dimension of each rectangle. The term for rectangles with $b/t > 10$ may be approximated by $bt^3/3$.

b) For closed shapes of uniform thickness, $J = \dfrac{4A_m^2 t}{s}$

where A_m = the mean of the areas between the inner and outer boundaries, s is the length of the boundary at mid-thickness, and t is the boundary thickness.

For rectangular tubes with side dimension a with thickness t_1 and side dimension b with thickness t_2 (see Figure CB.1.1)

$$J = \frac{2t_2t_1(a - t_2)^2(b - t_1)^2}{t_2(a - t_2) + t_1(b - t_1)}$$

If $t_1 = t_2 = t$, $\quad J = \dfrac{2t(a - t)^2(b - t)^2}{a + b - 2t}$

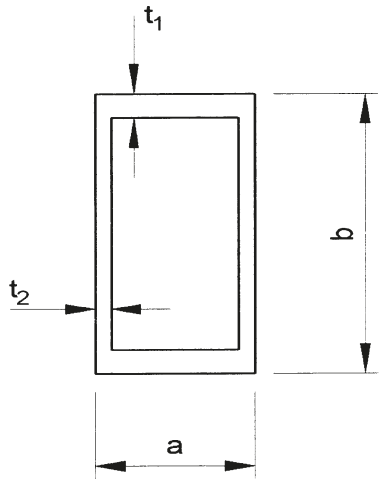

Figure CB.1.1
CROSS-SECTIONAL NOTATION

c) For shapes containing open parts and closed parts, J is the sum of J for the open parts and J for the closed parts.

B.2 LOADS AND LOAD COMBINATIONS

B.2.1 Building-Type Structures

ASCE 7 Section 2.3 provides LRFD load combinations and ASCE 7 Section 2.4 provides ASD load combinations for building-type structures.

For seismic loads, ASCE 7 requires the use of the seismic response modification coefficient R that depends on the construction material and the type of lateral force resisting system used (for example, a shear wall or a moment frame). This factor addresses the inelastic response of the system to seismic loads. ASCE 7 does not provide this factor for aluminum lateral force resisting systems. If R is taken as 1, seismic loads are conservatively assumed to be resisted elastically, without taking advantage of the potential for inelastic behavior.

The inelastic response of aluminum structures to seismic loads was investigated by Meimand, et al. (2016). They used the FEMA P695 procedure to compare seismic response modification factors, R, for two geometrically identical frames, one of steel and the other of 6061-T6 aluminum extrusions. These one-story structures used a three-span ordinary moment frame as the lateral force resisting system. The structure was found to satisfy the P695 criteria for an aluminum design with $R = 3$. The procedure was validated by showing that the steel frame met FEMA P695 requirements with $R = 3.5$, the factor prescribed by ASCE 7 for a steel ordinary moment frame. The study was limited to one structure without welding, one lateral force resisting system (an ordinary moment frame) and ignored fracture limit states, but included local buckling, local-global buckling interaction, and yielding.

B.2.2 Other Structures

Loads and load combinations for structures other than building-type structures may be determined from specifications that address such structures. For example, AASHTO's *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (2015) may be used to determine the loads for structures within its scope.

B.3 DESIGN BASIS

Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD) are equally acceptable in this *Specification*.

B.3.1 Limit States

A limit state is a condition in which a structure or component is judged to be no longer useful for its intended service (serviceability limit state) or to have reached its ultimate load-carrying capacity (strength limit state). An example of a serviceability limit state is a deflection beyond which the

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structure is unfit for service. An example of a strength limit state is member buckling of a column.

B.3.2 Required Strength

This *Specification* permits the use of elastic analysis only in determining required strengths.

B.3.2.1 Design for Strength Using Load and Resistance Factor Design (LRFD)

Design by LRFD requires that equation B.3-1 be satisfied; that is, the required strength determined from the LRFD load combinations does not exceed the design strength.

The design strength ϕR_n is the product of the resistance factor ϕ and the nominal strength R_n. Resistance factors are less than or equal to 1.0 and account for unavoidable deviations of the actual strength from the nominal strength and for the manner and consequence of failure.

The basis for load and resistance factor design is given by Ellingwood, et al. (1982). The resistance of the structure R and the load effect Q are modeled as statistically independent random quantities as shown in Figure CB.3.1. Failure occurs when the resistance R is less than the load effect Q; the probability of this occurring is represented by the overlap between the two curves in Figure CB.3.1. This probability is a function of the difference between mean value of the resistance and the mean value of the load effect and the distribution shapes of the R and Q curves.

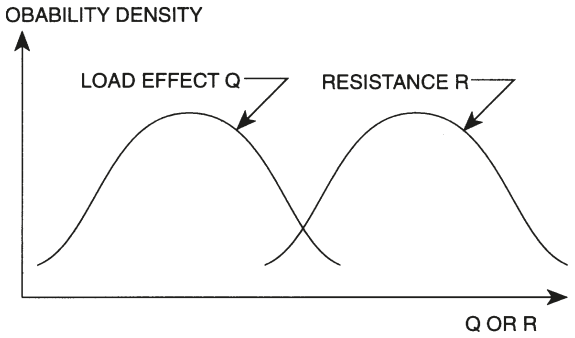

Figure CB.3.1
SCHEMATIC REPRESENTATION OF PROBABILITIES OF THE LOAD EFFECT AND THE RESISTANCE

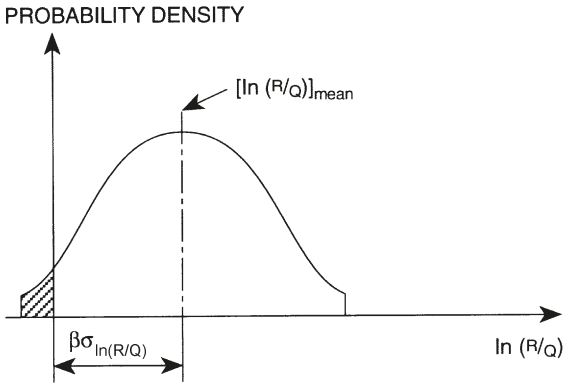

Figure CB.3.2
DEFINITION OF THE RELIABILITY INDEX β

Table CB.3.1 SUMMARY OF RELIABILITY INDEX STATISTICAL DATA

Sec 3.4.*	Limit State	Ω	P_m	M_m	F_m	R_m/R_n	V_P	V_M	V_F	V_R	Category
1,2,3,4	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	A
1,2,3,4	U	1.95	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	B
8,9	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
8,9	B	1.95	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	D
10	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
10	IB	1.95	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	D
10	EB	1.95	1.24	1.0	1.0	1.24	0.27	0.06	0.05	0.28	E
11,13,14	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
11,13,14	B	1.65	1.03	1.0	1.0	1.03	0.11	0.06	0.05	0.13	F
12,16.1	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
12,16.1	IB	1.65	1.01	1.0	1.0	1.01	0.05	0.06	0.05	0.09	G
12,16.1	EB	1.65	1.24	1.0	1.0	1.24	0.27	0.06	0.05	0.28	H
15,16,17	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
15,16,17	B	1.65	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	I
20	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
20	IB	1.65	1.07	1.0	1.0	1.07	0.09	0.06	0.05	0.12	J
20	EB	1.65	0.93	1.0	1.0	0.93	0.09	0.06	0.05	0.12	K

*Section number in *Specification for Aluminum Structures*, 2005.

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Failure can also be defined as $\ln(R/Q) < 0$. In Figure CB.3.2, failure is represented by the shaded area. The reliability index β is given by

$$\beta = \frac{\ln(R_m/Q_m)}{\sqrt{V_R^2 + V_Q^2}}$$

where R_m = mean value of resistance
Q_m = mean value of load effect
V_R = coefficient of variation of resistance
V_Q = coefficient of variation of load effect.

Galambos (1979) determined the reliability index for building-type structures for limit states in the *Specifications for Aluminum Structures*. His work is summarized in Tables CB.3.1, CB.3.2, and CB.3.3.

Notes Table CB 3.1:

1. Limit states are: Y = yield; U = tensile rupture; B = buckling; IB = inelastic buckling; EB = elastic buckling.
2. Parameters are:
   Ω = safety factor
   P_m = mean value of the ratio of actual strength to theoretical strength
   M_m = mean value of the ratio of material strength to specified material strength
   F_m = mean value of the ratio of fabricated dimensions to nominal dimensions
   $R_m/R_n = P_m M_m F_m$
   V_P = coefficient of variation of the ratio of actual strength to theoretical strength
   V_M = coefficient of variation of the ratio of material strength to specified material strength
   V_F = coefficient of variation of the ratio of fabricated dimensions to nominal dimensions
   $V_R = \sqrt{V_P^2 + V_M^2 + V_F^2}$.

Table CB.3.2 LIMIT STATE CATEGORIES

Category	Ω	R_m/R_n	V_R	Description
A	1.65	1.10	0.08	yield in tension
B	1.95	1.10	0.08	rupture in tension
C	1.65	1.10	0.08	yield in compression
D	1.95	1.00	0.09	local buckling in columns
E	1.95	1.24	0.28	elastic local buckling of curved elements in compression
F	1.65	1.03	0.13	lateral torsional buckling of beams
G	1.65	1.01	0.09	inelastic local buckling of curved elements in bending
H	1.65	1.24	0.28	elastic local buckling of curved elements in bending
I	1.65	1.00	0.09	local buckling in beams
J	1.65	1.07	0.12	inelastic shear buckling
K	1.65	0.93	0.12	elastic shear buckling

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Table CB.3.3 RELIABILITY INDICES

Category	β for $D/L = 0.1$	β for $D/L = 0.2$	Description
A	2.46	2.64	yield in tension
B	3.16	3.40	rupture in tension
C	2.87	3.09	yield in compression
D	2.72	2.92	local buckling in columns
E	2.44	2.51	elastic local buckling of curved elements in compression
F	2.01	2.13	lateral torsional buckling of beams
G	2.08	2.22	inelastic local buckling of curved elements in bending
H	1.98	2.03	elastic local buckling of curved elements in bending
I	2.04	2.18	local buckling in beams
J	2.20	2.34	inelastic shear buckling
K	1.65	1.75	elastic shear buckling

Resistance factors in this *Specification* were chosen to achieve similar levels of safety and reliability for ASD and LRFD. To do so, the relationship between safety factors and resistance factors can be established as follows:

For ASD: $R_n / \Omega = D + L$

For LRFD: $\phi R_n = AD + BL$

where A = dead load factor = 1.2

B = live load factor = 1.6.

Solving for ϕ

$$\phi = [A(D/L) + B]/[\Omega(1 + D/L)].$$

Table CB.3.4 shows that for D/L ratios of about 0.5 or less, resistance factors of 0.75 for rupture, 0.90 for all other member limit states, 0.65 for bolt or rivet failure, and 0.5 for screw failure, in most cases, are no less conservative than ASD and in all cases are not significantly larger than the tabulated ϕ values; therefore, this *Specification* uses these resistance factors. This matches the 2016 AISC *Specification* for rupture and other member limit states.

Table CB.3.4 RELATING RESISTANCE FACTORS TO SAFETY FACTORS

Dead-to-live load ratio	D/L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
dead load factor	A	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
live load factor	B	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Limit state: rupture										
safety factor	Ω	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
resistance factor	ϕ	0.82	0.80	0.79	0.77	0.76	0.75	0.74	0.74	0.73
All other member limit states										
safety factor	Ω	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
resistance factor	ϕ	0.97	0.95	0.93	0.91	0.90	0.89	0.88	0.87	0.86
Limit state: bolt, rivet failure										
safety factor	Ω	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
resistance factor	ϕ	0.68	0.67	0.66	0.64	0.63	0.63	0.62	0.61	0.61
Limit state: screw failure										
safety factor	Ω	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
resistance factor	ϕ	0.53	0.52	0.51	0.50	0.50	0.49	0.48	0.48	0.47

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B.3.2.2 Design for Strength using Allowable Strength Design (ASD)

For building-type structures, the *Specification for Aluminum Structures* has historically used a safety factor of 1.65 on yield and beam buckling limit states and 1.95 on tensile rupture limit states, and those are used in this edition of the *Specification*.

The safety factor for column member buckling in this *Specification* has effectively been 1.65, since in editions before 2015 a safety factor of 1.95 was prescribed without applying a factor for out-of-straightness, which is approximately 0.85, and $1.95 \times 0.85 = 1.65$. Because a column out-of-straightness factor of 0.85 is applied in editions of the *Specification* after 2010, the safety factor for column member buckling for those editions is 1.65.

The safety factor for column local buckling is 1.65, consistent with the safety factor for beam local buckling. An out-of-straightness factor has not been applied to local buckling because the local buckling strength is not sensitive to out-of-straightness (Sharp (1993)).

B.4 BUCKLING CONSTANTS

The buckling constants given in Section B.4 are used to determine inelastic buckling strengths and reflect the tangent modulus of elasticity in the inelastic range, as documented by Clark and Rolf (1966). The stress-strain curve for artificially aged tempers (those beginning with T5, T6, T7, T8, or T9) has a different shape after yield than that for non-artificially aged tempers (those beginning with O, H, T1, T2, T3, or T4). Therefore, different buckling constant formulae are used for artificially aged tempers than those used for non-artificially aged tempers.

Buckling constants are used to determine the inelastic buckling stress as a function of slenderness. Buckling constant B is the y-intercept of the inelastic buckling curve (the inelastic buckling stress when the slenderness is zero). Buckling constant D is the slope of the inelastic buckling curve. Buckling constant C is the slenderness at the intersection of the inelastic and elastic buckling curves except for non-artificially aged tempers given in Table B.4.1. For buckling constants determined using Table B.4.1, the inelastic buckling curve comes close to the elastic buckling curve, but they do not intersect. The buckling constant C for these cases is therefore where the curves are closest.

The equations for the buckling constant C_t for curved elements were derived by curve fitting and normalizing the compressive yield strength with respect to E so that the equations are independent of the system of units used. Buckling constants from the approximate equations differ from buckling constants determined by trial-and-error solution by no more than 14%. This results in a small difference in buckling strengths when the slenderness lies between the C_t given by the approximate equation and the C_t determined by trial-and-error.

Buckling constants are tabulated in Part VI Tables 1-1 and 1-2 for the alloy-tempers and products listed in Table A.4.3.

The weld-affected zone in non-heat treatable alloys has the annealed (O) temper strength, and the weld-affected zone in heat-treatable alloys has a strength slightly less than the solution heat-treated (T4) temper. For this reason, buckling constants for weld-affected zones of all alloys are determined from Table B.4.1, which applies to O and T4 temper material.

B.5 ELEMENTS

B.5.1 Width of Flat Elements and Stiffeners

If the inside corner radius exceeds 4 times the element thickness, the inside radius is taken as 4 times the thickness in calculating the element width. This rule is arbitrary but deemed reasonable.

B.5.2 Radius of Curved Elements

The mid-thickness radius of curved elements is used to determine their slenderness to be consistent with the work by Clark and Rolf (1964).

B.5.3 Thickness of Elements

Kim (2003) provided the method used in this Section for determining the slenderness for members that have linearly tapered thickness elements with $\delta \le 2.0$ (i.e., $t_{max} \le 3t_{min}$). The tapered flanges of C-shapes and S-shapes meet this criterion.

Three types of edge supports for elements with tapered thickness are addressed in Section B.5.3:

a) Tapered thickness elements with the thick edge supported and the thin edge free (Figure CB.5.1(a)): For such elements, it is conservative to use b/t_{avg} for the slenderness. Using b/t_{avg} gives a slenderness that is conservative by as much as 28% compared to finite element analysis for $\delta = 2$. Section B.5.3a provides an approximate expression for the slenderness that is less conservative and more accurate than using b/t_{avg}.

b) Tapered thickness elements with the thin edge supported and the thick edge free (Figure CB.5.1(b)): For such elements, the slenderness can be approximated by $1.02b/t_{avg}$. Using b/t_{avg} understates the slenderness by only 3% compared to finite element analysis, so this *Specification* allows the use of b/t_{avg}.

c) Tapered thickness elements supported on both edges (Figure CB.5.1(c)): The slenderness can be approximated by $(1.02 + 0.02\delta)\ b/t_{avg}$. Using b/t_{avg} understates the slenderness by at most only 5% compared to finite element analysis, so this *Specification* allows the use of b/t_{avg}.

Once the slenderness has been determined, use the *Specification* Section for a constant thickness element with the same edge conditions to determine the strength of the element.

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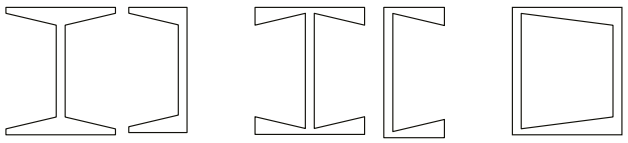

(a) (b) (c)

Figure CB.5.1

B.5.4 Strength of Elements in Uniform Compression

Sections B.5.4.1 through B.5.4.5 address the compressive strengths of beam elements assuming that the supported edges of elements are fixed against translation and free to rotate.

The strength of elements in uniform compression is the weighted average of the strengths of the unwelded and weld-affected zones of the element. The strength of elements with transverse welds is not limited by yielding because yielding at a transverse weld does not cause an appreciable change in length. The weld-affected zone for transverse welds that extend across the full width of an element is the gross area of the element.

B.5.4.1 Flat Elements Supported on One Edge

Sooi and Peköz (1993) determined the post-buckling strength given in Section B.5.4.1 for slenderness ratios greater than λ_2.

Using the buckling coefficient $k = 0.425$ for an element with one edge simply supported and the other free from Ziemian (2010) Figure 4.2 and $\nu = 0.33$ (see Section A.4.1), the elastic buckling stress can be determined as

$$F_e = \frac{k\pi^2 E}{12(1-\nu^2)(b/t)^2} = \frac{0.425\pi^2 E}{12(1-0.33^2)(b/t)^2}$$

$$= \frac{\pi^2 E}{25.16(b/t)^2} = \frac{\pi^2 E}{(5.02b/t)^2}$$

In columns buckling about a principal axis that is not an axis of symmetry (for example, channels buckling about the weak axis), the centroid of the stresses may not be the same as that for the full section. This is due to the non-linear post-buckling stress distribution in the section's elements. Although some post-buckling strength may exist, it may not be as large as that if the buckling axis were an axis of symmetry. Therefore, this Section limits the strength in such cases to the elastic local buckling strength.

B.5.4.2 Flat Elements Supported on Both Edges

Using the buckling coefficient $k = 4.00$ for an element simply supported on both edges from Ziemian (2010) Figure 4.2 and $\nu = 0.33$ (see Section A.4.1), the elastic buckling stress is:

$$F_e = \frac{k\pi^2 E}{12(1-\nu^2)(b/t)^2} = \frac{4.00\pi^2 E}{12(1-0.33^2)(b/t)^2}$$

$$= \frac{\pi^2 E}{2.673(b/t)^2} = \frac{\pi^2 E}{(1.64b/t)^2}$$

Jombock and Clark (1968) determined the post-buckling strength given in Section B.5.4.2 for slenderness ratios greater than λ_2.

B.5.4.3 Flat Elements Supported on One Edge and with a Stiffener on the Other Edge

The study by Sooi and Peköz (1993) used to establish these provisions was based on sheet metal shapes where the thickness of the stiffener is the same as the thickness of the stiffened element, and these provisions give the same result regardless of the stiffener thickness. Therefore, this *Specification* requires that the stiffener be at least as thick as the element to be stiffened.

The denominator in each of Equations B.5-7 and B.5-8 for ϱ_{ST} is the radius of gyration of a stiffener adequate to give the element being stiffened the strength of an element supported on both longitudinal edges (R_a). Sooi and Peköz adapted the equations for R_a from the AISI *Specification* (1986) and compared them with the equation proposed by Sharp (1966). The elastic buckling analysis by Sharp shows that $R_a = 6t$. Elastic buckling begins at a b/t ratio equal to λ_e where λ_e is the limiting b/t ratio at which a stiffened element is fully effective. At this value of b/t, the value of R_a obtained from Equation B.5-7 matches the value derived by Sharp. A linear relationship is assumed between R_a and b/t if b/t is between $\lambda_e/3$ and λ_e.

To develop post-bucking strength of the stiffened element, R_a is greater than $6t$. An edge stiffened element with a b/t ratio exceeding λ_e has post-buckling strength. Equation B.5-8 addresses such cases, where b/t is between λ_e and $2\lambda_e$. There is insufficient test data to develop an equation for R_a when b/t exceeds $2\lambda_e$.

The limitation on the D_s/b ratio prevents adverse interaction between local buckling of the edge stiffener and the stiffened element.

Stiffening bulbs and other complex shapes may provide greater strengths than those provided for in Section B.5.4.3. Sharp (1993) gives a method for estimating the buckling strength for these other shapes.

B.5.4.4 Flat Elements Supported on Both Edges and with an Intermediate Stiffener

The provisions in this Section are based on Sharp (1966), who developed an equation for flat elements supported on both edges with multiple intermediate stiffeners. Sooi and Peköz (1993) found that these provisions, in conjunction with the weighted average method, gave good agreement with test strengths.

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The stiffened element's strength, neglecting the stiffener, equals the strength given by Section B.5.4.2 as the following demonstrates: the Section B.5.4.4 slenderness neglecting the stiffener (in which case $A_s = 0$ and $I_o = 0$) is

$$\lambda_s = 4.62\left(\frac{b}{t}\right)\sqrt{\frac{1 + A_s/(bt)}{1+\sqrt{1+\frac{10.67I_o}{bt^3}}}}$$

$$= 4.62\left(\frac{b}{t}\right)\sqrt{\frac{1+0}{1+\sqrt{1+0}}}$$

$= 3.27b/t$, and since $b = b_{5.4.2}/2$

$\lambda_s = 1.63\ b_{5.4.2}/t$, where $b_{5.4.2}/t$ is the slenderness given by Section B.5.4.2.

B.5.4.5 Round Hollow Elements and Curved Elements Supported on Both Edges

The elastic local buckling strength of an ideal cylindrical shell (pipe or round tube) in axial compression is $\frac{\pi^2 E}{16R_b/t}$. The buckling strength of actual shells, however, is strongly affected by geometric imperfections (Ziemian (2010)). Tests indicate that this effect tends to increase with increasing R_b/t. The effect of imperfections is taken into account by dividing the ideal cylinder elastic buckling strength by $\left(1+\frac{\sqrt{R_b/t}}{35}\right)^2$ which is based on tests on tubes (Clark and Rolf (1964), Weingarten, Morgan, and Seide (1965)). No post-buckling strength is included in the resulting strength of $\frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1+\frac{\sqrt{R_b/t}}{35}\right)^2}$.

The strengths given in Section B.5.4.5 are for full round tubes, and are conservative for curved elements supported on both edges (Shepherd and Ziemian (2013)). The compressive strength of curved elements with a small arc (small curvature $1/R_b$) should approach the strength of flat elements, but the strength given in Section B.5.4.5 for such elements can be considerably less than the strength of flat elements and thus can be very conservative. For a small curvature (or large radius), that is, when the central angle is less than about 20 degrees between supported edges, Section B.5.4.2 produces a greater strength (ignoring the curvature) than Section B.5.4.5.

For transversely welded cylinders with $R_b/t > 20$, Sharp (1993) showed that Section B.5.4.5 may be very unconservative. Transversely welded slender-wall cylinders may have more severe geometric imperfections than stocky-wall cylinders, and AWS D1.2:2014 does not provide dimensional tolerances on welded tubes.

B.5.4.6 Direct Strength Method

Section B.5.4.6 provides an alternate method by which a more accurate assessment of element support conditions can be used to determine the compressive strength. The use of Section B.5.4.6 for welded members is prohibited because the accuracy of this method has not been established for welded members.

Strengths determined using the provisions of this Section agree well with the test strengths reported by Bijlaard and Fisher (1952) for I shapes and square tubes.

To determine F_c, the elastic buckling stress of the column with continuous lateral support, a linear elastic analysis such as the finite strip method, by which a member is divided into strips that run the length of the member, may be used.

B.5.5 Strength of Elements in Flexural Compression

The local buckling strength of elements in flexure is not affected by welds in the tension zone of the element. Therefore, only weld-affected zones in the compression portion of the element are considered in determining the local buckling strength of these elements. Further study is required to account for the effect of the location of the weld-affected zone, which is not addressed by the *Specification*.

B.5.5.1 Flat Elements Supported on Both Edges

The coefficients in the formula for inelastic buckling strength are the same as for solid rectangular shapes. When the neutral axis is at the mid-height of the element, the equivalent slenderness is $0.65b/t$, which applies to an element in bending with both edges simply supported. Simple support is assumed because the boundary conditions at the compression edge are more important than those at the tension edge and compression elements supporting the compression flange may buckle at the same time as the web.

B.5.5.2 Flat Elements Supported on Tension Edge, Compression Edge Free

The coefficients in the formula for inelastic buckling strength are the same as for solid rectangular shapes. The equivalent slenderness of $3.5b/t$ is based on partial restraint against rotation at the supported edge.

Section B.5.5.2 is based on elastic buckling strength. This type of element is assumed to have negligible post-buckling strength.

B.5.5.3 Flat Elements Supported on Both Edges and with a Longitudinal Stiffener

The coefficients in the formula for inelastic buckling strength are the same as for solid rectangular shapes. The equivalent slenderness is $0.29b/t$ based on simple support at the edges and at the stiffener using theory from Bleich (1952).

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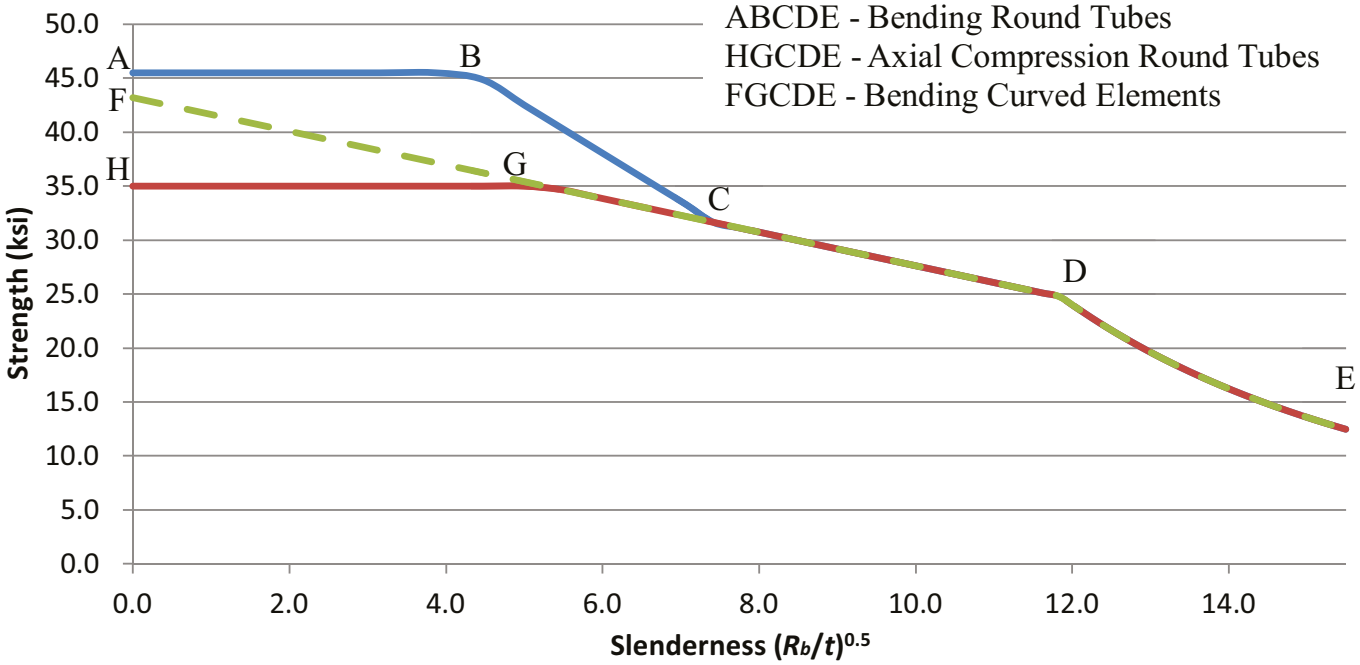

FIGURE CB.5.2
PIPES AND ROUND TUBES

Section B.5.5.3 requires that a longitudinal stiffener on a beam web shall be located so that the distance from the toe of the compression flange to the stiffener's centroid is 0.4 times the distance from the toe of the compression flange to the beam's neutral axis. This is the optimum location for increasing the buckling strength of the web. The resulting strength of the web is based on Bleich (1952). The stiffener's required moment of inertia is the same as that used in earlier ASCE specifications (1962a, 1962b), and agrees with tests by Rockey (1958). The factor α accounts for the effect of eccentricity for a stiffener on one side of the web only (Massonnet (1962)).

B.5.5.4 Pipes and Round Tubes

The inelastic buckling strength of round hollow elements (round tubes) in bending is based on experimental work by Clark and Rolf (1964).

λ_1 is the slenderness $\sqrt{R_b/t}$ at which the bending buckling strength and axial compression buckling strength curves intersect. For values of $\sqrt{R_b/t}$ greater than λ_1, the bending buckling strength is conservatively assumed to be the same as the axial compression buckling strength.

Figure CB.5.2 shows, for 6061-T6, the strength of various curved elements:

a) The uppermost four lines (ABCDE) represent the flexural compressive strength for round tubes given by Section B.5.5.4 and limited by the yield limit state of $(Z/S)F_{cy}$.

b) The lowest three lines (HGCDE) represent the axial compressive strength for round tubes given by Section B.5.4.5.

c) The dashed line (FG) represents an estimate of the flexural compressive strength for curved elements supported on both edges. Experience with building sheathing products such as corrugated roofing shows that their strength for low R/t ratios is less than that for complete cylinders.

B.5.5.5 Direct Strength Method

Sections B.5.4 and B.5.5 address the compressive strengths of beam elements assuming that the supported edges of elements are fixed against translation and free to rotate. Section B.5.5.5 provides an alternate method by which a more accurate assessment of element support conditions can be used to determine the compressive strength. Kim (2003) showed that Section B.5.5.5 is also reasonably accurate for shapes not addressed by Sections B.5.4 and B.5.5 and composed entirely of flat elements, including those with single or multiple intermediate stiffeners. The use of Section B.5.5.5 for welded members is prohibited because the accuracy of the alternate method given in Section B.5.5.5 has not been established for welded members.

When Section B.5.5.5 is used, the strength of a stiffened element need not be limited to the strength of the stiffener since the elastic buckling strength determined is the strength of the entire section, accounting for all elements.

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To determine F_e, the elastic buckling strength of the beam with continuous lateral support, a linear elastic analysis such as the finite strip method, by which a member is divided into strips that run the length of the member, may be used.

B.5.6 Elastic Buckling Stress of Elements

The elastic buckling stress of elements is the elastic local buckling stress. Since elastic local buckling stresses are used for the design of both members for compression (Chapter E) and members for flexure (Chapter F), the table of elastic local buckling stresses is provided in Chapter B.

The elastic local buckling stress F_e for elements supported on one edge and with a stiffener on the other edge is based on the effectiveness of the stiffener. When the stiffener has no effectiveness,

$$\rho_{ST} = 0 \text{ and } F_e = \frac{\pi^2 E}{(5.0b/t)^2}$$

and when the stiffener is fully effective

$$\rho_{ST} = 1 \text{ and } F_e = \frac{\pi^2 E}{(1.6b/t)^2}$$

The elastic buckling stress of elements in uniform compression is used to check the interaction between member buckling and local buckling for columns (Section E.4), and the interaction of lateral-torsional buckling and flange buckling for single web beams (Section F.4.3). This interaction can only govern if postbuckling strength is used. Postbuckling strength is used in Sections B.5.4.1, B.5.4.2, and B.5.4.3.

B.6 FABRICATION AND ERECTION

Section B.6 invokes Chapter M for fabrication and erection issues.

B.7 QUALITY CONTROL AND QUALITY ASSURANCE

Section B.7 invokes Chapter N for quality control and quality assurance issues.

B.8 EVALUATION OF EXISTING STRUCTURES

Section B.8 invokes Appendix 5 for the evaluation of existing structures.

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C.1 GENERAL STABILITY REQUIREMENTS

Design for stability includes the analysis to determine required strengths as well as proportioning the members and connections so they have adequate available strength.

C.2 CALCULATION OF REQUIRED STRENGTHS

The five factors listed in Section C.2 are the factors that must be accounted for in an accurate stability analysis of a structure.

a) The designer must determine whether connection deformations are significant and need to be considered.

b) Second-order effects are included in many structural analysis programs. To determine if a program properly includes second-order effects, the program's results can be compared to the two benchmark problems given in the AISC 2010 *Specification* commentary to Section C2.1. Most structural analysis programs that purport to address second-order effects include P-Δ effects, but some do not include P-δ effects. P-δ effects must be included in determining the required strength of individual compression members.

c) The pattern of geometric imperfections should be similar to the anticipated buckled shape of the structure and to the displacements caused by loads. Since the *Specification for Aluminum Structures* does not establish erection tolerances, Section C.2 requires that the imperfections be the tolerances specified by the designer. For example, if the maximum out-of-plumbness requirement for the structure is specified as $H/500$, then the imperfection at the top of a column relative to its base is $H/500$ where H is the height of the column.

Geometric imperfections could also be accounted for by applying equivalent notional loads to the structure that are a fraction of the gravity loads for nominally vertical and horizontal members. However, including the geometric imperfections in the analysis model is applicable to all structural configurations.

d) The factor for flexural stiffness τ_b due to inelasticity matches the factor used by AISC and ranges from 1.0 for $P_r \leq 0.5P_y$ to 0 for $P_r = P_y$. This can be addressed by using $\tau_b I$ in place of I in the analysis.

e) The 0.8 factor on member stiffness due to uncertainty in stiffness and strength is the product of the resistance factor for columns (0.90) and the reduction factor (0.85) on the buckling strength of slender columns. The 0.8 factor also accounts for additional softening under combined axial compression and bending of intermediate or stocky columns. This can be addressed by using $0.8E$ in place of E in the analysis.

The effective length method is not included in Chapter C since a second-order analysis must be made to determine if the effective length method is appropriate, and the method in Section C.2 is more direct. Also, it is often quite difficult to properly determine effective lengths. However, since Section C.1 allows any elastic method, the effective length method can be used if properly applied.

The reason for factoring ASD loads by 1.6 is that the structure may not behave linearly, which is why second-order analysis is performed. To produce the same overall result with ASD and LRFD, the ASD analysis must be done at the LRFD load level. Then, since ASD results are compared to ASD allowable stresses, the ASD results must be divided by 1.6.

The use of reduced stiffness (item e above) only pertains to analyses for strength limit states. It does not apply to analyses for other limit states such as serviceability (including deflection, vibration and period determination) and fatigue.

C.3 CALCULATION OF AVAILABLE STRENGTHS

Bracing requirements given in Appendix 6 do not apply to bracing that is included in the structural analysis performed in accordance with Section C.2.

An example of an effective length factor k less than 1 is a member fixed at one end and with translation prevented at the other end, for which k is theoretically 0.7 and is usually taken as 0.8 in practical cases.

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D.1 GENERAL PROVISIONS

The allowable tensile strength for building structures is the lesser of the two values that result from applying a safety factor of 1.65 to the yield strength of the gross section and 1.95 to the ultimate strength of the net section. These factors match those in ASCE (1962a) and ASCE (1962b) and have been used in the *Specification for Aluminum Structures* since its first edition in 1967.

D.2 TENSILE STRENGTH

The axial tensile strength is the lesser of 1) the yield strength of the gross section and 2) the ultimate (rupture) strength of the net section. This is because the net section usually exists over only a short portion of the overall length of the member, and the elongation of the member resulting from yielding across the net section is small. Thus, yielding on the net section is not a limit state.

The strength of tension members with transverse welds is limited by the strength of the transverse weld. Transverse welds are welds with an axis perpendicular to the member axis. If the entire cross section of the member is weld-affected, the tensile strength is $F_{tuw} A_e$. Yielding at a transverse weld is not a limit state, because, in a similar manner as for yielding at the net section, the elongation of the member resulting from yielding across a transverse weld is small.

Longitudinal welds are welds with an axis parallel to the member axis. Usually only part of the cross section of longitudinally welded members is weld affected. The strength of a cross section with only part of its area weld affected can be estimated by adding up the strength of the material in the weld-affected zone and the unaffected material outside this zone (Hill, et al. (1962)). Hill and Brungraber (1962) showed that for members with part of the section weld-affected, the strength is the sum of the strength of the weld-affected material and the strength of the non-weld-affected material.

D.3 AREA DETERMINATION

D.3.1 Net Area

Figures CD.3.1 and CD.3.2 illustrate the notation of this Section. The net section area for the bar shown in Figure CD.3.1 is

$$A_{net} = (b - 2d + \frac{s^2}{4g})t$$

where t is the thickness of the bar and d is the diameter of the hole. In Figure CD.3.2, the angle section is flattened out into a bar for the purpose of calculating the net section. The flattened width is $a + b - t$.

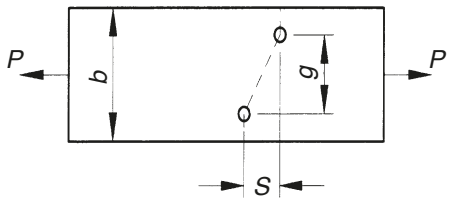

Figure CD.3.1
BAR IN TENSION

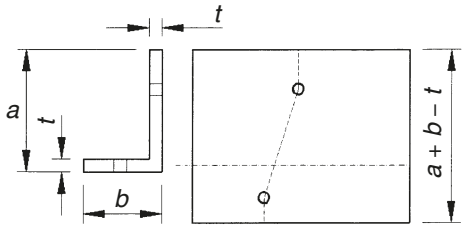

Figure CD.3.2
ANGLE IN TENSION

For staggered holes in shapes with different thickness elements (for example, staggered holes in a channel flange and web), the *Specification* does not address the thickness to be used to determine the net area from the net width based on the $s^2/4g$ rule. A possible approach in this instance is to use the weighted average thickness (weighted by the length of the failure path in a given element) (see Gaylord et al. (1992)).

The effective width of punched holes is the hole diameter + 1/32 in. (0.8 mm) to account for break-out on the back side of the part that punching may cause.

D.3.2 Effective Net Area

May and Menzemer (2005) showed that the effective area in tension is less than the net area due to the non-uniform stress distribution across the section at the connection for angles, tees, and channels connected by some but not all of their elements. This is accounted for by using the effective net area to calculate the tensile stress in the section. Designers should not combine bending stress due to the connection eccentricity with axial stress on the effective net area since the effect of the eccentricity is accounted for in the effective net area determination.

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To determine the eccentricities:

a) For tees connected only by their flanges (Figure CD.3.3(a)), the eccentricity in the *y* direction is the distance from the outside face of the flange to the neutral axis of the tee parallel to the flange. The eccentricity in the *x* direction is zero. For I-shaped sections connected only by their flanges (Figure CD.3.3(b)), split the section at the neutral axis parallel to the flanges to create two tees.

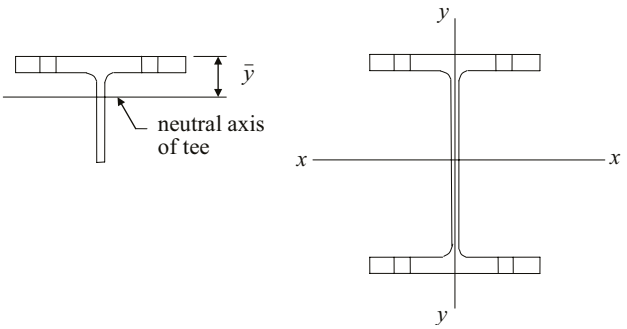

Figure CD.3.3

b) For channels connected only by their webs the eccentricities are as shown in Figure CD.3.4.

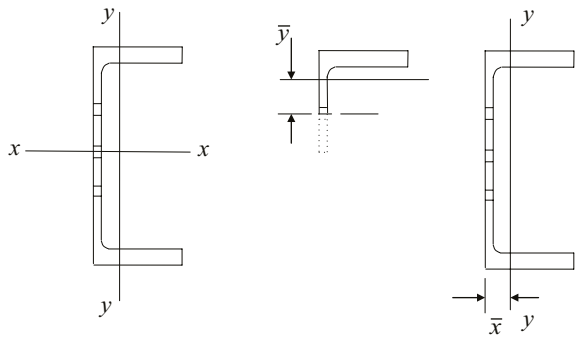

Figure CD.3.4

c) For angles connected only by one leg, the eccentricity in one direction is the distance from the face of the connected leg to the neutral axis of the angle parallel to the connected leg (Figure CD.3.5(a)). The eccentricity in the other direction is determined from a section obtained by subtracting the portion of the connected leg outside the centerline of the fastener closest to the unconnected leg. The eccentricity is the distance perpendicular to the unconnected leg from the centerline of the fastener closest to the unconnected leg to the neutral axis of the remaining section (Figure CD.3.5(b)).

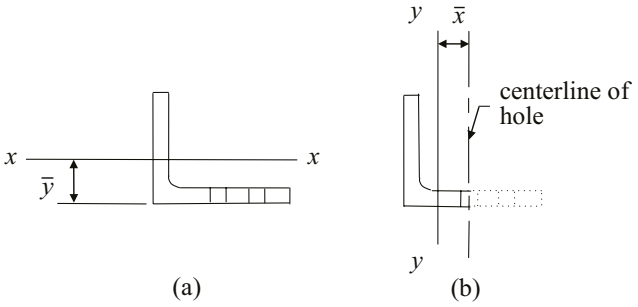

Figure CD.3.5

d) For I beams connected only by the web, eccentricities are determined as shown in Figure CD.3.6.

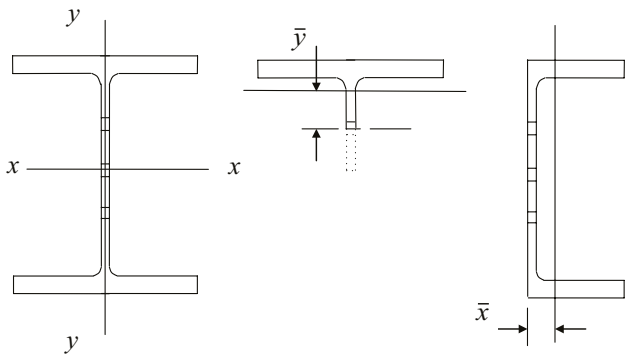

Figure CD.3.6

If there is only one row of bolts in the direction of load or the only weld has an axis perpendicular to the direction of load, the length of the connection *L* is zero and the effective net area is the net area of the connected elements.

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E.1 GENERAL PROVISIONS

Because column member buckling strength (E.2) did not account for an approximate 0.85 factor on strength due to standard tolerance on out-of-straightness, the safety factor for column member buckling for members designed using this *Specification* prior to 2010 was actually about (0.85)(1.95) = 1.66. The 2010 *Specification* included the 0.85 factor in the column member buckling strength but the safety factor changed from 1.95 to 1.65, so column member buckling allowable strengths did not change in the 2010 *Specification*.

The safety factor for column local buckling strength of 1.65 is consistent with the safety factor for local buckling of beams. Unlike member buckling, local buckling strengths need not be reduced for out-of-straightness since Sharp (1993) notes that "the practical plate with initial crookedness … has essentially the same strength as that for the perfectly flat plate."

E.2 MEMBER BUCKLING

When the member slenderness exceeds C_c, the buckling strength is based on the elastic buckling strength, also called the Euler buckling strength. When slenderness is less than C_c, Templin, et al. (1938) and Clark and Rolf (1966) showed that the inelastic buckling strength is approximated closely by a straight line.

Hill and Clark (1956) and Batterman and Johnson (1967) showed that load eccentricity and initial crookedness reduce the buckling strength. Sharp (1993) showed that strength of a 6061-T6 column that is out-of-straight by standard mill tolerance is about 83% of the strength of a perfectly straight column. This *Specification* uses a 0.85 factor on elastic member buckling strength to account for these effects in the elastic buckling range. In the inelastic buckling range the factor for out-of-straightness varies from 0.85 at the intersection of elastic and inelastic buckling to 1.0 at the intersection of yielding and inelastic buckling.

For very short columns, the compressive strength is the compressive yield strength. Such columns are sometimes referred to as stub columns, for which the limit state is yielding rather than buckling.

Brungraber and Clark (1962) investigated the strength of welded aluminum compression members. Welding can affect a member's compression strength by reducing strength in the heat-affected zone, causing residual stresses, and distorting the member shape.

Sharp (1993) showed that for calculating the member buckling strength, the buckling formula constants given in Table B.4.1 (non-artificially aged tempers) best represent weld-affected material.

Transverse welds not at the ends of a column supported on both ends or in a cantilever column may appreciably decrease the member buckling strength. Sharp (1993) showed that for these cases the strength calculated as though the entire column were of welded material is conservative.

If a column has both longitudinal and transverse welds, the strength determined considering the transverse welds usually is less than the strength determined considering the longitudinal welds.

The strength of a cross section with only part of its area heat affected (typically the case with longitudinally welded members) can be estimated by adding up the strength of the material in the heat-affected zone and the unaffected material outside this zone (Hill, et al. (1962)).

E.2.1 Flexural Buckling

For flexural buckling, the slenderness kL/r is the greater of the slenderness ratios taken about each of the principal axes of the member. Chapuis and Galambos (1982) addressed the effective length of aluminum columns as a factor k times the length of the column L between lateral supports.

E.2.2 Torsional and Flexural-Torsional Buckling

Section E.2.2 is similar to the AISC (2010) Section E4 for torsional and flexural-torsional buckling. Based on data provided by Abramson (1977), Sharp (1993) showed that the member buckling strength equations of Section E.2 can be used for torsional-flexural buckling if an equivalent slenderness is defined. The equivalent slenderness $\lambda = \pi\sqrt{\frac{E}{F_e}}$ is based on the elastic torsional-flexural buckling stress, which may be determined using the equations given in Section E.2.2 or by another method such as finite strip analysis.

For point-symmetric sections such as cruciforms, torsional buckling is the most likely mode of failure and F_e equals F_{et}.

E.3 LOCAL BUCKLING

The strength of elements with welds that are not along the element edges may have less strength than elements without welds for two reasons:

1) Welding reduces the yield and ultimate strength of the metal. This can be accounted for by using the welded yield strength and welded buckling constants to determine the element strength.

2) Welding may introduce distortions. AWS D1.2 Section 4.19.4 requires a flatness tolerance on welded webs of $d/100$, where d = web depth, and Section 4.19.5 requires a flatness tolerance of $w/100 < 0.25$ in. (6 mm) on welded flanges, where w = full width of the flange. For extrusions,

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Aluminum Standards and Data 2017 Table 11.8 requires a flatness tolerance of 0.4% to 1.4% of the width, depending on part thickness and width, being greater for thin parts and large widths. For sheet and plate, *Aluminum Standards and Data 2017* Table 7.17 requires a flatness tolerance of 0.5% to 1.3% of the width. Since the flatness tolerances for unwelded mill products and welded parts are approximately the same, distortions are not greater in welded elements than unwelded elements, and their strengths should not differ because of distortions.

Sharp (1993) Figure 7.9 shows that the compressive strength of longitudinally edge-welded elements is slightly less than the unwelded strength, and considerably greater than the all-welded strength. The flatness tolerance for the test specimens ranged from 0.1% to 0.7% of the width. Sharp noted that "Welds decreased the strength compared to unwelded plates but the decrease was not as much as that calculated for all-welded material". Compressive tests on welded aluminum plates (Conley, et al. (1963)) have demonstrated that the welds have little effect on postbuckling strength. To account for the reduction in strength in the weld-affected zone, a weighted average method is used.

E.3.1 Weighted Average Local Method

Crocket (1942) showed that the local buckling strength of a member is the sum of the local buckling strength of the member's elements. The compressive strength of portions of a column at the intersection of elements (for example, at the web-flange juncture in a channel) is taken as F_{cy} since this material does not buckle locally and is not included in the area of the flange element or the web element.

E.3.2 Direct Strength Method

The direct strength method for determining the local buckling stress is described in Section B.5.4.6.

E.4 INTERACTION BETWEEN MEMBER BUCKLING AND LOCAL BUCKLING

Sections B.5.4.1 and B.5.4.2 take advantage of the post-buckling strength of certain types of elements, because such elements may buckle elastically without causing failure of the member. However, if the elastic local buckling stress of the section is less than the member buckling strength of the column, the reduced stiffness that accompanies local buckling when post-buckling strength is used may reduce the member buckling strength. Sharp (1970) developed the strength equation given in Section E.4 to address this interaction between member buckling and local buckling. In Figure CE.4.1 Sharp's equation and the finite strip method are compared to the results of compression tests on H beams and square tube columns both with slender elements reported by Bijlaard and Fisher (1952).

The interaction between member buckling and local buckling is more likely to govern the strength when an element of the member has a large slenderness.

The elastic local buckling strengths given in Table B.5.1 are accurate for square tube shapes and conservative for other shapes. These values can be quite conservative for sections with elements whose edge restraint is more rigid than an element that is simply supported. Section E.3.2 provides a more accurate and less conservative method to determine the strength in such cases.

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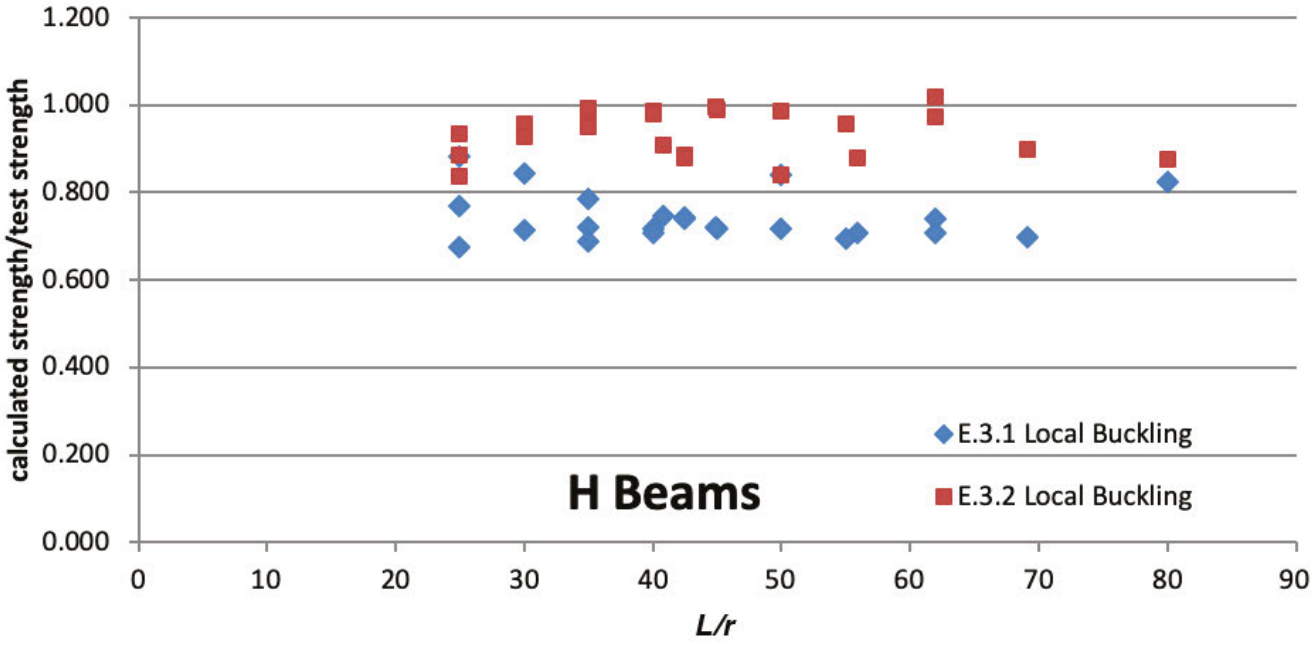

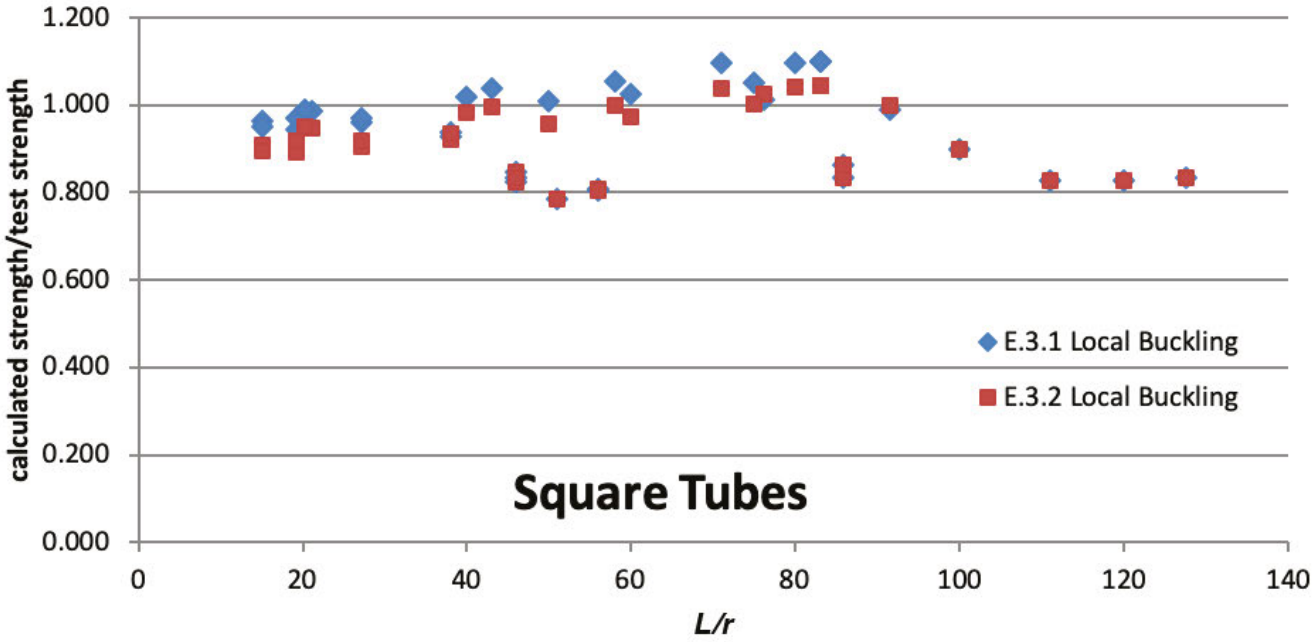

Figure CE.4.1

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When a transverse load parallel to a principal axis does not act through the shear center, the load can be resolved into a transverse load through the shear center and a torque.

F.1 GENERAL PROVISIONS

Resistance and safety factors are discussed in Sections B.3.2.1 and B.3.2.2.

F.2 YIELDING AND RUPTURE

In *Specification* editions prior to 2015, the compressive yield, tensile yield, and tensile rupture strengths for beams used the relationship between the plastic section modulus for the rigid-plastic case Z and the plastic section modulus for yield Z_y and for ultimate strength Z_u established by Sharp (1993). To define the yield limit state, Sharp plotted the "apparent stress" equal to the moment divided by the elastic section modulus. He determined the moment by integrating the area under the stress-strain curve (representing the stress distribution as a function of distance from the neutral axis) times the strain. Finally, he determined the 0.2% offset stress of this apparent stress as the yield stress.

This method is overly conservative and inconsistent with the AISC yield limit state. Since aluminum alloys provide strain hardening after yield, their post-yield capacity is greater than elastic-plastic materials such as mild carbon steel for the same yield strength (see Figure CF.2.1). Also, the bending moment at which the extreme fiber reaches the tensile ultimate strength determined by integrating aluminum alloy stress-strain curves is within 10% of the moment determined from the plastic section modulus. Therefore, the full plastic moment is now used to establish aluminum yield and rupture limit states.

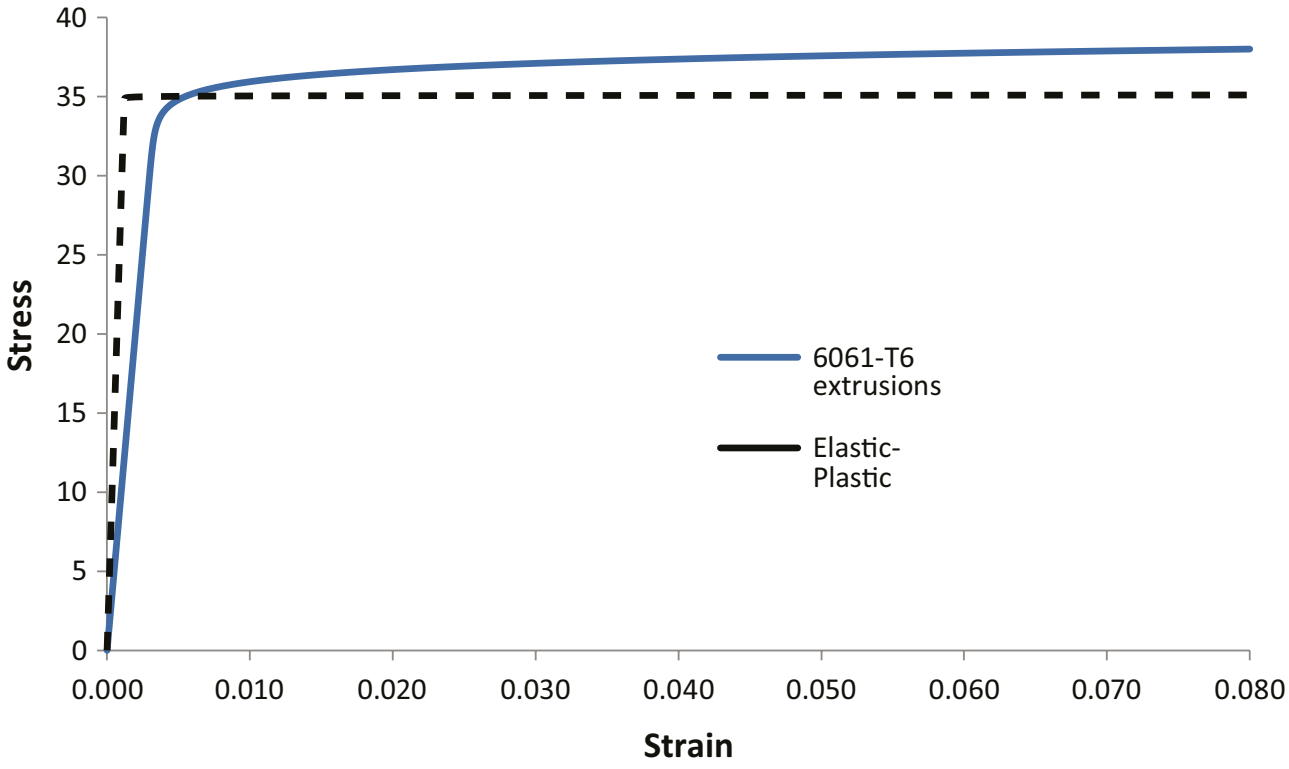

Figure CF.2.1

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The plastic modulus Z is determined by first locating the plastic neutral axis (PNA) as shown in Figure CF.2.2. The PNA is defined as the axis that divides the cross section such that the compression force from the cross sectional area in compression A_c equals the tension force from the cross sectional area in tension A_t. For members with all the material on the compression side of the neutral axis having the same yield strength F_{cy}, and all the material on the tension side of the neutral axis having the same yield strength F_{ty}:

$$F_{ty} A_t = F_{cy} A_c$$

Since $A_t + A_c = A$,

$$A_t = A F_{cy}/(F_{ty} + F_{cy}) \text{ and } A_c = A F_{ty}/(F_{ty} + F_{cy})$$

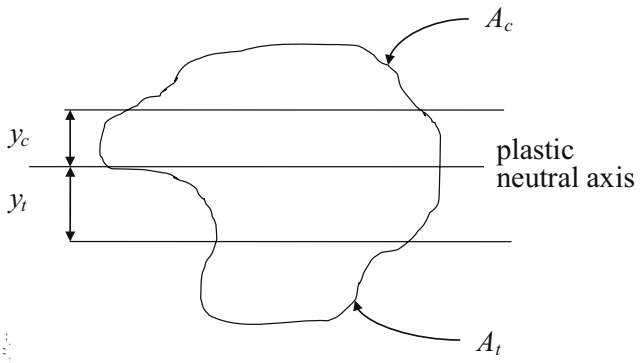

Figure CF.2.2

If $F_{ty} = F_{cy}$, then the PNA is the axis that divides the shape into two halves of equal area ($A_t = A_c$).

The plastic section modulus is the sum of the products of the areas of the cross section on each side of the PNA and the distance from the centroids of the two areas to the PNA.

$$Z = A_t y_t + A_c y_c = A_t (y_t + y_c F_{ty}/F_{cy}) = A_c (y_c + y_t F_{cy}/F_{ty})$$

The plastic moment is

$$M_{np} = F_{ty} A_t (y_t + y_c) = F_{cy} A_c (y_t + y_c)$$
$$M_{np} = F_{ty} Z_t = F_{cy} Z_c$$

where $Z_t = A_t (y_t + y_c)$ and $Z_c = A_c (y_t + y_c)$

For heat-treatable alloys, the compressive yield strength and the tensile yield strength are equal and for non-heat-treatable alloys, the compressive yield strength F_{cy} is nominally 90% of the tensile yield strength F_{ty}. The *Specification* conservatively uses F_{cy} to determine the yield moment so that only one plastic modulus needs to be determined.

The plastic modulus is limited to 1.5S to preclude yielding at service loads.

The ability of compact wrought aluminum shapes to deform plastically is required for unwelded aluminum by ASTM B209 and for welded aluminum by D1.2, which both require that specimens be capable of being bent 180° around a pin of a specified diameter. The ability of aluminum castings to deform plastically is not required by material or welding specifications. In fact, D1.2 requires a notched specimen fracture test instead of a bend test for weldments involving castings. Therefore, the limit state strength for yielding of castings is the lesser of $S_t F_{ty}$ and $S_c F_{cy}$

The Ramberg-Osgood equation for the stress-strain curve for a given aluminum alloy-temper can be determined using minimum specified values for the 0.2% yield stress F_{ty}, the ultimate stress F_{tu}, the modulus of elasticity E, and the strain at rupture ε_u: $\varepsilon = F/E + 0.002(F/F_{ty})^n$, where n is determined by substituting the ultimate stress and strain at rupture.

The bending moment at which the extreme fiber of a rectangular bar reaches F_{tu} can then be determined by numerically integrating the stress-strain curve. This moment can be compared to the allowable moment, determined as the lesser of ZF_{ty}/Ω_y and ZF_{tu}/Ω_u, to determine the actual safety factor Ω on rupture. The safety factors thus determined are tabulated below. The safety factor may be greater than 1.95 (the rupture safety factor) if yield governs, which occurs in the tabulated examples below for yield-to-ultimate strength ratios of 0.74 or less. The results show that the modulus of elasticity E and ultimate strain ε_u have little effect on the actual safety factor.

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ACTUAL SAFETY FACTOR ON FLEXURAL RUPTURE FOR VARIOUS ALLOY-TEMPERS BASED ON THE STRESS-STRAIN CURVE, LIMITING THE MOMENT TO THE LESSER OF ZF_{ty}/Ω_y AND ZF_{tu}/Ω_u

alloy-temper	E ksi	F_{ty} ksi	F_{tu} ksi	F_{ty}/F_{tu}	ε_u	Ω
2014-T6	10,800	53	60	0.88	0.07	1.91
5052-H32	10,100	23	31	0.74	0.11	2.14
5083-O	10,300	18	40	0.45	0.16	3.35
5083-H116	10,300	31	44	0.70	0.12	2.24
6061-T6 plate	10,000	35	42	0.83	0.10	1.93
6061-T6 extrusion	10,000	35	38	0.92	0.08	1.92
6063-T5	10,000	16	22	0.73	0.08	2.17
6063-T6	10,000	25	30	0.83	0.10	1.93

The safety factors in the table above are great enough to justify using the plastic modulus. In the case of 2014-T6 above and other alloy-tempers not listed above for which $k_t > 1$, the available rupture moment would be further reduced by the tension coefficient k_t to account for notch sensitivity.

F.3 LOCAL BUCKLING

The *Specification* provides three methods for determining the local buckling strength.

F.3.1 Weighted Average Method

Using equation F.3-1, the weighted average method combines strengths determined separately for each element from the *Specification* Sections B.5.4.1 through B.5.4.5 and Sections B.5.5.1 through B.5.5.4. This method was originally based on tests by Jombock and Clark (1968) of formed sheet beams and used for the weighted average compression and tensile bending strengths in *Specification* editions prior to 2005. Kim (2003) improved the weighted average method accuracy for a variety of members, as illustrated in Figure CF.3.1. The distance c for a compression flange is the distance to its centerline because buckling is based on the flange's average stress.

For beams composed of a single element, the weighted average local buckling strength is the local buckling strength of the element. For example, the weighted average local buckling strength of a round tube is simply the local buckling strength of the tube determined using Section B.5.5.4.

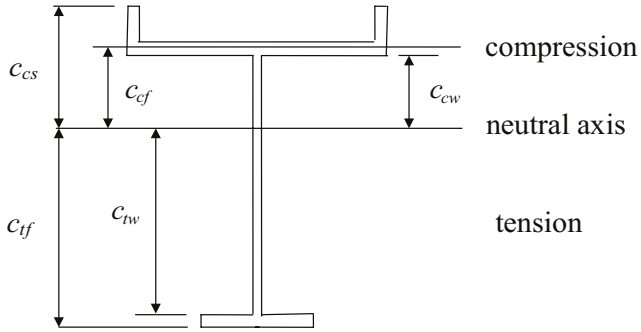

Figure CF.3.1

F.3.2 Direct Strength Method

In the direct strength method, the local buckling strength of the shape as a whole is determined by analysis such as the finite strip method which directly includes the interaction of the elements. This method is the most accurate of the three methods, and is based on the approach proposed by Kissell (2013). The advantage of this method is that the only section properties required to determine the local buckling strength are the plastic and elastic section moduli.

F.3.3 Limiting Element Method

This method limits the flexural stress in any element of the shape to the local buckling stress of that element. This method is less accurate because it does not account for interaction between elements.

F.4 LATERAL-TORSIONAL BUCKLING

Lateral-torsional buckling strengths are based on a beam

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with its ends prevented from lateral deflection and axial rotation but free to rotate about the vertical axis.

In the 2010 *Specification* and earlier editions, in the inelastic stress range the lateral-torsional buckling strength equation employed the straight line approximation to the tangent modulus buckling curve used for columns. Tests showed this curve to be conservative for beams (Clark and Rolf (1966)). In the 2015 *Specification*, the inelastic buckling strength is $M_{np}(1 - \lambda/C_c) + \pi^2 E \lambda S_{xc}/C_c^3$ so that beam strength is not limited to $B_c S_{xc}$, but rather to the plastic strength of the shape. For $\lambda = 0$, the strength is M_{np}, the plastic strength, and for $\lambda = C_c$, the strength is $\frac{\pi^2 E S_{xc}}{C_c^2}$, the elastic buckling strength.

Lateral-torsional buckling strengths of I-shapes determined in accordance with the *Specification* agree well with tests conducted by Wang, et al. (2012), and Guo, et al. (2015).

Sharp (1993) noted that there has been little investigation of the effect of welds on the lateral-torsional buckling strength of beams, but it is expected that the effect is similar to the effect of welds on columns. This approach is used in the *Specification*.

Lateral-torsional buckling can occur for beams bent about any axis. The *Specification* does not limit the lateral-torsional buckling strength check to beams bent about a major axis.

F.4.1 Bending Coefficient C_b

The bending coefficient is applied to segments of beams between brace points. Inflection points are not brace points.

The lateral-torsional buckling strengths given in Section F.4 are based on a uniform moment over the unbraced length. If the moment varies over the unbraced length, the lateral-torsional buckling strength is greater than the strength given by Section F.4. This strength increase can be accounted for by using the bending coefficient C_b given in F.4.1 provided by Wong and Driver (2010) and in the SSRC Guide 6th edition.

F.4.1.1 Members Supported on Both Ends

The formula for the bending coefficient C_b is equation 5.15d (modified by equation 5.16a (R_m in F.4.1.1) to address singly-

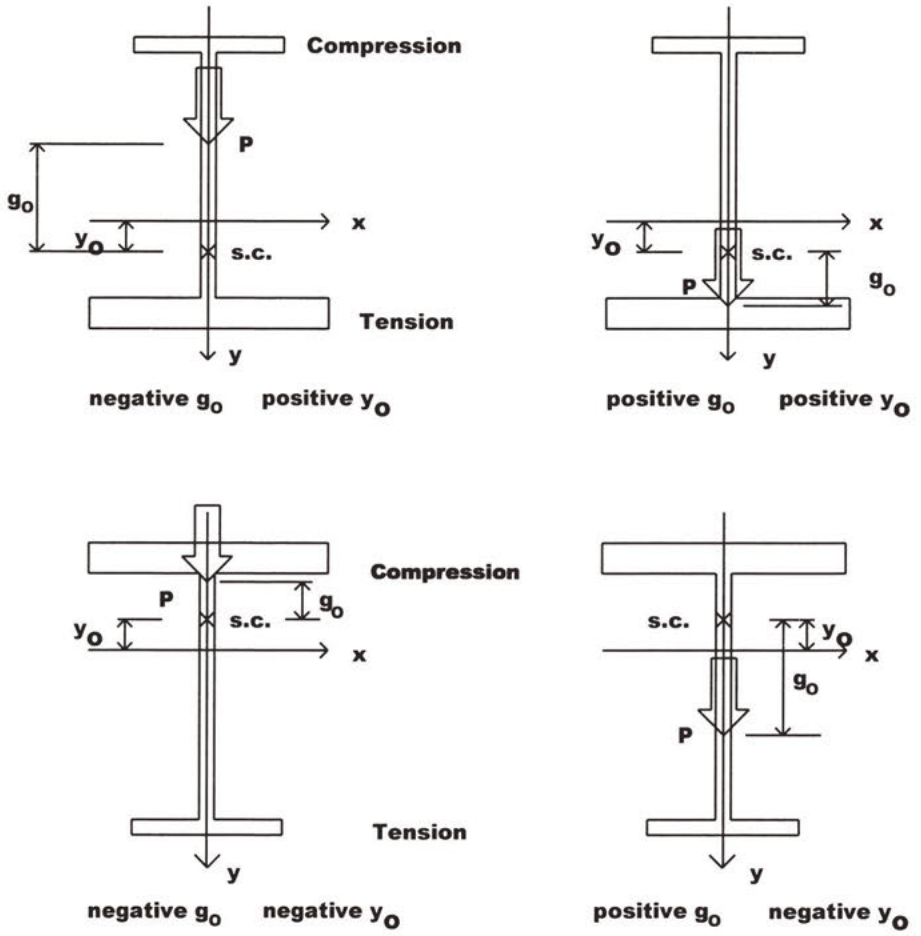

Figure CF.4.1
ORIENTATION OF THE AXES AND CROSS-SECTIONAL NOTATION

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symmetric beams subjected to double-curvature bending) given in the SSRC Guide 6th edition. The R_m expression applies only for members subjected to transverse loading, and not to members with only end moments. For double-curvature cases, one value for C_b is computed for the unbraced segment, but two elastic buckling strengths must be determined – one for the portion of the segment for which one flange is in compression, and one for the portion of the segment for which the other flange is in compression, and each is compared to the maximum moment in their respective portion of the segment.

Kitipornchai (1986) showed that if one of the two flanges is so small that $I_{yc}/I_y \le 0.1$ or $I_{yc}/I_y \ge 0.9$, C_b should be taken as 1.0. C_b should also be taken as 1.0 if rotational restraint is considered ($k_y < 1$) since Equation F.4-2 overestimates C_b when the unbraced length is factored by a k_y less than 1.

The 2016 AISC *Specification* Commentary addresses C_b for beams with continuous bracing on one flange.

F.4.1.2 Cantilevers

If the free end of a cantilever is torsionally braced, equation F.4-2 can be used to compute C_b. The SSRC Guide 6th edition Section 5.2.9 provides additional information on cantilevers.

F.4.2 Slenderness for Lateral-Torsional Buckling

F.4.2.1 Shapes Symmetric About the Bending Axis

The equation for M_e for any shape given in Section F.4.2.5 becomes, for shapes symmetric about the bending axis (in which case $\beta_x = 0$), assuming $C_1 = 0.5$ and that $g_o = \pm d/2$ so that $U = \pm d/4$:

$$M_e = \frac{\pi^2 E I_y}{(k_y L_b)^2}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right]$$

Combining the Section F.4.2.1 expression for the slenderness for shapes symmetric about the bending axis $\lambda = \frac{k_y L_b}{r_{ye}\sqrt{C_b}}$ and $\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}}$ gives

$$r_{ye} = \frac{k_y L_b}{\pi}\sqrt{\frac{M_e}{ES_x}}$$

Substituting for M_e in the equation above gives

$$r_{ye} = \frac{k_y L_b}{\pi}\sqrt{\frac{\pi^2 E I_y}{ES_x(k_y L_b)^2}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right]}$$

which simplifies to

$$r_{ye} = \sqrt{\frac{I_y}{S_x}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right]}$$

If the load is applied at the shear center, the d terms go to zero, giving

$$r_{ye} = \sqrt{\frac{I_y}{S_x}\sqrt{\frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}} =$$

$$\sqrt{\frac{\sqrt{I_y}}{S_x}\sqrt{C_w\left(\frac{k_y}{k_z}\right) + 0.038J(k_y L_b)^2}} \ .$$

If the torsional resistance to LTB is neglected k_y and k_z are taken as 1, and only the warping resistance is included, a reasonable and conservative approximation for open shapes,

$$r_{ye} = \sqrt{\frac{\sqrt{I_y}}{S_x}\sqrt{C_w}}$$

$S_x = 2I_x/d$, and for symmetric I-shaped members $C_w = I_y d^2/4$, so

$$r_{ye} = \frac{d}{2}\sqrt{\frac{I_y}{I_x}} = \frac{d}{2}\sqrt{\frac{r_y^2}{r_x^2}} = \frac{r_y d}{2r_x} \ .$$

For Aluminum Association standard I beams, $r_x \approx d/2.4$ so

$$r_{ye} = \frac{r_y d}{2(d/2.4)} = 1.2r_y \ .$$

This approximation ($r_y d/(2r_x)$ or $1.2r_y$) gives very conservative results for values of L_b/r_y exceeding about 50 and for beams with transverse loads applied in a direction away from the beam's shear center.

Figure CF.4.2 compares the slenderness ratios of 16 Aluminum Association Standard I-beams using $1.2r_y$ and r_{ye} given by equation F.4-4. Sharp's (1993) comparison of test data and calculations shows that using r_{ye} is conservative.

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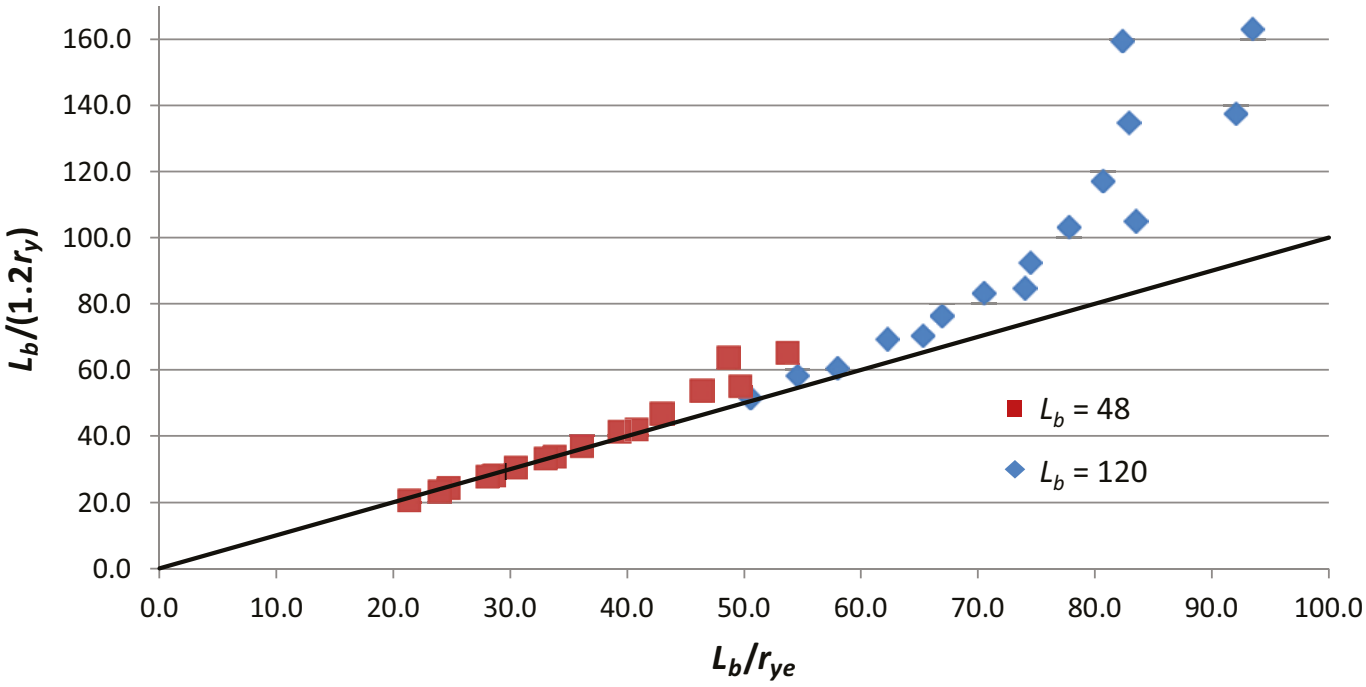

Figure CF.4.2
COMPARING LTB SLENDERNESS RATIOS FOR AA STANDARD W SHAPES

Section F.4.2.1 applies to any shape (open or closed) symmetric about the bending axis, without a transverse load or with a transverse load applied at either extreme fiber toward or away from the shear center.

In Sections F.4.2.1, F.4.2.3, F.4.2.4, and F.4.2.5, effective length factors k_y and k_z are taken as 1. This is because this is conservative for beams supported on both ends, and effective length factors cannot be accurately determined in cases other than single spans with well-defined, ideal support conditions. For beams free to rotate laterally at both ends (pinned supports), $k_y = 1$, and for beams restrained against lateral rotation at both ends (fixed supports), $k_y = 0.5$. For cantilevered beams, k_y may be as large as 2. For beams restrained against twist (rotation about their longitudinal axis) at both ends (the condition required by Chapter F), $k_z = 1.0$, and for beams restrained against twist and warping at both ends, $k_z = 0.5$. These effective length factors are for ideal support conditions; the values achieved in practice differ and may be estimated using the Commentary to Appendix 7 of the AISC *Specification for Structural Steel Buildings* (2016).

When $C_w = 0$, as for closed shapes, the equations given in F.4.2.1 reduce to the simpler expression for the slenderness of closed shapes given in Section F.4.2.3.

Selection of the proper equation for r_{ye} is illustrated by Figure CF.4.3. At point B for both beams, use Equation F.4-4. Use the same equation for point A if the distributed load is applied at the level of the neutral axis. If the distributed load is not applied at the level of the neutral axis, use Equation F.4-5.

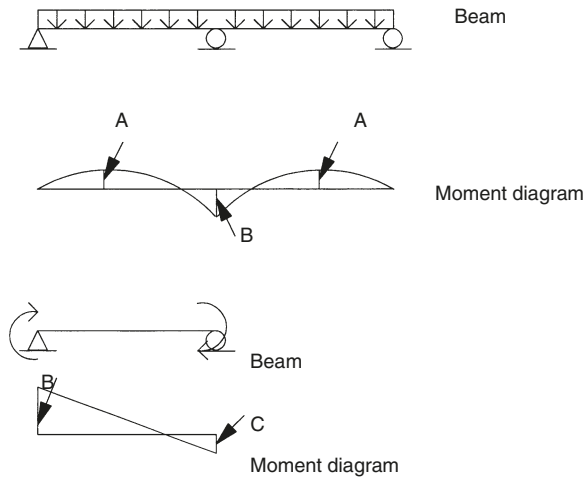

Figure CF.4.3 BEAM AND MOMENT DIAGRAM EXAMPLES

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F.4.2.2 Singly Symmetric Open Shapes Unsymmetric About the Bending Axis

For singly symmetric shapes that are unsymmetrical about the bending axis, an approximate bending strength can be determined using Section F.4.2.1 to determine r_{ye} taking r_y, I_y, S_x and J as though both flanges were the same as the compression flange with the overall depth remaining the same. This approximation is conservative when the smaller flange is in compression. The *Specification* prohibits using the approximation when the larger flange is in compression since the approximation is unconservative in this case. Section F.4.2.5 applies to all shapes, symmetric or unsymmetric about the bending axis, and is more accurate than Section F.4.2.2.

Winter (1941) determined a method for taking advantage of the effect of bracing the tension flange. He derived the elastic critical moment M_e for pure bending for an I-section with the tension flange prevented from lateral displacement but free to rotate:

$$M_e = \frac{EI_{yc}\, d\pi^2}{L_b^{\,2}} + \frac{GJ}{d}$$

where I_{yc} is the moment of inertia of the compression flange about the web. λ can be evaluated for this case using this M_e in $\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}}$, regardless of the size of the tension flange.

F.4.2.3 Closed Shapes

From the Commentary Section F.4.2.1 expression for the elastic buckling moment for shapes symmetric about the bending axis

$$M_e = \frac{\pi^2 EI_y}{(k_y L_b)^2}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right],$$

substituting $C_w = 0$ (an accurate approximation for tubes), and loading at the shear center so the d terms go to zero gives $M_e = \frac{0.195\pi^2 E}{k_y L_b}\sqrt{I_y J}$.

Combining this with $\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}}$ gives $\lambda = 2.3\sqrt{\frac{k_y L_b S_{xc}}{C_b\sqrt{I_y J}}}$ the slenderness given for closed shapes in Section F.4.2.3.

For shapes unsymmetric about the bending axis loaded at the shear center $U = \beta_x/4$ assuming $C_2 = 0.5$. Conservatively assuming (as above) $C_w = 0$ for tubes, and substituting $U = \beta_x/4$ into the Section F.4.2.5 equation for M_e,

$$M_e = \frac{\pi^2 EI_y}{(k_y L_b)^2}\left[\frac{\beta_x}{4} + \sqrt{\frac{\beta_x^{\,2}}{16} + \frac{0.038J(k_y L_b)^2}{I_y}}\right]$$

For unsymmetric shapes β_x is on the order of d. Tubes have a relatively large torsion constant, so for them the $\sqrt{\frac{d^2}{16} + \frac{0.038JL_b^{\,2}}{I_y}}$ term is much larger than $d/4$ so neglecting the effect of unsymmetry has little effect on the calculated strength.

Closed shapes are defined in the glossary as hollow shapes that resist lateral-torsional buckling primarily by torsional resistance rather than warping resistance. The wall thickness need not be uniform.

As shown above, the slenderness of a closed shape $2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}}$, was derived using the general theoretical equation for lateral buckling strength given in Section F.2.2.5 without transverse loads or with transverse loads applied at the shear center, assuming symmetry about the bending axis, and ignoring the warping resistance C_w of the beam, since, for closed shapes, this term is usually small in comparison to the term $0.038JL_b^2$ that represents St. Venant torsion. If C_w is not small compared to $0.038JL_b^2$, Section F.4.2.1 gives more accurate and less conservative results for shapes symmetric about the bending axis and Section F.4.2.5 gives more accurate results for shapes unsymmetric about the bending axis.

F.4.2.4 Rectangular Bars

Using the Commentary Section F.4.2.1 expression for the elastic buckling moment for shapes symmetric about the bending axis,

$$M_e = \frac{\pi^2 EI_y}{(k_y L_b)^2}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{0.038J(k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right],$$

substituting $C_w = 0$ (an accurate approximation for bars), and loading at the shear center, gives

$$M_e = \frac{0.195\pi^2 E}{k_b L_y}\sqrt{I_y J} \quad .$$

Combining this with $\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}}$ and recognizing for rectangular bars, $J = dt^3/3$, $I_y = dt^3/12$, and $S_x = td^2/6$ gives:

$\lambda = \frac{2.3}{t}\sqrt{\frac{k_y L_b d}{C_b}}$, the slenderness given for rectangular bars in Section F.4.2.4.

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Clark and Rolf (1966) showed that using this slenderness to determine lateral-torsional buckling strength agrees well with the results of tests of rectangular bars.

F.4.2.5 Any Shape

Section F.4.2.5 applies to shapes symmetric about the bending axis as well as shapes unsymmetric about the bending axis. However, Section F.4.2.1 gives the same results as F.4.2.5 for shapes symmetric about the bending axis and is easier to apply.

The slenderness for any shape ($\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}}$) is derived by combining the equation for a beam's elastic stress $f_e = C_b M_e / S_{xc}$ and the equation for elastic buckling stress $f_e = \frac{\pi^2 E}{\lambda^2}$.

Section F.4.2.5 applies to any beam bent by moments or by lateral loads applied through the shear center of the section.

The expression $M_e = A_g F_{ey}\left[U + \sqrt{U^2 + r_o^2\left(\frac{F_{ez}}{F_{ey}}\right)}\right]$

where $U = C_1 g_0 + C_2 \beta_x/2$ was derived by Clark and Hill (1960) based on elastic buckling theory. This expression considers non-symmetry of the section about the bending axis as well as the location of the laterally applied load with respect to the shear center. (Alternately, the elastic buckling moment can be determined by other methods, such as finite strip analysis).

Substituting for $F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_b)^2}\right)$,

$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_b}{r_y}\right)^2}$, and $G = 3E/8$

$M_e = \frac{\pi^2 E I_y}{(k_y L_b)^2}\left[U + \sqrt{U^2 + \frac{0.038 J (k_y L_b)^2}{I_y} + \frac{C_w}{I_y}\left(\frac{k_y}{k_z}\right)}\right]$

The orientation of the axes and the cross-sectional notation are illustrated in Figure CF.4.1. The magnitudes of y_o (positive if the loading places the smaller flange in compression, and dependent on the location of the shear center), torsion constant J and the warping constant C_w can be determined from references such as Roark and Young (1989). The approximate formula for β_x given in Equation F.4-12 is based on work by Kitipornchai et al. (1986).

For continuous beams there are no directly derived values of C_1 and C_2. For this reason, rational analysis must be used in estimating the values of these coefficients for such applications. For loading shown in Figure CF.4.1, conservative results are obtained by taking:

$C_1 = 0.41C_b$ and $C_2 = 0.47C_b$ when the smaller (top) flange is in compression (shown in the top two cases of Figure CF.4.1) and

$C_1 = 0$ and $C_2 = 0$ when the larger (top) flange is in compression (shown in the bottom two cases of Figure CF.4.1).

The coefficient C_1 is not needed when $g_o = 0$, that is, when there is no transverse load or the transverse load is applied at the shear center. The coefficient C_2 is not needed when the beam is symmetric about the bending axis. For beams unsymmetric about the bending axis and with transverse loads not applied at the shear center, the coefficients C_1 and C_2 approximately equal 0.5, but depend on the beam's shape and loading. For simply supported singly symmetric shapes with $0.1 < I_{yc}/I_y < 0.9$:

a) For a uniformly distributed load over the entire span,
$C_b = 1.13$,
$C_1 = 0.41C_b$
$C_2 = 0.47C_b$

b) For a concentrated load at a distance aL from one end of the span,
$C_b = 1.75 - 1.6a(1 - a)$
$C_1 = C_b[\sin(2\pi a)]/[a(1 - a)\pi^2]$
$C_2 = (C_b - C_1)/2$

c) For two symmetric concentrated loads at a distance aL from each end of the span,
$C_b = 1 + 2.8a^3$
$C_1 = 2C_b[\sin(2\pi a)]/(a\pi^2)$
$C_2 = (1 - a)C_b - C_1/2$

F.4.3 Interaction Between Local Buckling and Lateral-Torsional Buckling

This Section accounts for the effect that the reduced stiffness due to local buckling may have on the lateral buckling strength of single web beams based on work by Sharp (1970).

F.5 SINGLE ANGLES

The strength of single angles in flexure in this Section is similar to the AISC *Specification for Structural Steel Buildings* (2016).

The local buckling strength of an angle leg depends on the degree of end fixity that the other leg provides and the variation in stress across the width of the angle leg. The lower bound on end fixity is a pinned support and the upper bound is a fixed support. Equivalent slenderness ratios (from Sharp (1993) Table 7.1) are summarized in Table CF.5.1 for an angle leg of width b and thickness t:

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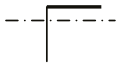
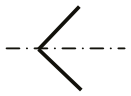
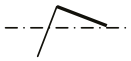
Table CF.5.1
EQUIVALENT SLENDERNESS RATIOS FOR ANGLE LEGS

Case		Stress distribution on leg of angle	Equivalent slenderness ratio/(b/t) (pinned support)	Equivalent slenderness ratio/(b/t) (fixed support)	Angle orientation
1	free edge supported edge		5.13	2.89	
2	free edge supported edge		4.45	2.62	
3	free edge supported edge		3.64	2.27	
4	free edge supported edge		2.56	1.36	

Case 1, uniform compression in an angle leg, is addressed in Section F.5a(2). Cases 2, 3, and 4 are addressed in Section F.5a(1) by conservatively using the worst case (Case 2) and assuming that the support is restrained slightly more than the pinned condition so that a factor of 4 (vs. 4.45) can be used.

F.5.1 Bending About Geometric Axes

Bending about geometric axes occurs when the moment is applied about an axis parallel to a leg of the angle as shown in Figure F.5.4. In such cases, when an angle is laterally restrained at the point under consideration, the neutral axis is the geometric axis as shown on the left side of Figure F.5.4 and addressed in subsections a and b. When the angle is laterally unrestrained, the section will deflect laterally as well as normal to the bending axis, causing the neutral axis to incline as shown on the right side of Figure F.5.4 and addressed in subsection c.

F.5.2 Bending About Principal Axes

Formulas for determining β_w are given in Part V. Since these formulas are cumbersome, β_w values for some common angle sizes are given in Table CF.5.2. β_w varies only slightly with angle thickness for the angles listed in ADM Part V.

Table CF.5.2

Angle Size (in.)	β_w (in.)①
8 × 6	3.31
8 × 4	5.48
7 × 4	4.37
6 × 4	3.14
6 × 3.5	3.69
5 × 3.5	2.40
5 × 3	2.99
4 × 3.5	0.87
4 × 3	1.65
3.5 × 3	0.87
3.5 × 2.5	1.62
3 × 2.5	0.86
3 × 2	1.56
2.5 × 2	0.85
equal legs	0.00

① β_w is positive or negative depending on the direction of bending.

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Chapter G Design of Members for Shear

G.1 GENERAL PROVISIONS

Shear limit states include yielding, buckling, and rupture. For limit states other than rupture, length effects as addressed in G.2, G.3, and G.4 must be considered.

G.2 MEMBERS WITH FLAT WEBS SUPPORTED ON BOTH EDGES

The buckling strength of unstiffened flat webs is for a web with partial restraint against rotation at the attachment to the flanges. The corresponding value of the slenderness is 1.25*b*/*t* based on Bleich (1952) and Gerard and Becker (1957). The buckling strength in the inelastic range was developed originally for shear buckling of tubes (Clark and Rolf (1964)) but also applies to flat elements in shear.

For webs with transverse stiffeners, the web's edges are assumed to be partially restrained against rotation, giving an equivalent slenderness of

$$\frac{1.25a_1}{t\sqrt{1+0.7\left(\frac{a_1}{a_2}\right)^2}}$$

A stiffened flat web that has buckled in shear can continue to carry load by diagonal tension action in the web (Moore (1947)), but this is not accounted for in the provisions of Section G.2.

The required moment of inertia for the transverse stiffener is sufficient to limit local buckling of shear webs to the panels between stiffeners and to provide postbuckling strength in the web. This moment of inertia is multiplied by the ratio of the applied shear load to the shear load causing buckling to adjust the stiffener size for the actual load applied. These formulas were used in the specifications published by ASCE (1962a, 1962b), agree well with the results of tests by Moore (1942) and are conservative in comparison with the stiffener size theoretically derived by Cook and Rockey (1962). Hartmann and Clark (1963) and Sharp and Clark (1970) provide further background.

G.3 MEMBERS WITH FLAT WEBS SUPPORTED ON ONE EDGE

This Section addresses shear in elements supported on one edge such as angles and tees. For a buckling coefficient $k = 1.2$ (see AISC *Specification for Structural Steel Buildings* Section G2, which refers to this case as unstiffened webs) and $\nu = 0.33$ (see Section A.4.1):

$$F_e = \frac{k\pi^2 E}{12(1-\nu^2)(b/t)^2} = \frac{1.2\pi^2 E}{12(1-0.33^2)(b/t)^2}$$

$$= \frac{\pi^2 E}{8.91(b/t)^2} = \frac{\pi^2 E}{(3.0b/t)^2}$$

G.4 ROUND OR OVAL TUBES

The provisions for transverse shear of round or oval tubes are based on local buckling of cylinders subjected to torsion, which is addressed in Section H.2.1. Since torsion is usually constant along the cylinder length but transverse shear usually varies along the length, the transverse shear strength is taken as 1.3 times the torsion strength as suggested by Ziemian (2010) in Section 14.3.4. This treatment is similar to AISC (2010).

In equation G.4-1, $V_n = F_s A_s/2$, it is assumed that the shear stress at the neutral axis $VQ/(Ib) = F_s$. For thin round tubes of radius R and thickness t, $I = \pi R^3 t$, $Q = 2R^2 t$, and $b = 2t$, which gives the shear stress at the neutral axis as $V/(\pi Rt) = V/(A_s/2)$.

G.5 RODS

Shear strength limit states for rods include shear yielding and shear rupture.

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H.1 MEMBERS SUBJECT TO FLEXURE AND AXIAL FORCE

Use of the interaction equation given in H.1 is predicated on a stability analysis performed in accordance with Chapter C. If the analysis is not performed in accordance with Chapter C, using the interaction equation given in Section H.1 can be unconservative.

H.2 MEMBERS SUBJECT TO TORSION

H.2.1 Pipes and Round or Oval Tubes

The equation for equivalent h/t is based on the theoretical elastic buckling strength of cylinders in torsion. Tubes loaded in torsion are not as sensitive to the effect of initial imperfections in the geometry as are tubes loaded in axial compression. Battdorf, et. al. (1947) showed this gives good agreement with the results of tests on thin cylinders that fail in the elastic range, and Clark and Rolf (1964) showed this agrees well with experimental results in the inelastic stress range. The elastic buckling strength of cylinders in torsion matches AISC (2010) *Specification* Section H.3.1, since

$$\frac{\pi^2 E}{(1.25\lambda_t)^2} = \frac{1.23E}{\sqrt{L/D}(D/t)^{5/4}}$$

where $\lambda_t = 2.9(R/t)^{5/8}(L/R)^{1/4}$ and $R = D/2$.

Sharp (1993) noted that the equivalent slenderness for tubes can give very conservative results for long tubes with both longitudinal and circumferential stiffeners. Figure CH.2.1 shows the change in the coefficient in Equation H.2-2 with length of tube. A coefficient of 2.9 is specified for all cases (solid line in Figure CH.2.1). A more accurate and less conservative value for long tubes is less than 2.9 as illustrated by the dashed line in Figure CH.2.1. The ordinate in this figure is a rearrangement of Equation H.2-2. The addition of longitudinal stiffeners as well as circumferential stiffeners usually increases the shear strength of a tube compared to a tube with circumferential stiffeners only.

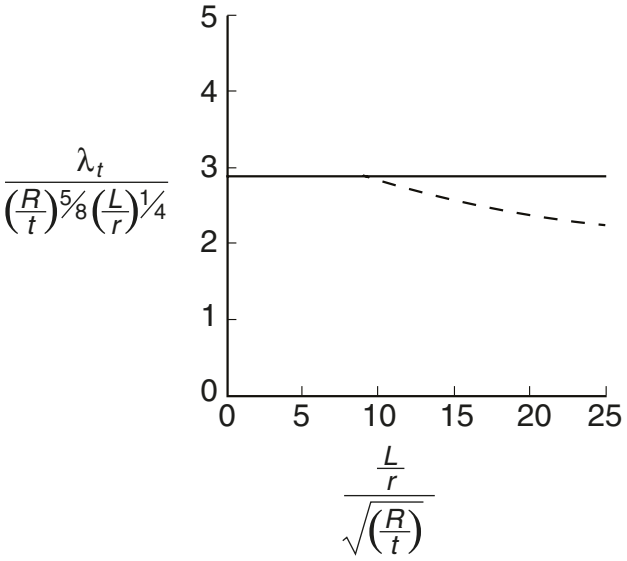

Figure CH.2.1
SHEAR BUCKLING OF TUBES WITH CIRCUMFERENTIAL STIFFENERS

H.2.2 Rectangular Tubes

Rectangular tubes were not specifically addressed before the 2010 *Specification*. The 2005 AISC *Specification* Section H3.1(b) addresses rectangular tubes with equations that give the same limit state shear stress as the equations given in AISC *Specification* Section G2.1(b)(i). Section H.2.2 matches the AISC approach, but uses the limit state shear stresses for aluminum webs given in the 2010 *Specification* Section G.2.

The torsional shear constant C for rectangular tubes of constant wall thickness t obtained by the membrane analogy is $2tA_m$ where A_m is the area bounded by the midthickness of the section. For a midthickness corner radius r,

$$C = 2t(b - t)(d - t) - 2tr^2(4 - \pi)$$

If the midthickness corner radius is conservatively taken as $1.5t$,

$$C = 2t(b - t)(d - t) - 4.5t^3(4 - \pi)$$

where

b = midthickness width of the tube
d = midthickness depth of the tube.

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H.2.3 Rods

Since shear buckling cannot occur in a rod, the limit states for a rod are yield and rupture. The yield limit state equation matches AISC (2010); the rupture limit state equation is from Sharp (1993).

H.2.4 Open Shapes

Shear stresses are the result of St. Venant torsion. If warping is restrained in open shapes subjected to torsion, normal stresses are present in addition to shear stresses.

H.3 MEMBERS SUBJECT TO TORSION, FLEXURE, SHEAR, AND/OR AXIAL COMPRESSION

H.3.1 Flat Elements

Equation H.3-1 is documented in Ziemian (2010) (equation 4.9).

H.3.2 Curved Elements

Equation H.3-3 is documented in Ziemian (2010) (equation 14.57), which is based on work by Schilling (1965).

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J.1 GENERAL PROVISIONS

J.1.3 Maximum Spacing of Fasteners

The maximum fastener spacing for tension member components is based on experience rather than tests or theory. Limiting the fastener spacing for tension member components reduces the chance of buckling if unanticipated compression acts on the member.

The maximum fastener spacing in built-up compression members is based on preventing buckling of the components between points of attachment.

J.2 WELDS

Aluminum welded connection types include groove, fillet, plug, slot, and stud welds. Moore et al. (1971) documented strengths of welds joining 6061-T6, and Sharp et al. (1982) documented strengths of aluminum welded connections.

J.2.1 Groove Welds

J.2.1.1 Complete Joint Penetration and Partial Joint Penetration Groove Welds

Groove welds are classified as either complete penetration or partial penetration for the purpose of determining the weld size. The method of classifying a groove weld is the same as that in AWS D1.2:2014. Groove welds made with permanent backing have less fatigue strength than groove welds without permanent backing (see Appendix 3).

J.2.1.2 Groove Weld Size

The definition of groove weld sizes matches AWS D1.2:2014.

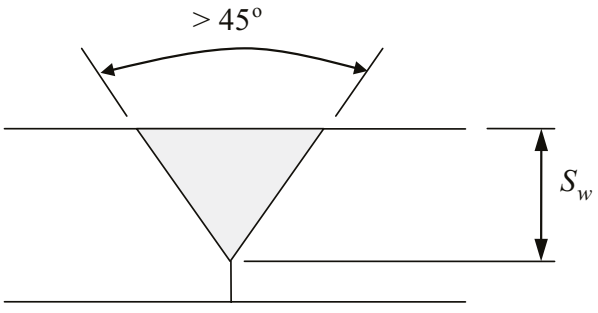

Figure CJ.2.1
PARTIAL JOINT PENETRATION GROOVE WELD

J.2.1.3 Groove Weld Effective Length

The definition of groove weld effective length is similar to AWS D1.2:2014.

J.2.2 Fillet Welds

J.2.2.1 Fillet Weld Size

The fillet weld effective throat definition matches AWS D1.2:2014. The effective throat of an equal leg fillet weld of size S_w is $0.707S_w$.

Minimum fillet weld sizes are intended to avoid small welds in thick parts. Such welds may crack upon cooling because the thick parts they join are not sufficiently heated during welding.

Maximum fillet weld sizes are intended to prevent the welder from melting the upper corner of the edge of the plate joined. This can result in a weld that appears to be full size but is not, and thus has a smaller throat than a full size weld. This situation is less likely to arise in parts thinner than ¼ in. (6 mm) since it is difficult to melt the upper corner of the plate without depositing a full size weld in a thin part.

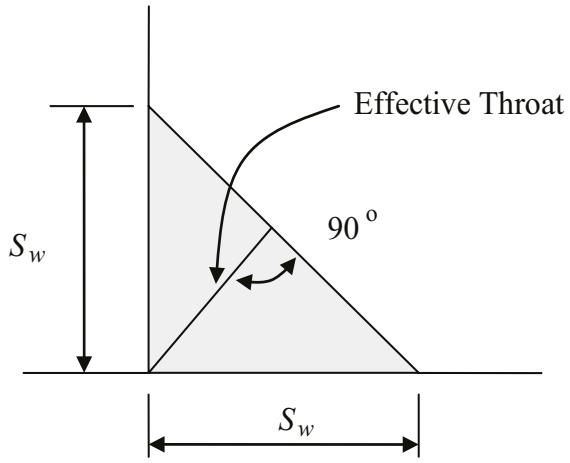

Figure CJ.2.2
EFFECTIVE THROAT OF A FILLET WELD

J.2.2.2 Fillet Weld Effective Length

The fillet weld effective length definition matches AWS D1.2:2014. Boxing is defined by AWS A3.0 as "the continuation of a fillet weld around a corner of a member as an extension of the principal weld".

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End-loaded fillet welds are oriented parallel to the stress in the member and transmit load to the end of an axially loaded member. Examples include longitudinally welded lap joints at the ends of axially loaded members and welds attaching bearing stiffeners. Examples of longitudinally loaded fillet welds that are not end-loaded include:

a) welds that connect parts to form built-up members in which shear is applied to each incremental length of weld depending on the shear distribution along the member's length;

b) welds attaching beam web connection angles and shear plates, because the flow of shear from the beam web to the weld is nearly uniform along the weld's length; and

c) welds attaching stiffeners to webs, since the stiffeners and welds are not subject to calculated axial stress and only serve to keep the web flat.

J.2.3 Plug and Slot Welds

Plug and slot welds are primarily used to transmit shear in the plane of the weld. An example is a cover plate attached to a flange with plug welds. The definition of effective area and the limit on slot length match those in AWS D1.2:2014.

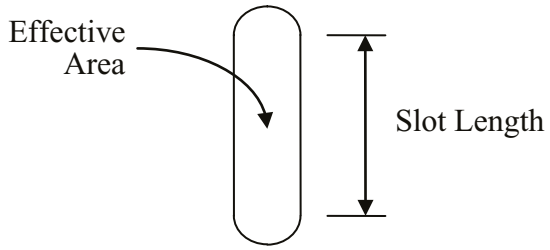

Figure CJ.2.3
SLOT WELD PLAN VIEW

J.2.4 Stud Welds

The base metal thickness requirements match those in AWS D1.2:2014.

J.2.5 Strength

The as-welded strength of aluminum filler alloys without post-weld heat treatment depends only on their chemical composition since the heat of welding erases cold-work and artificial aging heat treatment effects on strength. The chemical composition in the as-welded condition depends not only on the chemical composition of the filler but also on the base metal, since there is some mixing of the base and filler metals in the weld. To simplify weld strength calculations, however, the welded strength of fillers is considered to be independent of the base metal. When the filler has a similar chemical composition to the base metal, as is often the case, this is not an issue.

Nelson and Rolf (1966) tested the shear strengths of 1100, 2319, 4043, 4643, 5356, 5554, and 5556 fillers. Menzemer and Iasconne (2002) tested the shear strengths of 4047, 4643, and 5183 fillers. These studies used the same test method on fillet welds to determine shear strength. The average of the filler shear strengths determined in these studies was 50% of the tensile strengths given in Table J.2.2. (See Table CJ.2.1). The fact that this is less than the shear strength of wrought alloys, which averages 60% of tensile strength, is attributed to load eccentricity and stress concentrations present in fillet welds. Therefore, the shear strength of a fillet weld given in Table J.2.2 is F_{suw} times 0.85 (= 0.5/0.6).

Table CJ.2.1
RATIO OF FILLET WELD TESTS' SHEAR STRENGTH TO TENSILE STRENGTH

Filler	F_{tuw}	F_{suw}	F_{suw} Source	F_{suw}/F_{tuw}
1100	11	7.5	Nelson and Rolf (1966)	0.68
2319	35	16	Nelson and Rolf (1966)	0.46
4043	24	11.5	Nelson and Rolf (1966)	0.48
5183	40	21	Menzemer (2002)	0.53
5356	35	17	Nelson and Rolf (1966)	0.49
5554	31	17	Nelson and Rolf (1966)	0.55
5556	42	20	Nelson and Rolf (1966)	0.48

The strength of a PJP weld is 60% of the strength of a CJP weld to account for the notch effect of incomplete fusion at the root of the weld. This same factor is used in the AISC *Specification*, and should not be confused with the ratio of shear strength to tensile strength.

Allowable stresses for groove welds for various combinations of base metals are given in Part VI, Table 6-1, and LRFD design stresses are given in Part VI, Table 6-3. The strength of a groove weld is usually governed by the strength of the base metal rather than the filler metal.

Allowable stresses for fillet welds for various combinations of base metals are given in Part VI, Table 6-2, and LRFD design stresses are given in Part VI, Table 6-4. The strength of a fillet weld is usually governed by the strength of the filler metal rather than the base metal.

The shear strength for transversely loaded welds is based on a report by the Texas Transportation Institute (1980). This report determined a factor (1.36) to account for the additional strength of transverse welds above that of longitudinal welds. The AISC *Specification* (2010) provides a 1.50 ratio for longitudinal to transverse weld strength. Nelson and Rolf (1966) also documented the strength of transverse welds vs. longitudinal welds for various fillers; their results are summarized in Table CJ.2.2.

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Table CJ.2.2
RATIO OF TRANSVERSE TO LONGITUDINAL STRENGTHS OF FILLET WELDS (NELSON AND ROLF (1966))

Filler	Longitudinal Shear Strength F_{suwl} (ksi)	Transverse Shear Strength F_{suwt} (ksi)	F_{suwt}/F_{suwl}
1100	7.5	7.5	1.0
2319	16	16	1.0
4043	11.5	15	1.30
4643	13.5	20	1.48
5356	17	26	1.53
5554	17	23	1.35
5556	20	30	1.50

The stud weld strengths given in Table J.2.2 are based on theory rather than tests, since test data is lacking. AWS D1.2:2014 Table 6.1 provides minimum tensile strengths of 5083, 5086, 5183, 5356, 5554, and 5556 studs to qualify stud weld procedure specifications.

The stud weld strengths given in Table J.2.2 are for threaded studs.

J.2.7 Post-Weld Heat Treatment

The post-weld heat-treated strength of 6063 is based on a study of 27 weldments conducted by the National Electric Manufacturers Association in 1973. The artificial aging heat treatment is given in *Aluminum Standards and Data 2017* Table 3.4. The post-weld heat-treated strength is less than the artificially aged strength because after welding and before post-weld heat-treating, the weld-affected material does not have a solution heat treated temper. Post-weld heat-treated strengths for 6005A and 6061 are based on a 2014 study by Menzemer and are consistent, on a percentage basis, with post-weld heat-treated strength for 6063.

The tension coefficient k_t of the weld-affected zone after post-weld heat treatment is expected to be the same as the tension coefficient k_t of the precipitation heat treated temper of the alloy.

J.3 BOLTS

Material properties of aluminum bolts, washers, and nuts are addressed in Section A.4.5. See the commentary to Section A.4.5 for issues related to using steel bolts to connect aluminum parts.

J.3.1 Holes and Slots for Bolts

The AISC *Specification* requires that standard holes with a nominal diameter 1/16" greater than the nominal bolt diameter be used for all bolts ½ in. through 7/8 in. in diameter. It may be appropriate to limit hole diameter to 1/32 in. (0.8 mm) larger than the bolt diameter for bolts with a nominal diameter less than ½ in..

J.3.2 Minimum Spacing of Bolts

The minimum spacing requirement is intended to provide sufficient clearance for installation tools and washers.

J.3.3 Minimum Edge Distance of Bolts

Edge distance requirements (2*D* for full bearing strength and a minimum of 1.5*D* with reduced bearing strength) have been selected so that for a single fastener, the block shear strength equals or exceeds the bearing strength. So for a single fastener, meeting the bearing requirements negates the need to check block shear.

Edge distance requirements apply to free edges of a part only, and not to the corner of a structural shape such as the heel of an angle.

J.3.4 Bolt Tension

The use of the root area for determining the tensile strength of aluminum fasteners rather than the slightly larger tensile stress area used for steel fasteners is based on Dewalt and Mack (1980). The root area is based on the nominal minor diameter of UNR external threads ($D - 1.191/n$) given in ASME B1.1-2003, Unified Inch Screw Threads (reaffirmed in 2018) section 10.1.

Part VI, Table 5-3 gives tensile strengths for 2024-T4 and 7075-T73 bolts and cap screws.

The safety factor for bolt shear, bolt tension and rivet shear (2.34) is higher than for members (1.95) because it is preferable for the connections to be stronger than the members. If connections have greater strength, it is more likely that the structure will exhibit warning of an overload (e.g., excessive deflection and/or yielding of the members). Another reason for this higher safety factor is to lessen the likelihood that connection capacity-reducing conditions (e.g., limited amounts of corrosion or improper installation of fasteners) will have an adverse effect on the member's ability to reach its calculated nominal strength. Improper installation may include over- or under-tightening, missing nuts or washers, or presence of threads in the shear plane when this was not the design condition.

J.3.5 Bolt Shear

Rather than using approximate relationships between the threaded and unthreaded areas of bolts and different design stresses when threads are in the shear plane and when threads are not in the shear plane, this *Specification* uses the same design stress for both cases and adjusts the effective shear area appropriately.

Part VI, Table 5-3 gives shear strengths for 2024-T4 and 7075-T73 bolts and cap screws with threads in and threads not in the shear plane.

The root area term in equation J.3-2 matches the formula given in ASME B1.1 (1989).

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J.3.6 Bolt Bearing

The limit state of bearing is reached when elongation of the fastener hole becomes excessive. Menzemer et al. (2001) established the bearing strength as $2F_{tu}$ for a load at which hole deformation is approximately $D/4$, where D is the nominal diameter of the bolt.

Sharp (1993) and the Department of Defense (1994) show that for ratios of edge distance to fastener diameter as small as 1.5, it is conservative to reduce the allowable bearing stress by the ratio of the edge distance to twice the fastener diameter. Moisseiff et al. (1944) demonstrated that a relatively even distribution of load among the fasteners is achieved before ultimate failure of mechanically fastened joints in structural aluminum alloys.

For countersunk holes, caution should be exercised when the depth of the countersink approaches the thickness of the part, creating a knife-edge on the hole which may be easily damaged.

J.3.7 Slip-Critical Bolted Connections

J.3.7.1 General

This Section is based on European specifications and testing conducted by Kissell and Ferry (1997). Aluminum slip-critical connections are included in Canadian, British, ISO, and Eurocode specifications. In the US, use of high strength steel bolts is governed by the Research Council on Structural Connections (RCSC) *Specification for Structural Joints Using High Strength Bolts*. The RCSC *Specification* addresses the use of these high strength steel bolts to connect steel parts and so is modified here for connections using aluminum parts. All parts of the RCSC *Specification* not modified by the provisions of Section J.3.7 (for example, provisions on inspection) apply to aluminum slip-critical connections.

Slip-critical connections resist shear by friction between the faying surfaces of the connected parts, which are tightly clamped together by high strength steel bolts. Slip-critical connections are used when it is desirable to prevent movement of connected parts relative to one another. Such connections are useful for joints subjected to dynamic or fatigue loads, as well as joints in which both bolts and welds share the load, joints with oversize holes, and joints with slotted holes with loads not applied normal to the axis of the slot.

In addition to the requirements for bearing connections, slip-critical connections are subject to the additional requirement that the slip resistance of the joint be greater than the applied shear loads. The design strength of slip-critical connections cannot be greater than the design strength of the same connection designed as a bearing connection. The design strength of a slip-critical connection is limited to the lesser of the design strength of the bolt in shear and bearing and the slip resistance of the joint.

J.3.7.2 Material

Since hot-dip galvanizing may embrittle A490 bolts and galvanizing is required to discourage galvanic corrosion between the steel fastener and the aluminum parts, A490 bolts are not allowed in aluminum slip-critical connections.

The RCSC *Specification* limits the bearing stress under the bolt head in steel to 64 ksi (440 MPa) for steel with a yield strength less than 40 ksi (275 MPa) by requiring such steel with A490 bolts to have washers. The *Specification for Aluminum Structures* requires the use of washers under bolt heads and nuts, and bearing stresses under the washer can reach approximately 24 ksi (165 MPa) with A325 bolts. Therefore, aluminum slip-critical connections are limited to those alloys with a tensile yield strength of 15 ksi (105 MPa) or greater.

Thin parts, such as aluminum sheet and drawn tube, are effectively prohibited from slip-critical connections by bearing stress limitations on the sides of the hole.

ASTM F3125 allows both hot-dip galvanizing and mechanical galvanizing of A325 fasteners. F3125 further requires that all components of a fastener assembly (bolt, nut, and washer) be coated by the same process, since mixing bolts and nuts galvanized by different processes may result in an unworkable assembly.

J.3.7.3 Holes

For convenience, nominal hole dimensions from the RCSC *Specification* are given in the Table CJ.3.1.

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Table CJ.3.1
HOLE DIMENSIONS FOR SLIP-CRITICAL JOINTS

Bolt Diameter (in.)	Hole Dimensions (in.)			
	Standard (Diameter)	Oversized (Diameter)	Short Slotted (Width x Length)	Long Slotted (Width x Length)
1/2	9/16	5/8	9/16 × 11/16	9/16 × 1 1/4
5/8	11/16	13/16	11/16 × 7/8	11/16 × 1 9/16
3/4	13/16	15/16	13/16 × 1	13/16 × 1 7/8
7/8	15/16	1 1/16	15/16 × 1 1/8	15/16 × 2 3/16
1	1 1/16	1 1/4	1 1/16 × 1 5/16	1 1/16 × 2 1/2
≥1 1/8	d + 1/16	d + 5/16	(d + 1/16) × (d + 3/8)	(d + 1/16) × (2.5d)

J.3.7.4 Bolt Tension and Shear

Slip-critical connections must be designed assuming slip could occur, placing shear on the bolt and bearing on the sides of the hole.

J.3.7.5 Slip Resistance

Slip coefficients are given for two contact surfaces: roughened aluminum on roughened aluminum, and roughened aluminum on zinc-rich painted steel. Kissell and Ferry (1997) tested these surfaces in accordance with the test method given in the RCSC *Specification* for both slip and creep. Slip coefficients for other surfaces may be determined by testing in accordance with the RCSC *Specification*.

Luttrell (1999) and Fortlin, et al. (2001) showed that bolt tension is not significantly affected if the temperature changes from the installation temperature.

Tests of mill finish aluminum surfaces degreased and dried have generally achieved relatively low coefficients of friction.

J.3.7.6 Washers

Washers are required under all bolt heads and nuts. This requirement is intended to minimize galling of the outer ply of aluminum and creep relaxation of bolt tension.

J.3.8 Lockbolts

A lockbolt assembly includes a pin, which is similar to a bolt, and a collar, which performs the function of a nut. The collar is swaged onto locking grooves on the pin. Lockbolts are available in carbon steel, stainless steel, and aluminum.

J.4 RIVETS

Aluminum rivet material properties are addressed in Section A.4.6.

J.4.1 Holes for Cold-Driven Rivets

Holes for cold-driven rivets are sized so that the rivet completely fills the hole when driven.

J.4.3 Minimum Edge Distance of Rivets

See Section J.3.4.

J.4.4 Rivet Tension

Rivets are sensitive to grip (the thickness of the parts joined) and hole size, since these parameters affect the fastener's head dimensions, unlike bolted installations. If the hole is too large or mislocated, or if the parts are slightly thicker or thinner than the thickness the rivet was selected for, the rivet head formed during installation is imperfect. These effects are greater on tensile strength than shear strength, since unless the rivet falls out of the connection, shear can still be resisted, but in tension the parts can begin to disengage without a proper head on both sides of the parts joined. The tensile strength of riveted connections, therefore, can vary significantly.

J.4.5 Rivet Shear

The shear strength of aluminum rivets is based on the rivet filling the hole so the effective shear area of the rivet is the nominal hole diameter.

J.4.7 Blind Rivets

Installing blind rivets requires access to only one side of a connection.

J.5 TAPPING SCREWS

Screwed connection provisions are based on Peköz (1990), who considered over 3500 tests on light-gage steel and aluminum connections worldwide. ECCS (1987) and

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BSI (1987) were also considered. AISI S905 addresses tests to establish shear and tensile strengths of screwed, riveted, or bolted connections.

Proper installation of screws is important to achieve satisfactory performance. Power tools with adjustable torque controls and driving depth limitations are usually used.

Screw connection tests used to formulate the provisions included single fastener specimens as well as multiple fastener specimens. However, it is recommended that at least two screws should be used to connect individual elements. This provides redundancy against under torquing, over torquing, etc., and limits lap shear connection distortion of flat unformed members such as straps.

The safety factor for screwed connections in building-type structures is 3.0, which matches AISI (2001). The safety factor for screw bearing is consistent with the safety factor for screw shear and tension. (See also Section J.5.5.1).

Aluminum screw material properties are addressed in Section A.4.7. See the commentary to Section A.4.7 for issues related to using steel screws to connect aluminum parts.

J.5.1 Holes for Screws

This *Specification* requires that the nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than 1/16 in. (1.6 mm). Many designers specify that the nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than 1/32 in. (0.8 mm).

Tables J.5.1 and J.5.2 provide diameters for holes that are subsequently threaded by tapping screws and are based on AAMA (2014) Tables 20 and 21, respectively, which were used for the hole sizes on which Section J.5.4.1.1 pull-out strengths are based.

J.5.2 Minimum Spacing of Screws

See Section J.3.2.

J.5.3 Minimum Edge Distance of Screws

See Section J.3.3.

J.5.4 Screwed Connection Tension

The smallest screw head or washer size allowed is 5/16" since the diameter of a hex washer head for a No. 8 screw (the smallest screw size allowed by this *Specification*) is 5/16".

J.5.4.1 Pull-Out

J.5.4.1.1 Screws in Holes

The equations for pull-out are derived from research conducted by AAMA (2014) Section 22.0, including over 400 pull-out tests. These equations are based on three regions of behavior: yield (circumferential stretching and bending of the aluminum around the screw), shearing of the internal threads in the hole, and a transition region between yield and shearing. For most cases they are less conservative than the pull-out equation in the *Specification's* 6th edition ($P_{not} = 0.85 t_c DF_{tu2}$), especially for UNC threads in aluminum parts thicker than 0.084 in. (2.1 mm). Pull-out strengths are a function of the type of thread: coarse (UNC) or spaced. A UNC thread is often referred to as a "machine" thread, and a spaced thread screw is termed a "sheet metal" screw.

Internal thread stripping areas A_{sn} are given in Part VI Table 5-6 for Class 2B UNC threads.

J.5.4.1.2 Screws in Screw Slots

Menzemer (2008) tested spaced thread screw types and machine thread screw types to develop Equation J.5-7. The average of all spaced thread tests was 0.2% greater than the strength given by Equation J.5-7, and the average of all machine thread tests was 4.2% greater than the strength given by Equation J.5-7. Because both spaced threads and machine thread pull-out strengths matched Equation J.5-7 well, this *Specification* does not provide different strengths for the different screw types.

J.5.4.1.3 Screws (1/4 in. Diameter) in Screw Chases

The pull-out strength of screws in screw chases is based on testing summarized by Dolby, et. al. (2016). They performed 150 pull-out tests with 1/4 in. nominal diameter 300 series stainless steel screws, varying the following parameters:

- 6 extrusion profiles (3 with ribbed-wall chases and 3 with flat-wall chases; *Specification* Glossary Figures GL.1a and GL.1b illustrate ribbed-wall and flat-wall chases)
- 3 alloy-tempers (6005-T5, 6061-T6, and 6063-T6)
- thread engagement lengths varying from 0.240 to 0.572 in. (6.1 to 14.5 mm)
- 2 screw thread spacings (14 and 20 threads per inch (25.4 mm))
- 3 fastener types (AB tapping screws, F tapping screws, and UNC machine screws)
- nominal chase widths varying from approximately 0.180 to 0.220 in. (4.6 to 5.6 mm) (0.72*D* to 0.88*D*)

The pull-out strength equation in *Specification* Section J.5.4.1.3 is of the form:

$$R_n = K\, D\, L_e\, F_{tu}\, (14/n)^2 (0.75D/w_c)$$

This equation differs from the equation given by Dolby, et. al. (2016) in that it has an additional factor $0.75D/w_c$ to improve the accuracy of the equation by addressing the effect of the chase width. The coefficient of variation of the predicted strength-to-test strength ratios for this equation is 0.311.

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Specification Section 1.3.2 provides an equation for determining the resistance factor to be used with the average of test results:

$$\phi = 1.5 M_m F_m e^{-\beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}} = 0.44$$
or $$= 1.5 M_m F_m e^{-\Psi} = 0.44$$

where
$$\Psi = \beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}$$

n = number of tests = 150

C_n = correction factor = $\dfrac{n^2 - 1}{n^2 - 3n} = 1.02$

F_m = mean value of the fabrication factor, the ratio of the specimen's relevant geometric property to its nominal value. Since dimensional tolerances for the screw chase width and screw diameter are balanced, $F_m = 1.0$

M_m = mean value of the material factor, the ratio of the specimen's tensile ultimate strength to the specified minimum strength = 1.12, based on the tensile coupon tests

V_M = coefficient of variation of the material factor = 0.06

V_F = coefficient of variation of the fabrication factor = 0.05

V_P = coefficient of variation of the ratio of the test strengths to the predicted strengths = 0.311

V_Q = coefficient of variation of the loads = 0.21

β_o = the target reliability index = 3.5 for connections

Specification Section J.5.4 prescribes a resistance factor of 0.5 for screws in tension. Because the calculated resistance factor is 0.44 rather than 0.5, the pull-out strength equation to be used for design is determined so that its strength is 0.44/0.5 = 0.88 times the average strength, which is

$$R_n = 0.45 D\, L_e\, F_{tu}\, (14/n)^2 (0.75D/w_c)$$

where:

D = nominal diameter of the screw
L_e = thread engagement length
F_{tu} = tensile ultimate strength of the extrusion
n = number of threads per in.
w_c = nominal width of the chase

When this expression is evaluated for D = ¼ in. (the only screw diameter tested),

$$R_n = (0.021 \text{ in}^2) L_e\, F_{tu}\, (14/n)^2 / w_c$$

This is the expression used in the *Specification*.

Deductions from the screw length to determine the thread engagement length L_e account for the portion of the screw length for which the screw threads are not present or not full height. The deduction is a function of the dimensions of the screw point, as shown in Figure CJ.5.1.

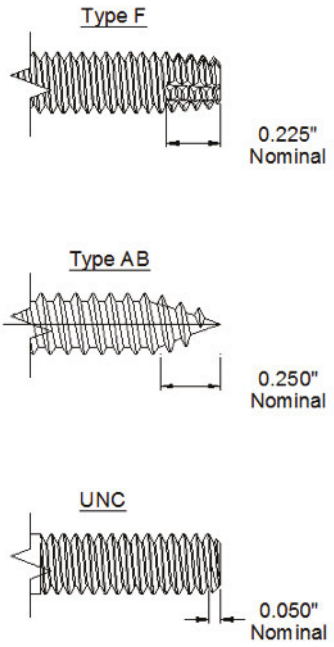

Figure CJ.5.1
POINT LENGTH FOR TYPE F, TYPE AB, AND UNC FASTENERS

The pull-out strength equation does not account for the stiffness of the chase walls against spreading, which probably also affects pull-out strength. Neglecting the stiffness simplifies the equation but reduces its accuracy. The minimum chase wall thickness of 0.150 in. (= 0.6D) and the maximum chase depth of 0.750 in. (= 3D) limit these parameters affecting the flexibility of the chase walls to those tested.

The outward force exerted by the screw on the chase wall depends on the coefficient of friction of the screw on the chase. For 60° screw threads, the outward force on the chase walls is 0.29 times the tension in the screw when the coefficient of friction is zero, and the outward force on the chase walls is zero when the coefficient of friction is 0.58. This suggests that the outward force is between zero and 29% of the tension in the screw.

The screw chase pull-out strength given in the *Specification* addresses a subset of screw chase configurations. As additional data become available, other configurations may be addressed in the *Specification*.

J.5.4.2 Pull-Over

Sharp (1993) provided the pull-over strength equation for non-countersunk screws. Screws may be placed through the valley or the crown of corrugated roofing and siding. (See Figure CJ.5.2). A coefficient of 0.7 is used when the connected parts are not in contact, such as for fastening through the crown of roofing when a spacer block is not used between the roofing and the structural member sup-

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porting the roofing. The test strengths of such screwed connections are more variable than those with the connected parts in direct contact at the connection such as the fastener through the valley in Figure CJ.5.2.

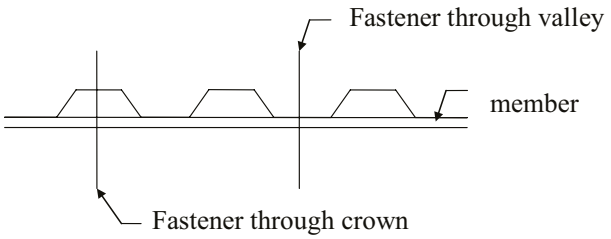

Figure CJ.5.2
FASTENERS IN ROOFING

Alternate pull-over strengths are given for screws in tight-fitting holes based on tests conducted by LaBelle and Dolby (2009). In these tests, screws had hex heads with integral washers. Screw nominal diameters were 0.164, 0.190, 0.216, and 0.25", and part nominal thicknesses were 0.04, 0.06, 0.09, and 0.125". The holes were "free fit" with the following nominal sizes:

Screw Size	Hole Diameter (in.)	Drill Size
8	0.177	16
10	0.201	7
12	0.228	1
¼	0.266	H

These hole sizes average 0.013" larger than the screw diameter, smaller than the 0.062" oversize the *Specification for Aluminum Structures* allows. The average ratio of predicted strength (using *Specification* equation J.5-9) to test strength was 0.83 with a coefficient of variation of 7.3%.

The equation for the pull-over strength of countersunk screws is based on over 200 tests by LaBelle and Dolby (2004) using 5 different flathead screw sizes, 6 sheet thicknesses, and 2 alloy-tempers. Testing was limited to commonly used screws with 82 degree nominal angle heads, so the equation is not known to apply to other head angles.

Variation in actual diameters of hand-drilled countersunk holes can have a significant effect on pull-over strength. Caution should be used to avoid excessive oversizing of countersunk holes. Oversizing should be limited so that the top of the screw head is no more than the lesser of $t_1/4$ and 1/32 in. (0.8 mm) below the top of the sheet.

J.5.4.3 Screw Tension

The tensile strength of aluminum screws is given in Part VI Tables 5-1 and 5-2.

J.5.5 Screwed Connection Shear

Screwed connections loaded in shear have limit states of screw shear, block shear rupture (see Section J.6.3), tilting, and bearing failure of the joined materials.

J.5.5.1 Screw Bearing

The bolt bearing strength given in the *Specification* is the force that produces a hole deformation of $D/4$, where D is the fastener diameter. The safety factor for screw bearing is greater than the safety factor for bolt and rivet bearing (3.0 vs. 1.95) because screwed connections are less tolerant of hole deformation than bolted or riveted connections. (Similarly, the resistance factor for screw bearing is less than the resistance factor for bolt and rivet bearing). In a screwed connection tapped hole, deformation of the hole reduces thread engagement with the tapped part, reducing the pull-out strength, and in a screwed connection untapped hole, deformation of the hole reduces the pull-over strength. These reductions in tensile strength of the screwed connection are of concern because even in screwed connections designed only for shear, screws are typically in tension due to tightening the screw during installation and, in single shear cases, screws may be in tension due to rotation of the screw caused by the eccentricity of the forces applied through the centroids of the connected sheets.

J.5.5.2 Screw Tilting

Screw tilting occurs when the part under the screw head is thicker than the part beneath it. The shear force on the joint causes the axis of the screw to tilt toward the plane of the connected parts and the screw threads to tear out of the lower sheet.

J.5.5.3 Screw Shear

The shear strength of aluminum screws is given in Part VI Tables 5-1 and 5-2

J.6 PINS

J.6.1 Holes for Pins

Hole requirements for pins are intended to provide a relatively uniform bearing stress at the hole and proper functioning of the pin.

J.6.2 Minimum Edge Distance of Pins

The minimum edge distance for pins is the same as that for bolts.

J.6.3 Pin Tension

Pins provide little resistance to forces acting parallel to the axis of the pin.

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J.6.4 Pin Shear and Flexure

Two limit states are addressed for pins: yielding and rupture. The limit state of yielding is addressed because a pinned connection must accommodate rotation, which may be impaired by inelastic deformation of the pin at service loads. Since a pinned connection uses only one pin, by definition, there is no redundancy. For this reason a flexural strength check is required for a pin in addition to a shear strength check.

The resistance and safety factors for pin rupture match those for rupture of bolts and rivets. The resistance and safety factors for pin yield match those for other yield limit states.

The shear strength of aluminum pins is based on the average shear stress $f_s = V/A$. For a rod,

$$f_s = \frac{V}{A} = \frac{4V}{\pi D^2}$$

Setting $f_s = F_{su}$, the shear ultimate strength of the pin, and rearranging, $V_n = \frac{F_{su}\pi D^2}{4}$

The flexural rupture and yield strengths of aluminum pins are based on a ratio of plastic modulus to elastic modulus of 1.5. This ratio is 1.7 for rods, but is reduced to 1.5 to preclude yielding at service loads.

$$M_{nu} = \frac{1.5F_{tu}S}{k_t} = \frac{1.5F_{tu}\pi D^3}{32k_t} = \frac{\pi D^3 F_{tu}}{21.3k_t}$$

$$M_{ny} = 1.5F_{ty}S = \frac{1.5F_{ty}\pi D^3}{32} = \frac{\pi D^3 F_{ty}}{21.3}$$

The interaction equation for combined shear and flexure of pins is based on Kulicki (1983).

J.6.5 Pin Bearing

The bearing strength for an element with a pin is 2/3 the bearing strength for an element with a bolt in a hole. This limits hole deformation in elements at a pin to less than that at a bolt. Less deformation can be tolerated at a pin hole because the connected parts rotate about the pin. A single pin is used at a pinned connection to allow rotation, whereas multiple bolts are typically used in bolted connections. Also, pins exert no clamping force holding the connected parts together, unlike bolted connections.

J.7 AFFECTED ELEMENTS OF MEMBERS AND CONNECTORS

J.7.2 Strength of Connectors in Shear

The resistance factor for shear yielding of connectors (1.00) is higher and the safety factor (1.50) is lower than for shear yielding of members. This is because shear yielding of connectors is unlikely to produce significant deformation of the structure as a relatively small portion of the structure is comprised of connectors.

J.7.3 Block Shear Strength

The block shear strength of mechanically fastened connections is based on tests by Menzemer (1999) and Marsh (1979) in Table CJ.7.1, and investigated by Teh and Deierlein (2017).

Teh and Deierlein (2017) showed that the block shear strength of connections with non-uniform stress distributions was accurately predicted by equation J.7-1 without the use of a non-uniform stress factor U_{bs} used in the 2016 AISC *Specification*.

In the absence of test data, the block shear strength of welded connections is derived from theory and is simply the sum of the strengths of the weld-affected portion and the non-weld-affected portion of an assumed failure path.

J.8 BEARING STRENGTH OF FLAT SURFACES

The bearing strength for flat surfaces is 2/3 the bearing strength for elements with fasteners in holes.

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TABLE CJ.7.1

MENZEMER (1999); 6061-T6

Sample No.	t mm	end e mm	pitch s mm	hole d_h mm	gauge g mm	no. of trans. rows	no. of long. rows	F_{ty} MPa	F_{tu} MPa	test P_t kN	P_t/R_n
ST1-1	6.25	31.75	63.5	17.5	50.8	2	4	263	310	500	0.98
ST1-2	6.25	31.75	63.5	17.5	50.8	2	4	263	310	540	1.06
ST1-3	6.25	31.75	63.5	17.5	50.8	2	4	263	310	524	1.03
ST1-4	6.25	31.75	63.5	17.5	50.8	2	4	263	310	526	1.03
ST1-5	6.25	31.75	63.5	17.5	50.8	2	4	263	310	524	1.03
ST2-1	6.25	31.75	63.5	17.5	101.6	2	4	263	310	610	1.00
ST2-2	6.25	31.75	63.5	17.5	101.6	2	4	263	310	620	1.02
ST2-3	6.25	31.75	63.5	17.5	101.6	2	4	263	310	634	1.04
ST2-4	6.25	31.75	63.5	17.5	101.6	2	4	263	310	626	1.03
ST2-5	6.25	31.75	63.5	17.5	101.6	2	4	263	310	600	0.99
ST3-1	6.25	31.75	63.5	17.5	50.8	2	7	263	310	900	1.01
ST3-2	6.25	31.75	63.5	17.5	50.8	2	7	263	310	885	0.99
ST3-3	6.25	31.75	63.5	17.5	50.8	2	7	263	310	885	0.99
ST3-4	6.25	31.75	63.5	17.5	50.8	2	7	263	310	850	0.95
ST3-5	6.25	31.75	63.5	17.5	50.8	2	7	263	310	885	0.99
ST4-1	6.25	31.75	63.5	17.5	101.6	2	7	263	310	980	0.99
ST4-2	6.25	31.75	63.5	17.5	101.6	2	7	263	310	980	0.99
ST4-3	6.25	31.75	63.5	17.5	101.6	2	7	263	310	970	0.98
ST4-4	6.25	31.75	63.5	17.5	101.6	2	7	263	310	950	0.96
ST4-5	6.25	31.75	63.5	17.5	101.6	2	7	263	310	990	1.00

MARSH (1979); 6063-T6

	in.	in.	in.	in.	in.			k/in²	k/in²	k	
1	0.250	0.50	0.00	0.406	1.00	2	1	25	30	8.1	1.01
2	0.250	0.75	0.00	0.406	1.00	2	1	25	30	10.0	0.97
3	0.250	1.00	0.00	0.406	1.00	2	1	25	30	12.5	1.00
4	0.250	0.75	0.00	0.406	0.75	3	1	25	30	10.5	0.95
5	0.250	0.50	0.00	0.406	1.00	3	1	25	30	11.7	0.94
6	0.250	0.75	0.00	0.406	1.00	3	1	25	30	14.7	1.00
7	0.250	1.00	0.00	0.406	1.00	3	1	25	30	17.1	1.01
8	0.250	0.50	1.00	0.406	0.00	1	2	25	30	11.0	1.02
9	0.250	0.75	1.00	0.406	0.00	1	2	25	30	12.2	0.94
10	0.250	1.00	1.00	0.406	0.00	1	2	25	30	14.4	0.94
11	0.250	0.50	1.00	0.406	1.00	2	2	25	30	14.5	0.95
12	0.250	0.75	1.00	0.406	1.00	2	2	25	30	16.5	0.94
13	0.250	1.00	1.00	0.406	1.00	2	2	25	30	18.5	0.94
14	0.250	0.50	1.00	0.406	1.00	3	2	25	30	17.6	0.89
15	0.250	0.75	1.00	0.406	1.00	3	2	25	30	19.5	0.89
16	0.250	1.00	1.00	0.406	1.00	3	2	25	30	19.9	0.82

Notes

1. $R_n = [F_{su}\,(A_{nv} + A_{gv})/2 + F_{tu}\,A_{nt}]/k_t$

Mean **0.98**

Min 0.82 Max 1.06

COV **0.048**

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J.9 FLANGES AND WEBS WITH CONCENTRATED FORCES

Section J.9 addresses flange local bending, web local yielding, and web crippling. Examples of applications of this section include beam-column connections, beam support reactions, and hanger loads on beams. In addition to this Section, designers may wish to consult the AISC *Specification* regarding web sidesway buckling, web compression buckling, and web panel-zone shear and consider appropriate adjustments for aluminum. Use of the AISC approaches to these issues may require investigation beyond substituting material mechanical properties.

J.9.1 Flange Local Bending

Flange local bending assumes a single tensile concentrated line load applied transverse to an I-section flange by a welded connection. It does not apply to other shapes or loading conditions. This section is based on the same rationale as the AISC *Specification* and given in Graham, et. al. (1959). Graham determined the flange local bending strength using yield line theory assuming that the effective length of the flange was $12t_f$. He determined the minimum strength for standard steel rolled shapes and conservatively factored this strength by 0.8 to establish a nominal strength of $6.25F_{tyf}\,t_f^2$.

Applying Graham's approach to shapes with the Aluminum Association standard I shape dimensions gives very similar results, as shown in Table CJ.9.1. While the effective flange length used in Table CJ.9.1 is $12t_f$, the calculated strength exceeds $6.25F_{tyf}\,t_f^2$ for any flange effective length. Although a strength of $6.25F_{tyf}\,t_f^2$ is thus likely conservative, in the absence of tests and for simplicity, the AISC strength is used in the *Specification*. Because the load is delivered to the beam flange by a welded connection, the welded yield strength of the flange is conservatively used for simplicity (even though the entire effective length of the beam flange may not be weld-affected).

Table CJ.9.1

Size	d (in.)	b_{fc} (in.)	t_f (in.)	t_w (in.)	R (in.)	m (in.)	n	C	$(2Ct_f^2 + mt_f)/t_f^2$
AW 3 x 1.64	3.000	2.500	0.200	0.130	0.250	0.630	0.804	3.97	11.1
AW 3 x 2.03	3.000	2.500	0.260	0.150	0.250	0.650	0.868	4.48	11.5
AW 4 x 2.31	4.000	3.000	0.230	0.150	0.250	0.650	0.780	3.86	10.6
AW 4 x 2.79	4.000	3.000	0.290	0.170	0.250	0.670	0.841	4.22	10.8
AW 5 x 3.70	5.000	3.500	0.320	0.190	0.300	0.790	0.829	4.12	10.7
AW 6 x 4.03	6.000	4.000	0.290	0.190	0.300	0.790	0.757	3.79	10.3
AW 6 x 4.69	6.000	4.000	0.350	0.210	0.300	0.810	0.811	4.01	10.3
AW 7 x 5.80	7.000	4.500	0.380	0.230	0.300	0.830	0.795	3.93	10.0
AW 8 x 6.18	8.000	5.000	0.350	0.230	0.300	0.830	0.734	3.74	9.8
AW 8 x 7.02	8.000	5.000	0.410	0.250	0.300	0.850	0.782	3.87	9.8
AW 9 x 8.36	9.000	5.500	0.440	0.270	0.300	0.870	0.771	3.83	9.6
AW 10 x 8.65	10.000	6.000	0.410	0.250	0.400	1.050	0.730	3.73	10.0
AW 10 x 8.65	10.000	6.000	0.500	0.290	0.400	1.090	0.791	3.91	10.0
AW 12 x 11.7	12.000	7.000	0.470	0.290	0.400	1.090	0.717	3.71	9.7
AW 12 x 14.3	12.000	7.000	0.620	0.310	0.400	1.110	0.800	3.95	9.7
AW 14 x 16.0	14.000	8.000	0.600	0.300	0.400	1.100	0.745	3.76	9.4
								average	10.2
							Compare to 6.25:	min	9.4
								max	11.5

where:

b_{fp} = loaded width of the flange, taken in the table above as the full flange width b_f

$p = K_fl\,t_f$ = effective length of the flange

t_f = flange thickness

t_w = web thickness

K_fl = effective length factor for the flange

$m = t_w + 2R$

R = inside radius of the web-flange fillet

$q = (b_f - m)/2$

$l = (b_{fp} - m)/2$

$\beta = p/q$

$\lambda = l/q$

$$n = \frac{\beta}{4}\left(\sqrt{\beta^2 + 8\lambda} - \beta\right)$$

$$C = \frac{4/\beta + \beta/n}{2 - n/\lambda}$$

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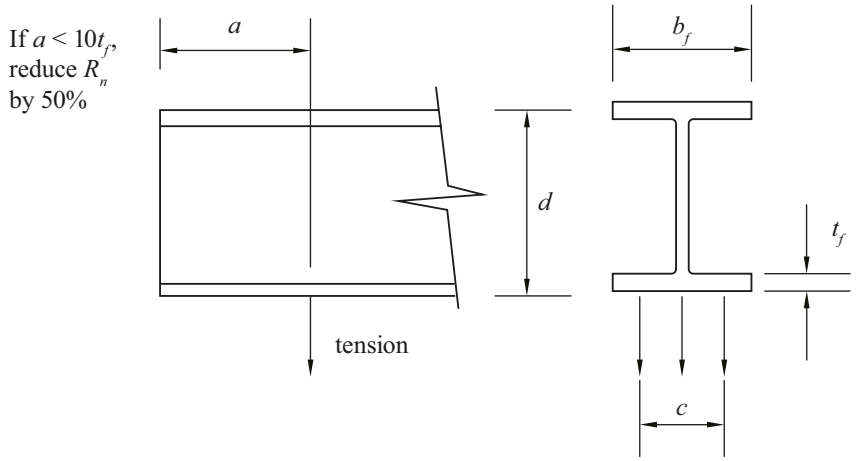

Figure CJ.9.1
FLANGE LOCAL BENDING

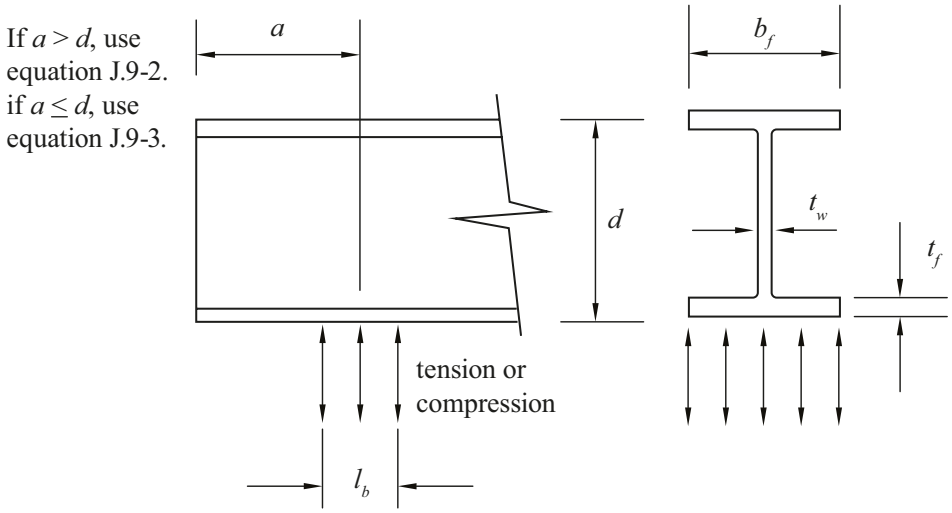

Figure CJ.9.2
WEB LOCAL YIELDING

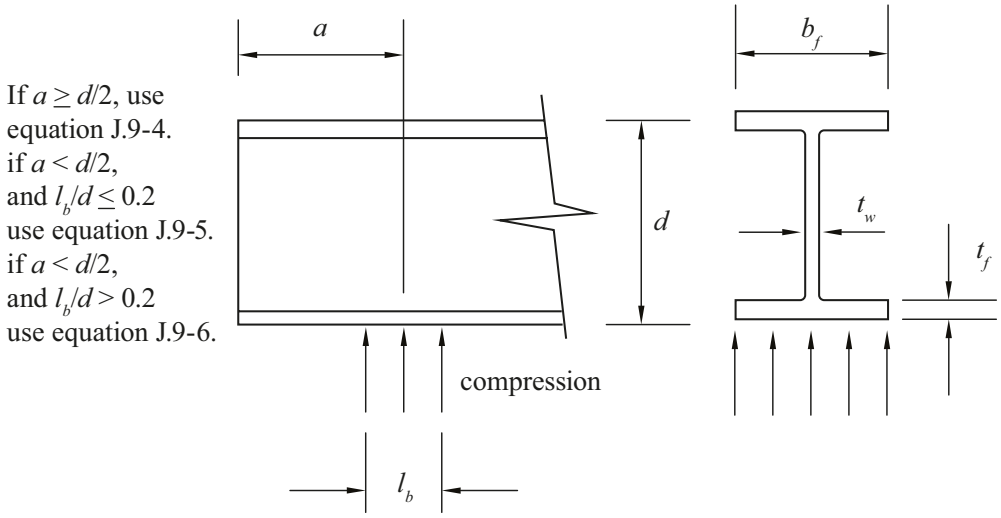

Figure CJ.9.3
WEB CRIPPLING OF EXTRUDED MEMBERS

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J.9.2 Web Local Yielding

This section is based on the approach developed by Roberts and Rockey (1979) and Roberts (1981) and as summarized by Gozzi (2007) using a four-hinge mechanism for web yielding and equating the internal and external work done. When the yield strength of the flange and web are the same ($F_{yw} = F_{yf}$), the web-flange fillet radius equals the flange thickness t_f, and the ratio of flange width to web thickness $b_f/t_w = 20$ (as are typical), the web yield strength is $F_{yw}\ t_w\ (l_b + 9t_f)$, which is very similar to the AISC strength of $F_{yw}\ t_w\ (l_b + 5k) = F_{yw}\ t_w\ (l_b + 10t_f)$. Since yielding is not a function of the elastic modulus, the yield strength is not affected by the different moduli of steel and aluminum. The *Specification* uses the more general equation in order to address the greater variety of shapes encountered in aluminum.

J.9.3 Web Crippling

This section addresses web buckling. Both web buckling and web local yielding (Section J.9.2) must be checked.

J.9.3.1 Web Crippling of Extruded Members

This section is based on the approach developed by Roberts and Rockey (1979) and Roberts (1981). The equations used in this section are the same as used in the AISC *Specification*.

J.9.3.2 Web Crippling of Formed Sheet Members

The formulas given in this Section are based on Sharp (1993), who tested aluminum formed sheet members. The crippling strength is a post-buckling strength.

J.9.3.3 Combined Crippling and Flexure of Flat Webs

The formulas given in this Section are empirical, based on Sharp (1993).

J.9.4 Supports for Flexural Members

Unless other means are provided, a pair of transverse stiffeners, one on each side of the web, are required at beam support points to satisfy the Chapter F requirement that beams be restrained against rotation about their longitudinal axis at supports. Such stiffeners are connected to the restrained flange (for example, the bottom flange at the end of a beam with its bottom flange supported on a bearing plate and anchored to a foundation), but do not need to extend beyond the toe of the fillet of the other flange unless connection to the other flange is required for other purposes, such as resisting a concentrated compression load on the other flange.

J.9.5 Additional Stiffener Requirements for Concentrated Forces

The AISC Design Guide 13, *Stiffening of Wide-Flange Columns at Moment Connections: Wind and Seismic Applications*, has additional information.

J.9.6 Additional Doubler Plate Requirements for Concentrated Forces

A doubler plate is a plate parallel with a member's web, added to increase the member's strength where concentrated forces act on the member. When doublers are required, the sum of the strengths of the member element and the doubler(s) must exceed the required strength and the doubler plate must be welded to the member element.

J.10 ROOFING AND SIDING CONNECTIONS

J.10.3 Fasteners in Laps

The minimum size of #12 screws or 3/16 in. (5 mm) diameter rivets is specified in end laps and side laps to give neat, weather-resistant closures. In many cases, the primary, sheet-to-support fasteners will give satisfactory closures at the endlaps, but in side laps additional fasteners should be used if the joint does not interlock.

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Chapter L Design for Serviceability

L.1 GENERAL PROVISIONS

This chapter addresses preserving a structure's appearance, maintainability, durability, occupants' comfort, or function. Specific limits on parameters (for example, deflection) are not provided, since these depend on the type of structure and its use.

L.2 CAMBER

Camber should be measured without load acting in the camber plane. This may be achieved by measuring camber with a beam resting on a flat surface parallel to the camber plane.

L.3 DEFLECTIONS

Members and structures deflect under load. For example, the lateral deflection of a building under wind load is called drift.

If the compressive stress exceeds the elastic local buckling stress F_c, the full section is not effective in resisting deflection. This *Specification* only allows this if the element strength is based on post-buckling strength as it is in Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, and B.5.5.3. Reduced effective section provisions do not apply to B.5.4.4, for example, since this section does not allow post-buckling strength for such elements (supported on both edges and with an intermediate stiffener). The method used to account for the effect of local buckling on the post-buckling behavior of structural members is to consider that at stresses above the local buckling stress only part of the buckled element is effective in carrying load. Sooi and Peköz (1993) and Jombock and Clark (1968) documented this approach.

AAMA TIR A11 limits deflections of components that support glass or similar brittle materials. Some building codes also limit deflections.

L.4 VIBRATION

Vibration of aluminum structural members can cause fatigue failures. Vibrations may be caused by cyclically applied loads from machinery, by wind or other fluids moving over the structure, or by traffic on a bridge. When the frequency of the applied load is close to the natural frequency of the structure, the amplitude of the vibrations can be large, especially for lightly damped structures. The amplitude of the vibrations can be minimized by adjusting the stiffness of the structural components so that the natural frequency of the structure is less than half or more than twice the frequency of the applied loads or by sufficiently dampening the structural movement.

L.5 WIND-INDUCED MOTION

Wind on round tube members can cause motion of the members due to vortex shedding, by which regular impulses transverse to the wind direction are caused by the shedding of vortices on alternating sides of the member. Sharp (1993) gives the frequency of vortex shedding as

$$f = SV/d$$

where f = vortex shedding frequency
V = wind velocity
d = outside diameter of tube
S = Strouhal number = 0.2 for tubes.

If this frequency is near the natural frequency of the tube and sufficient damping is not provided, wind-induced motion will be large. (See Section L.4).

L.6 EXPANSION AND CONTRACTION

Aluminum's coefficient of thermal expansion is approximately $13 \times 10^{-6}/^{o}F$ ($23 \times 10^{-6}/^{o}C$). For structures exposed to ambient temperature fluctuations, provision for thermal movement such as expansion joints may be required to limit stresses.

L.7 CONNECTION SLIP

Slip-critical connections are addressed in Section J.3.7.

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M.2 CUTTING

M.2.1 Methods

The heat of plasma arc and laser cutting tends to produce edge cracking, especially in heat treatable alloys (2xxx, 6xxx, and 7xxx series). AWS D1.2 has additional requirements for edges that will be welded.

M.2.2 Edge Quality

The edge quality roughness requirement is the same as in the AISC *Specification*.

M.2.3 Re-entrant Corners

Fillets reduce stresses at re-entrant corners of parts. The proper fillet radius varies depending on the part and its use. AWS D1.1:2015, the steel structural welding code, Section 5.15, requires a minimum fillet radius of 1 in. (25 mm). AWS D1.2:2014, the aluminum welding code, Section 4.13, requires ½ in. (12 mm) for statically loaded members and ¾ in. (20 mm) for cyclically loaded members. In *Specification* Table 3.1, the smallest radius for attachments for which fatigue categories are provided is 2 in. (50 mm). *Specification* Section 3.4 specifies a minimum radius of ¾ in. for members subject to fatigue.

M.3 HEATING

Base metal alloys 535.0, 5083, 5086, 5154, and 5456 and filler alloys 5183, 5356, 5556, and 5654 have magnesium contents greater than 3%. When such alloys are held within the temperature range of 150°F (66°C) to 450°F (230°C), they may "sensitize" and subsequently suffer exfoliation and stress corrosion cracking. The length of time in this temperature range determines the degree of sensitization to exfoliation and stress corrosion cracking.

The strength of tempered metal can be reduced by exposure to elevated temperature processes (such as factory paint curing, firing of porcelain enamel coatings, and hot forming). See the commentary to Section A.4.1.1.

M.4 HOLES

M.4.1 Fabrication Methods

The prohibition against punching parts thicker than the hole diameter is to guard against break-out at the back side of the hole.

M.5 BENDING

Minimum bend radii for 90° cold forming of sheet and plate are given in Part VI Table 3-1 for various alloys and tempers. These radii are approximate and are a function of the direction of the bend line with respect to the rolling or extruding direction. Cracking of heat treated alloys is more readily avoided with the bend line perpendicular to the rolling or extrusion direction, while the opposite is true for non-heat treatable alloys.

M.6 FINISHES

M.6.1 Where Protective Coating Is Required

Examples of protective coatings include anodizing, painting, and Alclad products.

The American Architectural Manufacturers Association offers these Voluntary Specification, Performance Requirements and Test Procedures for coating aluminum:

AAMA 2603 Pigmented Organic Coatings on Aluminum Extrusions and Panels

AAMA 2604 High Performance Organic Coatings on Aluminum Extrusions and Panels

AAMA 2605 Superior Performing Organic Coatings on Aluminum Extrusions and Panels.

Where water is allowed to stand between aluminum parts in contact, oxidation called water staining may result. While this oxidation has little or no effect on material strength and will not progress after the water is removed, it is unsightly and difficult to remove. It can be prevented by keeping aluminum dry or out of contact with other aluminum parts when moisture can be present.

M.6.2 Surface Preparation

Proper surface preparation is required for good paint adherence.

M.6.3 Abrasion Blasting

Abrasion blasting can be used to clean material or finish the surface. Abrasive media includes steel grit, silica sand, aluminum oxide, crushed walnut shells, or coal slag. Peening can be used to improve fatigue strength by introducing compressive stress near the surface and is typically achieved with steel or stainless steel shot.

Residual stresses from blasting or peening can curl thin material. Abrasion blasting may also reduce the thickness of material. Consideration should be given to the effect on strength if the thickness is reduced by more than standard mill tolerances for the material.

M.7 CONTACT WITH DISSIMILAR MATERIALS

Isolators such as Teflon and neoprene may be placed between aluminum and other materials to prevent contact. The isolator must be nonporous to avoid trapping water or other substances in the joint and compatible with both the aluminum and the dissimilar material in the intended service.

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Aluminum may be coated to prevent contact between aluminum and other materials. Consult paint manufacturers for information on suitable paints and their application. Care should be taken to avoid heating above 150°F during the coating process as this may reduce the strength of aluminum products.

M.7.1 Metals

The electrical potential difference between aluminum and zinc and cadmium in salt water is small, so galvanic corrosion usually will not occur when aluminum is in contact with these metals. Doyle and Wright (1988) conducted tests showing that zinc-coated steel is especially effective in resisting atmospheric exposure galvanic corrosion when in contact with aluminum. Coating the steel is usually more effective than coating the aluminum to prevent galvanic corrosion between aluminum and steel. Additional information on galvanic corrosion is given in Part III Section 6.

For 300-series stainless steel, the oxide layer limits corrosion current to small values because stainless steels are easily polarized in mild environments. This layer results in less corrosion than would otherwise be expected based on the relative positions in the galvanic series for stainless steel and aluminum. [See ASM Handbook (vol. 13B, page 102; dated 2005) and other corrosion references.]

Some metals can cause deposition corrosion of aluminum. Copper is the most common of these metals used in construction, but terne-coated steel (which has a lead/tin coating) may also have this effect.

See Section A.4.5 regarding the use of steel fasteners to connect aluminum parts.

M.7.2 Wood, Fiberboard, or Other Porous Materials

Wood that has been treated with preservatives is usually corrosive to aluminum. Chromated copper arsenate (CCA) treated wood is about twice as corrosive to aluminum as non-treated wood. Residential use of CCA treated wood ended in 2003 and was replaced by alkaline copper quaternary (ACQ) treated wood, which is about four times as corrosive to aluminum as untreated wood. ASTM G198, *Standard Test Method for Determining the Relative Corrosion Performance of Driven Fasteners in Contact with Treated Wood*, may be helpful in addressing this issue.

M.7.3 Concrete or Masonry

To avoid staining and surface corrosion, mill finished aluminum and anodized aluminum should be protected from uncured concrete, mortar, and similar alkaline substances and muriatic acid used in cleaning concrete and masonry.

Masonry products designed to remain at a relatively low pH during and after curing (such as magnesium phosphate grout, which does not exceed a pH of 8.5) do not corrode aluminum.

M.8 FABRICATION TOLERANCES

The *L*/960 straightness tolerance in the *Code of Standard Practice for Fabricating and Erecting Structural Aluminum*, was chosen so that the reduction in buckling strength versus a perfectly straight member is no greater than about 20%. The standard tolerance for some mill products does not meet the *L*/960 straightness tolerance for fabricated members required here (Aluminum Association (2017)). (An example is T6511 extrusions with wall thicknesses less than 0.095 in. (2.5 mm)). Such members may require additional straightening or tighter tolerance specifications to meet the requirements of this Section.

M.9 WELDING

AWS D1.2 provides requirements for qualifying, fabricating, and inspecting aluminum welds. Welding is done in the shop or in an enclosure because shielding gas must cover the arc and wind can disrupt the shield.

Groove welds (Figure CM.9.1) are utilized for butt joints. Groove welds are shaped for ease of root penetration, to allow for less dilution of the filler by the base metal (where hot cracking is a problem), or to permit a desirable sequence of weld bead depositions when welding in other than flat positions. Fatigue strength can be significantly increased by removing weld reinforcement.

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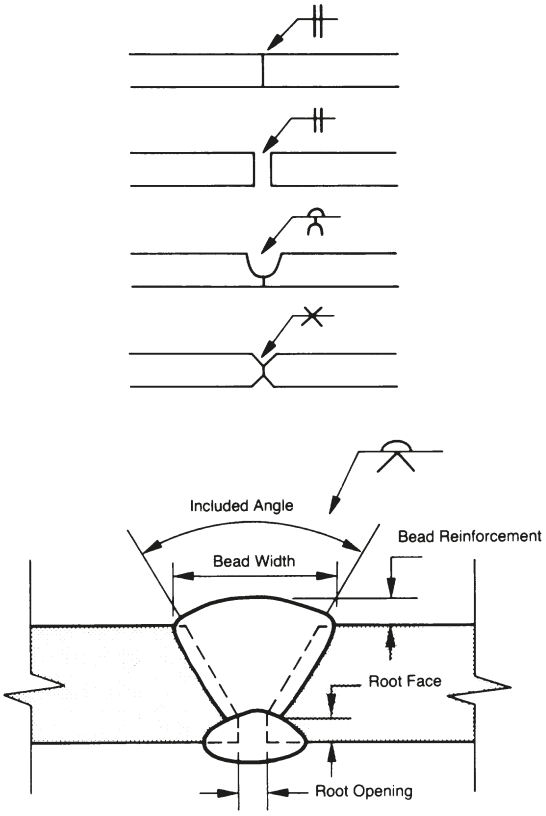
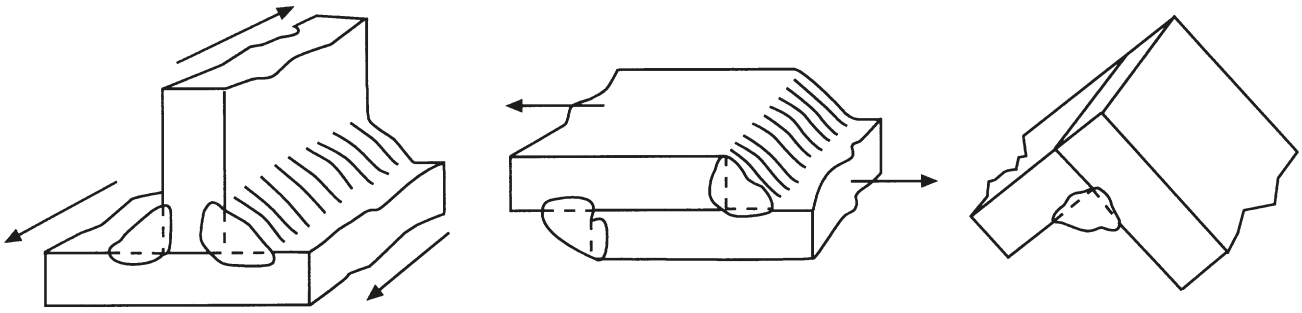


Figure CM.9.1

Fillet welds (Figure CM.9.2) are used to join surfaces to each other in lap, T, or corner joints; the filler usually determines the strength of these joints. A sounder and more economical structure results from using continuous welds rather than intermittent ones. While an intermittent weld may reduce welding time, filler wire consumption, heat input and/or distortion, it may produce unfavorable local stress concentrations. The possibility for poor weld quality and end craters increases with the repeated stopping and restarting of the welding. Since the cost of fillet welds is a function of the square of their size, large intermittent welds are not as efficient in carrying loads as small continuous fillets. Intermittent welds also make a structure more susceptible to moisture infiltration, which may ultimately lead to corrosion.

Fillet welds exhibit different strengths depending on the geometry of the part and the type of loading on the weld. The filler shear strengths in the *Specification* are based on tests of longitudinal fillet welds (see Figure CM.9.2a), which results in pure shear on the throat of the weld. Transverse welds (Figure CM.9.2b is one type) can have higher strengths in some cases, since the stress on the weld throat is a combination of shear and tension.



a. Longitudinal Fillet **b. Transverse Fillet** **c. Corner Weld**

Figure CM.9.2

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There are many joint details that can be utilized to improve weld performance:

1) A butt joint between different thicknesses of metal should have the thicker one beveled to match the thinner one (Figure CM.9.3). This helps balance the heat sink for uniform melting and good fusion, and reduces the stress raiser caused by change in thickness.

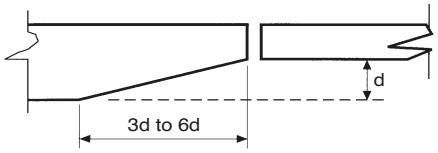

Figure CM.9.3

2) Welds may have lower strength than the base metal (e.g., welds in 6061-T6 alloy). One way to reduce the effect this has on load carrying capacity is by locating the welds in areas of low stress. Beams can be fabricated by welding together longitudinal extrusions with joints located in webs near the neutral axis (Figure CM.9.4). Since the web is often much thinner than the flanges, the amount and cost of welding are reduced.

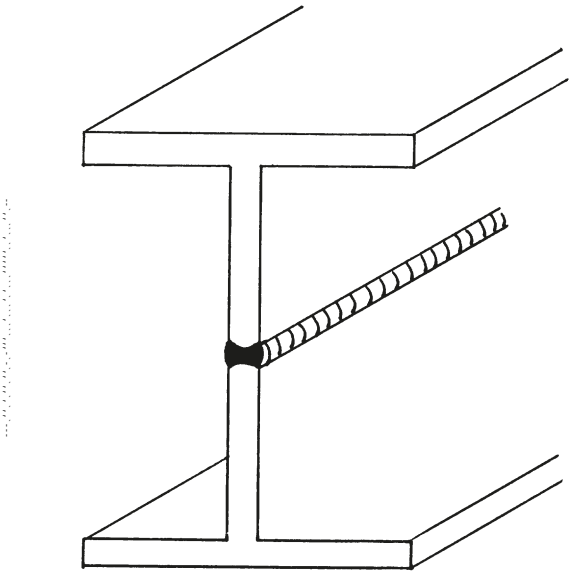

Figure CM.9.4

3) Rectangular doubler plates welded on four sides have transverse welds which reduce the member's strength. If only the sides of the doubler are welded, the longitudinal welds may become so highly stressed that they fail. When a doubler plate is necessary, it should be diamond shaped (Figure CM.9.5), avoiding a sudden cross-sectional change.

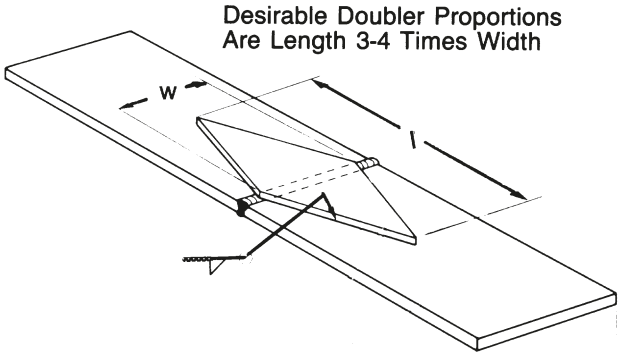

Figure CM.9.5

No welding should be done across the ends. The doublers should be as wide as possible, consistent with leaving room for a fillet weld on each side. The doubler length (l) should be greater than its width (w) by a ratio of at least 3 to 1, which orients the fillet welds nearly parallel to the stress direction.

4) When stiffening a panel or member, care should be taken to avoid abrupt changes in cross sections. Reinforcing stiffeners should have tapered ends (Figure CM.9.6) to avoid fatigue cracks at the end of the stiffener.

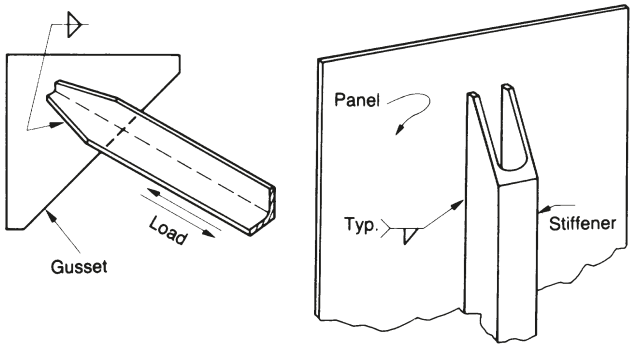

Figure CM.9.6

5) A common design issue is joining members at corners to give an economical, structurally sound, and aesthetically pleasing connection. Figure CM.9.7 illustrates corner details. Double fillets or bends to allow a butt or a lap joint should be used.

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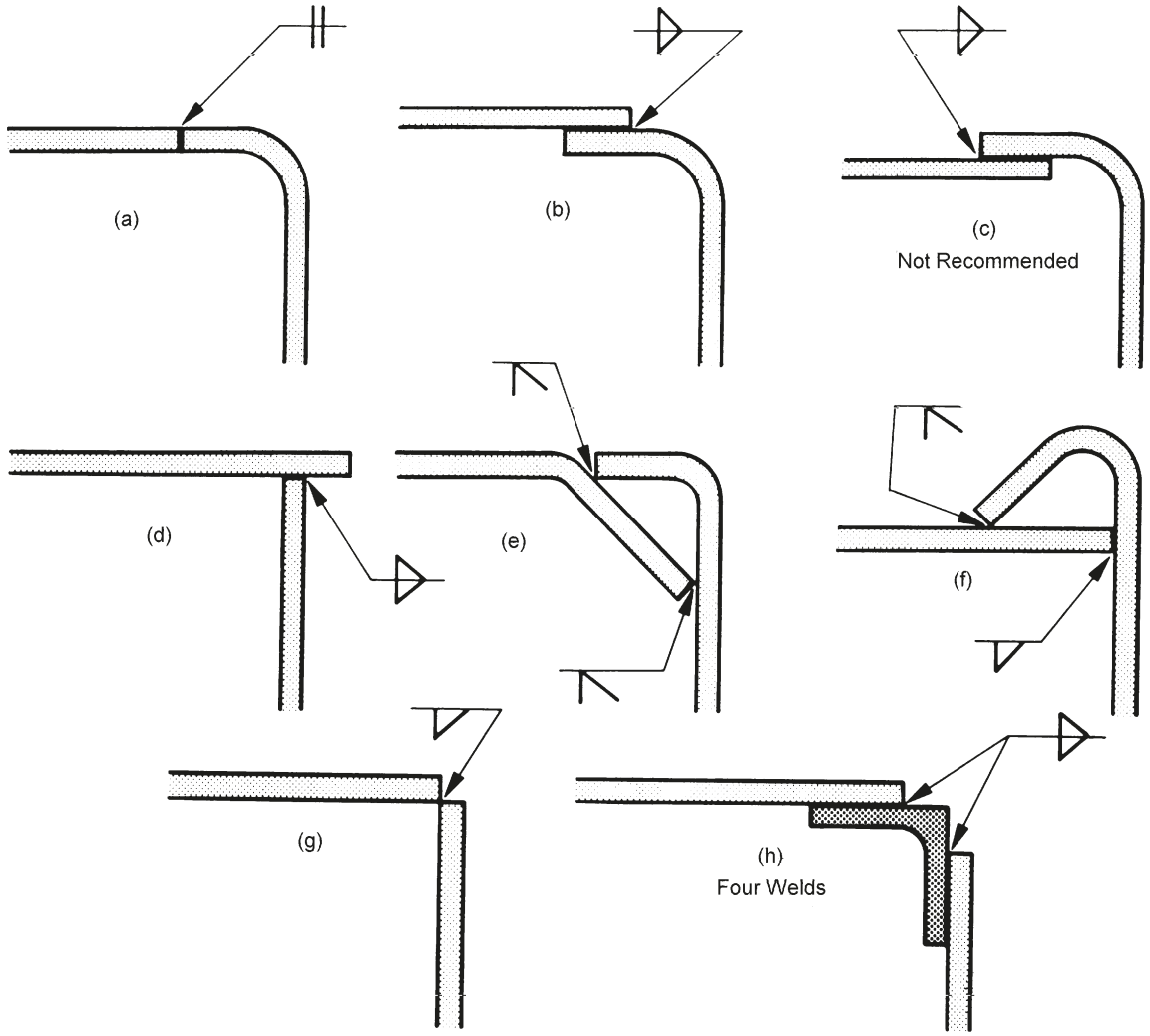

Figure CM.9.7

6) When sheets are to be welded to extruded members, an attempt is sometimes made to use a joint opening between sheets and make a groove weld (Figure CM.9.8). In effect, what is desired resembles a slot weld, which seldom proves practical. The joint fit and the welding procedure are both critical if the sheet edges are hot enough to melt back from the joint when the welding current is high enough to penetrate the extrusion. Therefore, conventional lap joints are recommended instead for this application.

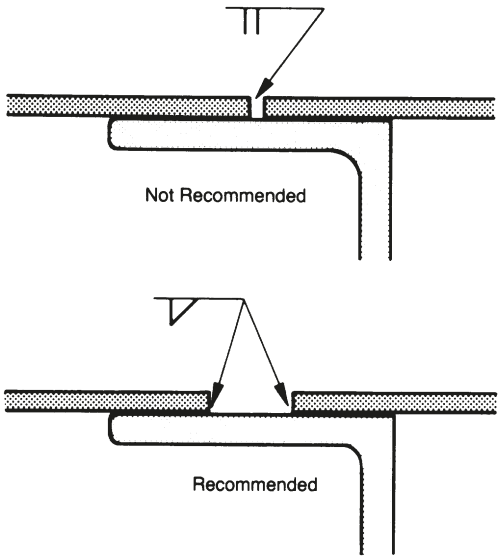

Figure CM.9.8

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M.10 BOLT INSTALLATION

Snug tightness, a condition achieved when all plies in a joint are in firm but not necessarily continuous contact, can usually be attained by a few impacts of an impact wrench or the full effort of a person using an ordinary spud wrench. A specific clamping force is not necessary in non-slip-critical connections because the design accounts for parts slipping relative to each other.

No rules for determining the tightening torque for aluminum bolt bearing connections have been established because test results vary widely depending on the friction developed in the threads and other bearing surfaces. A recommendation sometimes made for establishing a tightening torque for aluminum bolts is as follows: Tighten several bolts of a given size and type to the breaking point under the same conditions of lubrication as will be encountered on the job and use 70% or 80% of the lowest torque obtained from the tests. The 70% value should be used for bolts that may need to be removed occasionally, while the 80% value applies to permanent bolts. Lubricating the threads and bearing surfaces is helpful.

These recommendations for tightening may be modified for bolts or other threaded parts that carry fluctuating axial tensile loads that can cause fatigue failures. Under these conditions, the tightness (initial axial tensile load) should be slightly more (about 5%) than the maximum tensile load on the bolts during service. There are many devices available to prevent loosening, and guidance is available for their use (AAMA (2014)). Lock washers are commonly used; less common are locking inserts built into the nut threads.

For slip-critical bolted connections, minimum bolt tensions from the RCSC *Specification* are given in the Table CM.10.1.

Table CM.10.1
MINIMUM BOLT TENSION FOR SLIP-CRITICAL JOINTS

Bolt Diameter (in.)	A325 Bolt Tension (k)
1/2	12
5/8	19
3/4	28
7/8	39
1	51
1 1/8	56
1 1/4	71
1 3/8	85
1 1/2	103

Turn-of-nut tightening of slip-critical connections is performed by bringing the assembly to a snug tight condition and then applying a prescribed number of turns of the nut. Aluminum's lower modulus of elasticity versus steel means more turns would be needed for aluminum assemblies than for steel assemblies if the bolt tension at the start of turn-of-nut tightening were the same for both steel and aluminum assemblies. However, the flexibility of aluminum parts enables them to be brought closer to full contact by snug tightening than steel, resulting in higher bolt tension in aluminum assemblies at the beginning of turn-of-nut tightening. The net effect, confirmed by testing, is that aluminum assemblies require approximately the same number of turns as steel assemblies after the snug tight condition is attained to reach the bolt tension prescribed above.

Galvanizing increases the friction between the bolt and nut threads and makes torque-induced tension more variable, but lubrication both reduces the torque and makes it more consistent. Therefore, ASTM A325 requires that a galvanized bolt and lubricated galvanized nut be assembled in a steel joint with a galvanized washer and tested in accordance with ASTM A563 by the manufacturer prior to shipping to assure that the fastener can be rotated beyond the required rotation from the snug-tight condition without breaking. Since some lubricants are water soluble, galvanized bolts and nuts should be shipped in plastic bags in wood or metal containers.

M.11 RIVET INSTALLATION

M.11.1 Driven Head

Rivet head styles are shown in the 2005 ADM, Part VII, Table 5-6. Part VII, Table 5-13 provides maximum rivet grips for given lengths for flat driven heads.

M.11.2 Hole Filling

Recommended hole diameters for cold-driven rivets are shown in the 2005 ADM, Part VII, Table 5-8. Rivet lengths are given in Part VII, Table 5-12 for various grips and diameters.

M.12 ERECTION TOLERANCES

Erection tolerances are often expressed in terms of tolerances on the plumbness and levelness of structural members. The erection tolerances used for the stability analysis performed in accordance with Chapter C must not be greater than the erection tolerances used in construction.

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Chapter N Quality Control and Quality Assurance

N.1 SCOPE

This chapter was added to the *Specification* in 2015.

N.2 FABRICATOR QUALITY CONTROL PROGRAM

Because different aluminum alloys have a similar appearance but different properties, it is important to maintain identification of aluminum products. ASTM B666 provides identification marking requirements for aluminum products. ASTM aluminum product specifications such as B209 (sheet and plate) do not require identification marking of aluminum products unless the purchaser specifies such identification.

The *Specification for Aluminum Structures* requires that aluminum welding comply with AWS D1.2, which requires that welding procedure specifications (WPSs) be qualified by the company that will use them. This qualification is recorded in the procedure qualification record (PQR). D1.2 does not allow the use of prequalified welding procedure specifications.

ASTM aluminum product specifications such as B209 do not require material certification unless the purchaser specifies such certification. Since Section N.2 requires that fabricators and erectors obtain material certification, fabricators and erectors must specify material certification when they purchase aluminum material in order to comply with Section N.2.

N.3 ERECTOR QUALITY CONTROL PROGRAM

See the commentary to Section N.2.

N.5 INSPECTION REQUIREMENTS

AWS D1.2 requires that all welds be visually inspected by the entity performing the welding. Additional inspection (RT, UT, or PT) is only performed when required by the contract documents. The extent of RT, UT, or PT is also determined by the contract documents. Acceptance criteria for RT and PT are given in AWS D1.2.

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Appendix 1 Testing

1.1 GENERAL PROVISIONS

An example of a nationally recognized accreditation service is the International Code Council's (ICC) International Accreditation Service (IAS). The ICC publishes the *International Building Code*.

1.3 DESIGN BASED ON TESTING

The *Specification* provides two methods by which design based on testing can be performed:

Method 1: Using a) a minimum strength determined from the average test strength, number of tests, and variation in the test strengths in accordance with Section 1.3.1 with b) the safety and resistance factors given in the *Specification*, or

Method 2: Using a) the average test strength with b) safety factors adjusted upward or resistance factors adjusted downward from the safety and resistance factors given in the *Specification* in accordance with Section 1.3.2.

These methods are equally valid. When numerous test results are available, as is more often the case with small specimens such as fasteners, Method 1 may be more easily performed; for large assemblies for which individual tests are expensive and the number of tests conducted is small, Method 2 may be more easily performed.

1.3.1 Method 1

Section 1.3.1 provides an equation to statistically establish the strength, with a confidence of 95%, which 99% of the material is expected to exceed. This nominal strength, which is the minimum strength used elsewhere in the *Specification*, is applied in conjunction with the resistance or safety factors given in the *Specification*. Equation 1.3-1 is from Goepfert (1994). Values for K are taken from Juran (1988) and are one-sided factors affording 95% confidence that at least 99% of the population would fall above the predicted minimum value. Johnson (1994) provides K values for several n values greater than 100, including $K = 2.326$ for n = infinity. (See Section A.4.2 for discussion of the statistical basis for mechanical properties of aluminum alloys).

1.3.2 Method 2

Resistance and safety factors determined in Section 1.3.2 are based on the methods used to determine the resistance and safety factors given in the *Specification*. Method 2, therefore, produces resistance and safety factors similar to those in the *Specification* when many tests are performed, the default values for α, M_m, F_m, V_M, and V_F apply, and V_P is small (i.e., the test results vary little).

The coefficient of variation V_P of the test results is the coefficient of variation for the sample. The correction factor C_n accounts for the effect of a small number of tests; as the number of tests increases, the effect of C_n becomes negligible.

1.4 TESTING ROOFING AND SIDING

Deflection limits for roofing and siding tests should be selected accounting for the possibility of ponding.

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Appendix 3 Design for Fatigue

3.1 GENERAL PROVISIONS

Sanders and Day (1983) studied fatigue behavior of aluminum weldments. Sanders and Fisher (1985) provided the fatigue provisions that appeared in the 1986 *Specifications for Aluminum Structures*. These provisions were subsequently revised based on work by Menzemer (1992) on full scale welded beams and by Kosteas, et al. (1985).

The major factors affecting fatigue behavior are the number of stress cycles, the magnitude of the stress range, and the type and location of the member or detail. Fatigue cracks generally grow perpendicular to the plane of maximum stress. This *Specification* uses a nominal stress range determined by elastic analysis. The effect of stress concentrations are accounted for by the proper selection of fatigue details. Many other factors, including temperature, corrosive substances, weld defects, and post-weld mechanical treatment can have an effect on fatigue strength but are not addressed by this *Specification*.

Finite element analysis considers the effect of stress concentrations, so using FEA with the fatigue provisions of Appendix 3 would consider this effect twice.

If information on the number of stress cycles is available for similar structures of materials other than aluminum, the same values may be used for aluminum structures.

Wind-induced vibrations of undamped structures or components can cause large numbers of cycles and high stresses and thus should be avoided. Vibration dampers may be used to limit wind-induced vibrations. Vibration of structures caused by unbalanced forces from machinery can be minimized by the use of properly designed vibration mounts and proper design of the structure. If the loading frequency is between 1/2 and 2 times the natural frequency of a structure, damping should be considered (Sharp (1993)).

The fatigue strength of mechanically fastened connections with a stress ratio less than or equal to zero is based on Atzori, et al. (1997), who considered data from about 750 tests of bearing and friction joints with a wide variety of conditions. The data used to determine the fatigue strength of joints with a stress ratio of zero conservatively include numerous tests with a stress ratio of 0.1.

Azzam and Menzemer (2006) established the fatigue strength for detail category F1.

The use of S-N curves given in the *Specification* is the most common but is only one of five methods of designing for fatigue. The others are hot spot (addressed by Sharp (1996a, 1996b)), strain-life, fracture mechanics, and good practice design methods.

Sharp, Nordmark, and Menzemer (1996b) showed that fatigue strengths are reduced at temperatures above room temperature, and suggest that this reduction in fatigue strength may be approximately equal to the reduction in static strength.

Fatigue-resistant joints can be made using gradual changes in geometry of components and joints and avoiding areas of concentrated load and stress. Because most fatigue failures initiate at areas of localized high stress, particularly joints, these details should be designed carefully. Two approaches to address this are given below.

- Joints may be eliminated by using extrusions, thus removing sites for fatigue crack initiation. Sometimes the designer can locate joints or discontinuities in areas of low stress to improve fatigue resistance.
- Joints can be enhanced to improve fatigue strength. These include shaping the weld toes and peening the edges of the welds. Adhesives can be employed in mechanically fastened (and spot welded) joints. Tests are required to establish fatigue strength in such cases. See Section M.6.3 for the use of peening to improve fatigue life.

3.2 CONSTANT AMPLITUDE LOADING

The allowable stress range is based on a 95% confidence for 97.7% probability of survival. The constant amplitude fatigue limit was assumed to occur at 5×10^6 cycles for each detail except category F1. This *Specification's* static strength provisions limit the allowable stress range for low numbers of cycles.

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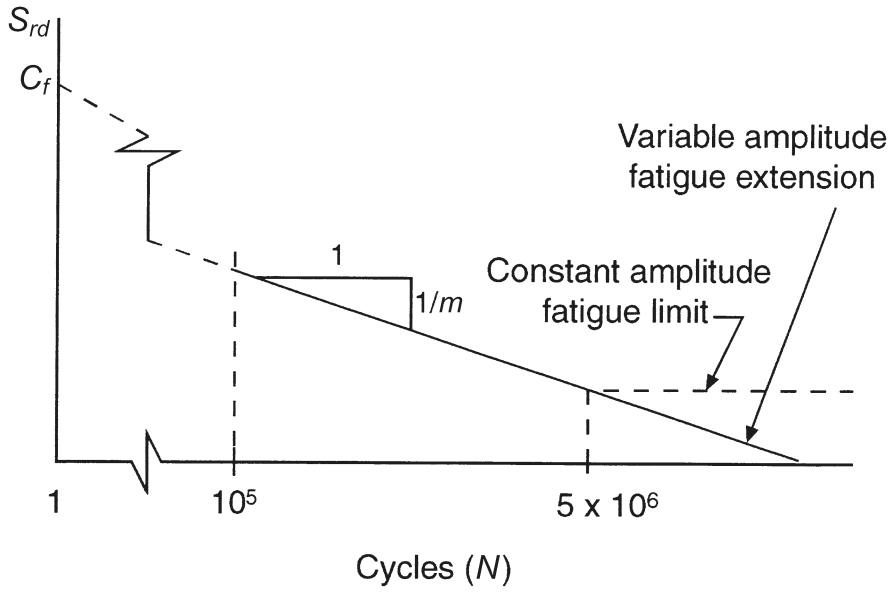

Figure C3.2.1
SCHEMATIC FATIGUE CURVE

3.3 VARIABLE AMPLITUDE LOADING

Actual load histories are frequently more complicated than the constant amplitude loading addressed in Section 3.2. Section 3.3 provides a design method for the variable amplitude loadings experienced by many structures. This equivalent stress method is based on nominal stress ranges, linear damage accumulation, and no sequencing effects. The rainflow method (Fuchs and Stephens (1980), Smith, et al. (1988)) is a commonly used cycle-counting method.

The equation for the equivalent stress range is derived from Miner's Rule when the S-N curve is a straight line in log-log space. Miner's rule is

$$\frac{\sum n_i}{N_i} \le 1.0 \qquad (3.3\text{-}1)$$

where

n_i = number of cycles of the ith stress range

N_i = number of cycles constituting failure at the ith stress range.

When this fraction approaches unity, some of the details within the group have begun to fail. Miner's rule may be used over the equivalent stress range to assess the remaining life of an existing structure or when fatigue data is not linear in the log(stress)-log(life) space.

Allowable stress ranges for variable amplitude fatigue are determined in the same manner as for constant amplitude fatigue except that the constant amplitude fatigue limit is not used because data for variable amplitude loads show continuing strength decrease at long lives. Structures subjected to variable amplitude loading may not exhibit a fatigue limit because a crack can be initiated by the higher stress cycles of the spectrum and propagate at stresses below the fatigue limit.

There also may not be a fatigue limit in mechanical connections that fail by fretting, whereby relative movement of the connected parts causes part wear to occur. Tests may be required to evaluate the possibility of fretting failures.

3.4 FABRICATION AND ERECTION REQUIREMENTS

These requirements prohibit details that cause local stress concentrations which reduce fatigue strength. The reentrant corner radius requirement is consistent with AWS D1.2:2014.

Punched or scribed layout marks serve as fatigue crack initiation sites and thus are prohibited for material subject to fatigue.

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Appendix 4 Design for Fire Conditions

4.1 GENERAL PROVISIONS

This appendix is similar to the AISC (2010) appendix on design for fire conditions. While aluminum is non-combustible as determined by ASTM E136 tests, aluminum strengths and stiffness are less at elevated temperatures than at room temperature. Batista, et. al.,(2019) compared steady-state (members are heated and then loaded) and transient methods (members are loaded and then heated) with experimental results by Maljaars, et. al., (2009) for predicting the strength of aluminum columns at elevated temperatures.

4.1.3 Load Combinations and Required Strength

The analysis must be performed in accordance with the requirements of Chapter C.

4.2 DESIGN FOR FIRE CONDITIONS BY ANALYSIS

4.2.3 Material Properties at Elevated Temperatures

Eurocode 9 Part 1-2 provides additional information on aluminum material properties at elevated temperatures.

4.2.3.1 Mechanical Properties

The modulus of elasticity E_m at elevated temperatures is not a function of time at the elevated temperature. The moduli given by Table 4.1 are from Kaufman (1999).

Strengths at elevated temperatures are a function of time at the elevated temperature. The strengths given in Table 4.2 are from Kaufman (1999) for 10 hours at the elevated temperature. Kaufman provides test data for additional alloy-tempers.

4.2.3.2 Thermal Expansion

The coefficient of thermal expansion increases with temperature and does not vary significantly by alloy.

4.2.3.3 Specific Heat

Specific heats increase with temperature.

Aluminum Standards and Data (*2017*) Table 2.3 provides thermal conductivities for aluminum alloys at room temperature. Thermal conductivities vary by alloy and temper and increase with temperature.

Appendix 5 Evaluation of Existing Structures

5.4 EVALUATION BY LOAD TESTING

Test load magnitudes may be specified by other codes or limited by the authority having jurisdiction and are not addressed in this *Specification*. The magnitude of the test load may depend on the governing limit state and the safety, resistance, and load factors used in design of the component being tested. Test loading rates and increments should be carefully considered in preparing the testing plan.

The *Specification* states that the live load rating L of the structure is determined from the relationship that the tested strength = $1.2D + 1.6L$. This expression can be written as the live load rating L = (tested strength – $1.2D$)/1.6.

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Appendix 6 Member Stability Bracing

Stability requirements for lateral force resisting systems are provided in Chapter C. Appendix 6 applies to bracing that is not generally included in the analysis model of the overall structure, but is provided to stabilize individual columns, beams, and beam-columns. More details on bracing strength and stiffness and guidance for applying these provisions is provided in the Commentary to the AISC *Specification for Structural Steel Buildings*.

6.1 GENERAL PROVISIONS

A panel brace (formerly referred to as a relative brace) controls the angular deviation of a segment of the braced member between braced points (that is, the lateral displacement of one end of the segment relative to the other). A point brace (formerly referred to as a nodal brace) controls the movement at the braced point without direct interaction with adjacent braced points. A continuous bracing system consists of bracing that is attached along the entire member length.

The stability bracing requirements in Sections 6.2, 6.3, and 6.4 are based on buckling analysis models involving idealizations of common bracing conditions. Computational analysis methods may be used for greater generality, accuracy, and efficiency for more complex bracing conditions.

6.2 COLUMN BRACING

This section provides requirements only for lateral bracing. Column lateral bracing is assumed to be located at the shear center of the column. When lateral bracing does not prevent twist, the column is susceptible to torsional buckling as addressed in Section E.2.2. When the lateral bracing is offset from the shear center, the column is susceptible to constrained-axis torsional buckling.

6.2.1 Panel Bracing

If the stiffness of the connection to the panel bracing system is comparable to the stiffness of the panel bracing system itself, the panel bracing system and its connection to the column function as a panel and point bracing system arranged in series. Such cases may be evaluated using the alternative analysis methods listed in Section 6.1.

6.3 BEAM BRACING

6.3.1.1 Panel Bracing

The stiffness contribution of the connection to the panel bracing system should be assessed as provided in the Commentary to Section 6.2.1.

6.3.2 Torsional Bracing

Torsional bracing can be provided as point bracing, such as cross frames, moment-connected beams or vertical diaphragm elements, or as continuous bracing, such as slabs or decks.

6.3.2.1 Point Bracing

$\Omega = 1.5^2/\phi = 3.00$ in Equation 6-11 because the moment term is squared.

β_{sec} can be taken equal to infinity, and $\beta_{br} = \beta_T$, when a cross-frame is attached near both flanges or a vertical diaphragm element is used that is approximately the same depth as the beam being braced.

If $\beta_{sec} < \beta_T$, equation 6-10 is negative, which indicates that torsional beam bracing will not be effective due to inadequate web distortional stiffness.

For doubly symmetric members, $c = t$ and I_{yeff} = out-of-plane moment of inertia, I_y.

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PART III
DESIGN GUIDE

The Aluminum Association

ALUMINUM
DESIGN MANUAL
2020

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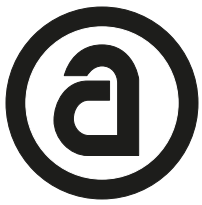
Aluminum Design Manual

PART III

Design Guide



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1. Introduction

This part of the Aluminum Design Manual addresses aluminum structural design issues not addressed in Part I, the specification for Aluminum Structures.

The nominal strength equations given in Part I may be applied to the design of any structural components, including buildings, bridges, ships, rail cars, automobiles, trucks, highway structures, and machinery. For example, the equations for a column given in the Specification apply equally to a column for a patio roof, a member in a latticed roof, a strut in a rail car or automobile, a member in a bridge truss, and a stanchion or pillar in a ship. However, the Specification (Part I) only provides resistance and safety factors for building-type structures (that is, structures addressed by a building code). Appropriate factors for other types of structures (e.g., bridges) must be determined separately.

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2. General Considerations

2.1 Aluminum's Attributes

Aluminum has many attributes that make it a cost-effective structural material. Most applications make use of a favorable life cycle cost, which includes costs for material, fabrication, erection or installation, operation, maintenance, and disposal.

For example, aluminum is the principal material in aerospace structures, primarily because of its high strength-to-weight ratio. The density of aluminum is about 1/3 that of steel, and aluminum alloys have strengths similar to those of construction steels. Aluminum aerospace structures are cost effective because smaller engines and less fuel are needed during service compared to those required for heavier structures.

Aluminum structures generally weigh 1/3 to 1/2 those of steel (see Section 2.3). Light weight and corrosion resistance are the major factors for the selection of aluminum for trucks, automobiles, and rail cars.

Aluminum's excellent corrosion resistance (see Section 6) helps reduce maintenance costs. Aluminum's corrosion resistance and its appearance, bare or finished, are major factors in its use in buildings. Many aluminum structures, such as light poles, overhead sign trusses, latticed roofs, and bridges do not require painting because of aluminum's corrosion resistance.

2.2 Alloy Selection

Sheet, plate, extrusions, forgings, and castings are made of aluminum. Alloys and tempers with both good strength and corrosion resistance are available. Aerospace alloys are generally not used for other types of structures because their combination of specialized properties results in relatively higher costs than that of other alloys. Examples of some of the common alloys and tempers used for each product are given in the following table.

Product	Application	Alloys
Sheet and Plate	Building	3105-H25, 5052-H34, 3004-H16
	Heavy Duty Structures	5083-H116, 5086-H116, 6061-T6
Extrusions	Building	6063-T5, 6063-T6
	General Purpose	6061-T6
Forgings	Wheels	6061-T6
Castings	General Purpose	356.0-T6, A356.0-T6
	High Elongation	A444.0-T4

2.3 Comparing Aluminum and Steel

Aluminum structural design is very similar to that for steel and other metals. Because many engineers are more familiar with steel than aluminum, aluminum and steel are compared in Table 2-1, taken from Sharp (1993).

Because of the difference in properties (modulus, for example), an aluminum design should be different than that for steel in order to use material efficiently. Figure 2-1 shows the relative weights of aluminum and steel box beams with the same bending strength and deflection. The yield strength of the two materials is the same. The aluminum part weighs about 50% of the steel part when its size is about 1.4 times that of steel. Other configurations provide less weight savings. Where deflection and fatigue considerations control the design, such as in bridge girders, automotive frames and other transportation vehicles, aluminum structures weigh about half that of steel structures.

TABLE 2-1

COMPARING ALUMINUM AND STEEL

Property	Steel	Aluminum	Importance for Design
Modulus of elasticity	29 x 10^3 ksi 200,000 MPa	10.1 x 10^3 ksi 70,000 MPa	Deflection of members Vibration Buckling
Weight per volume	0.284 lb/in^3 7860 kg/m^3	0.10 lb/in^3 2770 kg/m^3	Weight of product, vibration
Thermal expansion	7 × 10^{-6} /°F 12 x 10^{-6}/°C	13 x 10^{-6}/°F 23 x 10^{-6}/°C	Thermal expansion Thermal stress
Stress-strain curves	Varies	Varies	Depends on alloys. Steel often has higher strength and elongation at room temperature. Aluminum has better performance at low temperatures
Fatigue strength	Varies	Varies	For joints, aluminum has about 1/3 to ½ the fatigue strength as steel for same detail
Corrosion resistance	Needs protection	Often used unpainted	Aluminum usually is maintenance free. Aluminum is non-staining
Strain rate effects on mechanical properties	High strain rates increase properties—varies with type of steel	Much less change in properties compared to steel	Need to use dynamic properties for high-strain rate loadings

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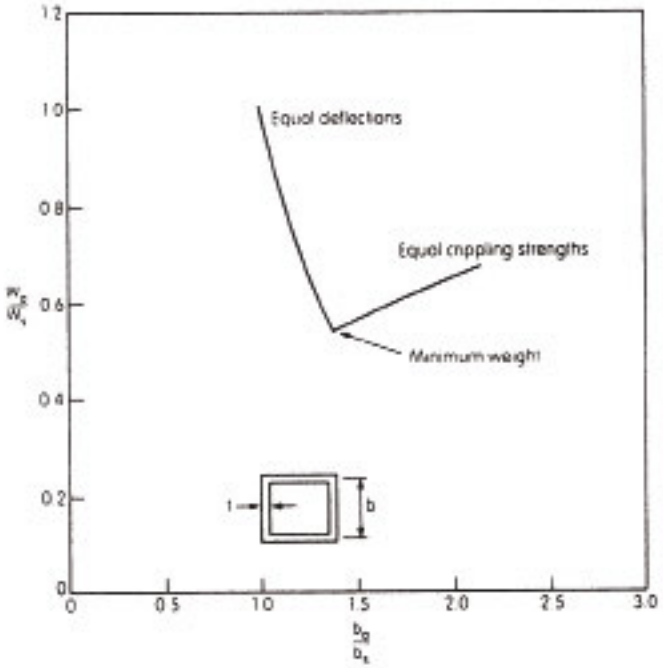

Figure 2-1
MINIMUM WEIGHT OF SQUARE TUBULAR SECTIONS

For structures controlled by static strength, such as automobile hoods and deck lids and some building components, aluminum structures weighing about 1/3 that of steel have been achieved. Such structures are designed for aluminum and do not have the same dimensions as the steel structure.

Figure 2-2 shows fatigue strengths for aluminum and steel for groove welds (a Category C detail). For long lives the fatigue strength of aluminum groove welds is about 40% that for steel. The difference is smaller at shorter lives.

In efficient designs, aluminum components are different from steel components for the same loading. Aluminum beams should be deeper than steel beams. The spacing of stiffeners on aluminum elements should be smaller than for steel. These geometrical differences will help meet deflection requirements for aluminum components and reduce stresses, helping with fatigue requirements.

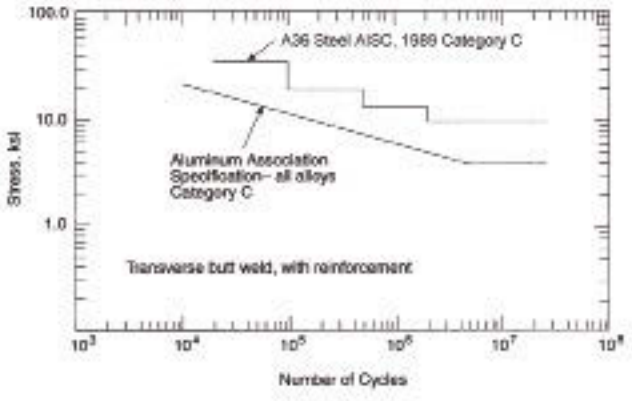

Figure 2-2
FATIGUE DESIGN CURVES
FOR ALUMINUM AND STEEL

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The following references are additional sources of information on aluminum structural design. References marked * are available from the Aluminum Association (www.aluminum.org/bookstore).

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2.4.6 Ships

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2.4.7 Storage Tanks, Pressure Vessels, and Pipe

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3. Structural Issues not Addressed in the Specification for Aluminum Structures

3.1 Ductility

The accepted measure of ductility of aluminum alloys is fracture toughness, and many high strength aluminum alloys used in aerospace applications have been evaluated as summarized by the Aluminum Association (1987). The ductility of alloys included in the *Specification* (non-aerospace alloys) is generally not a design issue for wrought products. The best proof of adequate ductility of alloys is the satisfactory service in buildings, bridges, automobiles, trucks, and rail cars. Menzemer (1992) showed that in laboratory fracture tests the normalized resistance curves (same fatigue strength) of parts made from 5456-H116 were higher than those of A36 steel at temperatures from -200 to +75 °F (-130 to 25°C). Sharp (1993) provides additional information on the toughness of aluminum alloys.

Welded strengths can be increased by welding in the solution heat-treated temper and then aging or by welding and then solution heat treating and aging. Light pole manufacturers typically use post-weld heat treatment. The ductility of transversely welded structures is usually reduced by post-weld heat treatment because the width of the zone of lower strength material is decreased (plastic deformation may be confined to a narrow zone). Post-weld heat treatments require careful evaluation of strength, ductility, and corrosion resistance implications.

3.2 Shear Diaphragms

Shear diaphragms are efficient in carrying shear loads. Corrugated panels can be used for a building's side or roof. The strength and stiffness of a corrugated panel subjected to shear depend on the alloy, configuration of the corrugation, size of the panel, and the type and configuration of the fastening to the framing members. Sharp presents the following design considerations:

1. Overall shear buckling of the panel may control strength. An equivalent slenderness ratio is defined for this mode of failure that is used with the buckling equations for shear.
2. Local buckling of the shear elements of the corrugations is given by the equations for unstiffened webs.
3. Failure of the corrugations and of the fastening at the supports must be calculated. Local failure of the corrugations at their attachment to supporting members can occur particularly if only part of the shape is connected.
4. Shear deflection of the panel is much larger than a flat panel of the same size. The major factors are size of panel, shape and thickness or corrugation, and the type and arrangement of the fastenings. Sharp (1993) provides equations of behavior for several standard corrugated shapes.

The Metal Construction Association's Primer on Diaphragm Design (2004) addresses aluminum diaphragms. Sooi and Peköz (1993) provide additional information on building diaphragms and their interaction with building frames.

3.3 Pipe Bursting Pressure

Sharp (1993) gives the bursting pressure of aluminum pipe as:

$$P = \frac{2tF_{tu}K}{D - 0.8t}$$

Where:

P = bursting pressure
t = pipe wall thickness
F_{tu} = tensile ultimate strength
$K = 0.73 + 0.33F_{ty}/F_{tu}$
D = pipe outside diameter
F_{ty} = tensile yield strength

Aluminum pipe applications may be governed by standards for that use. For example, aluminum pipe used in chemical plants and petroleum refineries is often designed in accordance with ASME B31.3, which provides a slightly different strength equation and safety factors appropriate to such applications.

3.4 Biaxial and Triaxial Stresses

The Aluminum *Specification* predates finite element analysis (FEA) and doesn't directly address all issues that arise from such analyses. For example, the *Specification* provides design stresses for prismatic members primarily under uniaxial stress, such as columns. FEA, on the other hand, can provide triaxial stresses by reporting, in addition to longitudinal stresses, through-thickness and transverse stresses. Many FEA programs calculate a von Mises stress (explained below) from the triaxial stresses at a given element.

Yielding occurs in ductile materials like aluminum when

$$(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2 \geq 2F_{ty}^2$$

where $f_1 f_2 f_3$ = principal stresses (the normal stress on each of three orthogonal surfaces such that the shear stresses on the surfaces are zero)
F_{ty} = tensile yield stress

This equation is called the von Mises criterion or distortion energy criterion. It predicts that yielding will occur when the distortion energy equals the distortion energy in an axially loaded member at yield. The above equation is for the general triaxial stress state. If stresses are biaxial, $f_3 = 0$, and the equation above predicts yielding when

$$(f_1 - f_2)^2 + f_2^2 + f_1^2 \geq 2F_{ty}^2$$

For convenience, the von Mises stress is defined from the von Mises criterion as

$$\sqrt{\frac{(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2}{2}}$$

so that it may be compared directly to the yield stress to determine if yielding will occur. In the biaxial stress state, the von Mises stress becomes

$$\sqrt{f_1^2 - f_1 f_2 + f_2^2}$$

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The von Mises criterion is used in the Aluminum *Specification* to determine the shear yield strength of aluminum alloys, since there is no established test method to measure shear yield strength. In the case of pure shear, the shear stresses in a biaxial stress element are τ and $-\tau$. Mohr's circle can be used to show that the principal stresses f_1 and f_2 are, then, also τ and $-\tau$, so the von Mises stress is

$$\sqrt{\tau^2 - \tau(-\tau) + \tau^2} = \tau\sqrt{3}$$

When the von Mises stress equals $F_{ty,}$ yielding occurs, so shear yield τ_y is

$$\tau_y = \frac{F_{ty}}{\sqrt{3}}$$

Local yielding in a member may not limit its usefulness if the amount of material that yields is small or positioned so as to have only a negligible effect on the shape and loadcarrying capacity of the member. Where yielding is a limit state, the von Mises stress should be limited to the yield strength of the material.

3.5 Aluminum Composite Material (ACM)

The 2018 International Building Code (IBC) Section 2 defines metal composite material (MCM) as "a factory-manufactured panel consisting of metal skins bonded to both faces of a solid plastic core". Panels with aluminum skins are called aluminum composite material (ACM) (see Figure 3-1). The IBC also defines a metal composite material system as "an exterior wall covering fabricated using MCM in a specific assembly including joints, seams, attachments, substrate, framing and other details as appropriate to a particular design." However, ACMs are not limited to exterior applications.

IBC Section 1406 provides requirements for two uses of MCM: one as exterior wall finish, and the other as architectural trim. Section 1406.4 requires that MCM exterior walls be designed for IBC Chapter 16 wind loads for components and cladding. Section 1406.5 requires that test results or engineering analysis be submitted to the building official to demonstrate this. IBC also specifies fire-resistance requirements that apply to both MCM uses.

ACM panels must be designed to meet deflection limits as well as provide sufficient strength for wind loads.

Typical ACM properties

Property	Value	Units
coefficient of thermal expansion	13 x 10^{-6} 23 x 10^{-6}	/°F /°C
available thicknesses	3, 4, and 6 0.118, 0.157, and 0.236	mm in.
skin thickness	0.020 0.50	in. mm

Manufacturers provide additional information on loadspan-deflection, dimensional tolerances, section modulus, stiffness, weight, thermal resistance, sound transmission, and fire resistance.

In a similar product, an aluminum-elastomer sandwich beam, the components comprising the structural elements also act together creating a combined strength and other characteristics that are greater than the sum of the parts. The composite beam may have to resist stresses due to a temperature gradient through the section as well as stresses from wind and dead loads. The amount of composite action can be determined by analysis (AAMA (2016)) or testing.

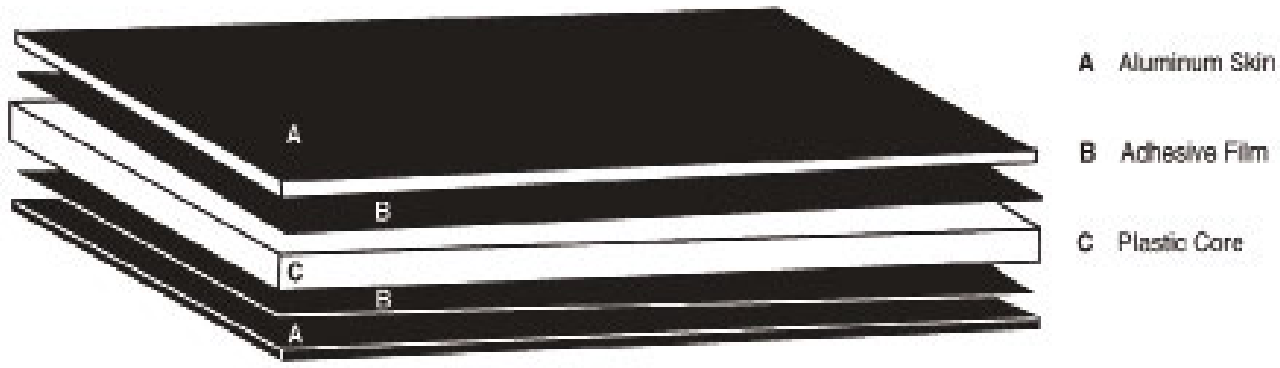

Figure 3-1
SANDWICH PANEL

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4. Adhesive Bonded Joints

An adhesive can be defined as a substance capable of holding materials, similar and dissimilar, together by surface attachment. The critical substrate surfaces can be held together by chemical and/or mechanical adhesion at the interfacial layer of contact between surfaces (D.A.T.A. (1986)).

4.1 Advantages and Disadvantages

Shields (1970) and Thrall (1984) address advantages and disadvantages of adhesives. Some advantages of adhesive bonding are:

- Ability to bond a variety of materials that may exhibit differing coefficients of thermal expansion, moduli, thickness, etc., with proper joint design and material selection.
- Improved cosmetics of the finished product by the elimination of protruding mechanical fasteners, such as rivets or bolts.
- Excellent strength to weight ratio in comparison to other joining methods.
- Good joint stiffness and fatigue performance, with appropriate choice of adhesive.
- Elimination of stress concentrations inherent to mechanical fastening methods, and a more uniform stress distribution over the bonded surface area.
- Adaptable to many production processes because of the variety of forms (pastes, films, emulsions, etc.) and methods of application of adhesives.

The advantages of adhesive bonding are most evident when joining relatively thin materials and components. The cost advantages and joint efficiencies decrease as the members become thicker.

Some disadvantages of adhesive bonding are:

- Expert joint design is critical in order to minimize peel and/or cleavage stresses.
- Temperature limitations may restrict the use of many adhesives from high temperature applications.
- Adhesives require surface pretreatment of the aluminum unless the adhesive manufacturer recommends that no pretreatment is necessary. Even with this recommendation, the durability required for the application should be verified.
- Difficulties in inspecting for initial bond integrity and an insufficient understanding of the effects of in-service damage on subsequent bond performance limit confidence in adhesive bonding as a primary structural joining method.

4.2 Adhesive Selection

Literally thousands of commercial adhesives are available. In order to select the proper adhesive for a particular application the user needs a systematic approach to adhesive selection. Major areas to address are:

- Substrates
- Pretreatment
- Application of adhesive
- Fabrication process
- Service environments
- Design

4.3 Types of Adhesives

Kinloch (1987) identified two groups of adhesives: thermoplastics and thermosets. Thermoplastics are materials which can be repeatedly softened by heat and hardened by cooling to ambient temperature. Thermosets are materials that undergo chemical reactions initiated by heat, catalyst, UV light, etc. Thermosets are generally more durable than thermoplastics.

From the two groups of adhesives extend several classes of adhesives, which include anaerobic, contact, cyanoacrylate, film, hot melt, one-part and two-part. Anaerobic adhesives are generally esters or acrylics in which, upon the restriction/lack of air/oxygen, curing of the adhesive initiates. Anaerobic adhesives can also be cured by UV exposure. Contact adhesives are coated to both substrate surfaces, and a solvent is allowed to evaporate before assembly of the substrates. Cyanoacrylates are known as instant cure adhesives. They are derivatives of unsaturated acrylates which cure at room temperature without the aid of a catalyst. Films are uniform layers of adhesives that are generally rolled onto coils. Films can be supported (with reinforcing fibers), unsupported, heat-activated, or pressure-sensitive. Hot melts are generally solvent-free thermoplastics, which are solids at room temperature but soften and flow at heat activation temperature. Upon cooling the hot melt regains its structural strength. One-part adhesives are usually 99-100% solid systems. This class of adhesives includes epoxies, moisture activated silicones, and polyimides which can be waterborne or organic solvent based. Two-part epoxies and acrylics are generally cured at room temperature or accelerated with heat.

4.4 Surface Pretreatments

A surface pretreatment prior to bonding is usually necessary in order to achieve long-term bond strength of aluminum substrates, although in some cases an adhesive manufacturer may state that their adhesive requires no surface pretreatment or that their adhesive is chemically incompatible with the proposed pretreatment. Many aluminum surface pretreatments have been examined to determine the best adhesive substrates for bonding. It is commonly accepted that chemically pretreating the surface yields more durable bond strength than mechanically abrading the aluminum surface. Some of the most popular chemical pretreatment systems to improve the adhesion of aluminum are degreasing, acid etching, and phosphoric acid anodizing. The adhesive manufacturer's recommendations for surface preparation should be followed.

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4.5 Joint Design

The decision to use adhesive bonding must consider joint geometry, the nature and magnitude of loading, the properties of the adhesive and the members to be joined, failure modes, and ease and reliability of manufacturing. Adapting a joint design intended for other joining methods often results in ineffective designs. The design must also consider the assembly scheme including needs for surface pretreatment, part tolerances, and fixturing.

The stresses present in adhesive-bonded joints are classified based on loading: normal, shear, peel, and cleavage (Figure 4-1). Cleavage and peel conditions describe a combination of normal and shear stresses specific to these two loading conditions. Cleavage stresses are concentrated on one side of the joint, while peel loads can occur with flexible members (Kinloch (1987)). Though technically different, tensile stresses normal to the bond line are also referred to as peel stresses in the literature. Because adhesives perform best when subjected to compressive and shear loads, joint design should distribute the loads in the adhesive layer as a combination of compressive and shear stresses to avoid tensile, cleavage and peel loadings.

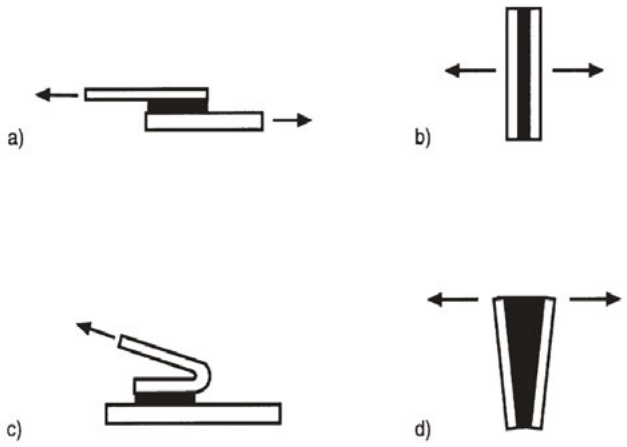

Figure 4-1
TYPES OF STRESSES: A) SHEAR; B) TENSION; C) PEEL; D) CLEAVAGE

There are four basic types of joints: angle, tee, butt, and surface or lap joints (Figure 4-2). In service, these joints may be subjected to the types of stresses mentioned in the previous paragraph. Most practical adhesive joint designs can be classified as variations of lap joints. Lap joint configurations are usually preferred because they require little or no machining. The use of overly complex configurations for low loads results in unnecessarily expensive designs. On the other hand, simple configurations are unacceptable if smooth uninterrupted surfaces are required, if high stresses are present in the bond, or if high loads must be sustained.

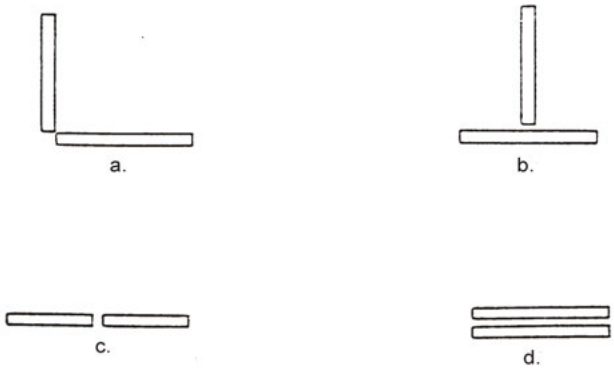

Figure 4-2
TYPES OF JOINTS: A) ANGLE; B) TEE; C) BUTT; D) SURFACE

In single lap joints that are not supported or restrained against joint rotation, bending within the joint and at the ends of the overlap causes locally high transverse tensile stresses in the bond. In joints that are designed to prevent or minimize joint rotation, the bond strength can exceed the full nominal strength of the members.

Although adhesive bonding has benefits in joining dissimilar materials, the application imposes additional design considerations. Using materials with different moduli may result in reduced joint efficiencies. If the materials do not have similar thermal expansion coefficients, temperature changes during elevated temperature cures and in service can increase stresses in adhesive bonds and lower joint strengths (Hart-Smith (1987)). If member materials are not identical, the design should equalize the in-plane and bending stiffnesses and the materials should have similar thermal expansion coefficients.

The identification of possible failure modes is crucial to effective joint design and satisfactory performance. For joints consisting of ductile isotropic materials such as aluminum alloys, four common failure modes are:

1) tensile or buckling failure of the member outside the joint area,
2) shear failure of the adhesive,
3) tensile cracking in the adhesive layer due to tensile or cleavage forces in the joint, and
4) adhesion failure at the adhesive/member interface.

Adhesion failures are least desirable because such interfacial failures typically result in low, inconsistent joint strengths. If the adhesive fails to adhere to the aluminum, this indicates incompatibility of the surface oxide of the aluminum with that particular adhesive. If the aluminum is pretreated and failure occurs at that interface between the pretreatment and the adhesive, this indicates adhesive/pretreatment incompatibility.

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The adhesive properties for joint designs may be obtained from mechanical tests. Tensile properties can be obtained using cast adhesive specimens as described in ASTM D638 (ASTM (2009a)). Adhesive shear properties can be generated using thick adherend tests (Dreiger (1985)) or a torsion test described in ASTM E229 (ASTM (2009b)). Properties should be obtained for temperatures throughout the range expected in service. Temperature can affect adhesive properties, ductility and toughness, which will affect joint design and performance, including stiffness and failure loads and modes. The adequacy of the design should be checked for the range of service temperatures. Summaries of technology and data are provided by Minford (1993).

For critical applications in complex structures, a complete analysis of the stress components is recommended along with the identification of the potential failure modes. Nonlinear behavior of the adhesive and members should be accounted for in the most effective method of conducting such analysis. Mechanical tests to simulate typical service conditions of adhesive-bonded joints should be performed to verify the predicted failure location and modes.

4.6 CurrentAdhesive Applications

Adhesives are gaining popularity as a viable structural means of joining aluminum. Today, aluminum adhesive bonding is being used in the transportation, construction, marine, aerospace, and electronic industries. Examples in each category are:

- Transportation: buses, trains, and trailers; automotive seats, hoods, and air bag containers
- Construction: architectural panels
- Marine: boats, ships, and desalination plants
- Aerospace: space vehicles, planes, and helicopters
- Electronics: antennas, computer boards, and cable wires

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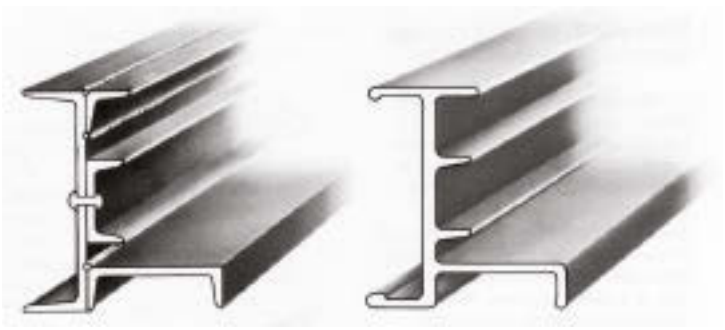
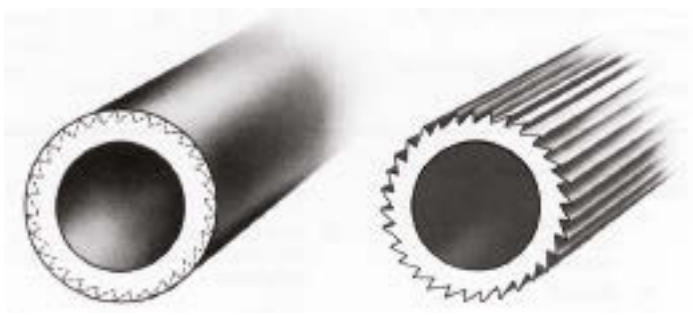
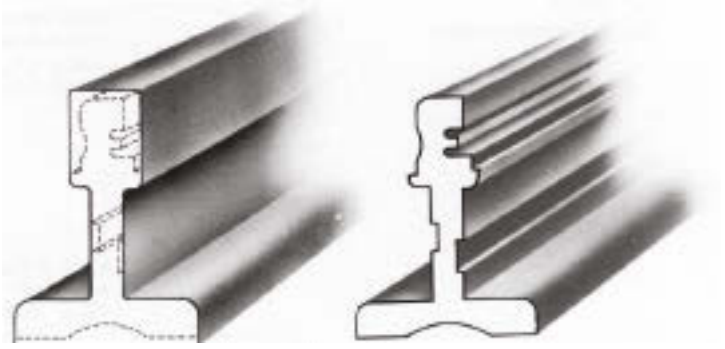
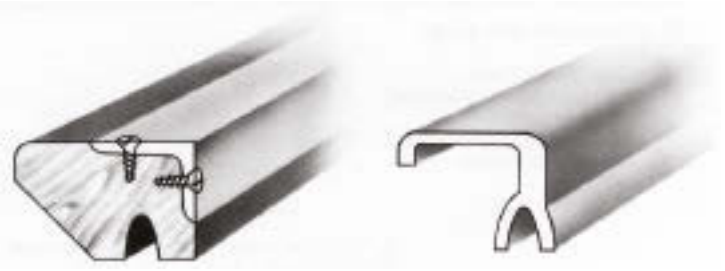
5. Extrusion Design

Aluminum can be easily extruded, unlike steel. The extrusion process consists of pushing hot aluminum through a die, likened to pushing tooth paste out of the tube. Custom shapes can be created that place the material where it is most effective.

Cross sections must be constant along their length but they may be intricate. Often fabrication costs can be lowered by consolidating parts or incorporating assembly aids by using extrusions. Extrusions that fit within a circle up to about 30 in. in diameter are possible, but the more common ones fit within a diameter of about 18 inches.

The following information in this section is from the *Aluminum Extrusion Manual* (1998**).**

5.1 Replacing Fabrications with Extrusions

As shown at right, several rolled and riveted structural shapes (left) can be combined into a single aluminum extrusion, thus eliminating all joining costs.	
Machined and stamped sections can be replaced by aluminum sections extruded to exact size and shape.	
As another example, the machining cost and weight of a framing member is reduced by redesigning the member as an extruded section.	
Aluminum extrusions may also replace wood sections. They can be made lighter, stiffer, and stronger, thus eliminating steel reinforcement.	

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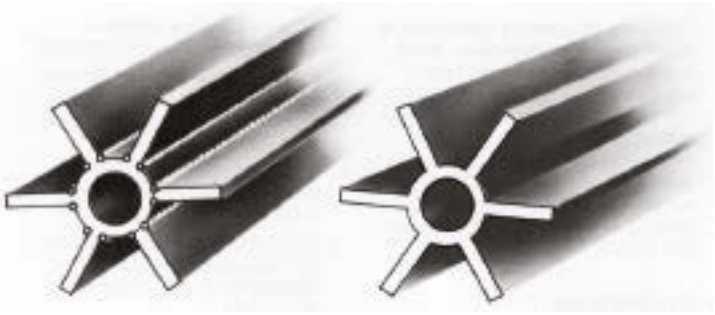
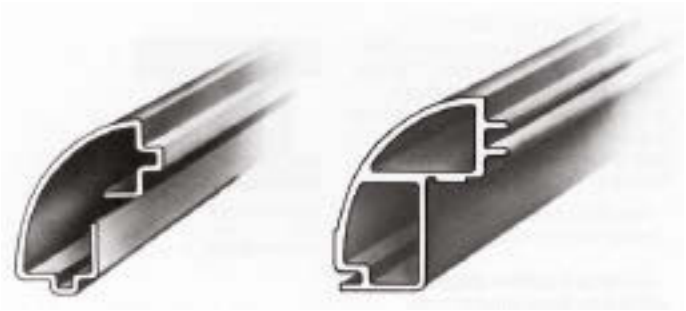
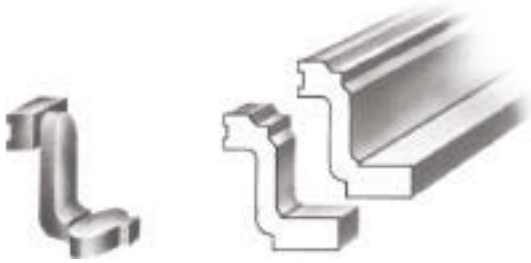
Welded assemblies are frequently redesigned into extruded sections. Not only is cost reduced, but accuracy and strength are increased.	
Because extrusions permit infinite changes in cross sectional design, they can be produced more readily to meet specific design requirements than rolled sheet sections.	
Crimped tubular sections frequently permit redesign in extruded shapes, with gains in both stiffness and strength. Cost of manufacture is also reduced.	
Small castings, forgings, and parts machined from bar stock may also permit redesign as an extrusion, as long as the cross section is symmetrical in at least one plane.	

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5.2 Design Parameters

Five major factors should be considered in the detailed development of an aluminum extrusion design:

- Shape configuration
- Tolerances
- Surface finish
- Alloy
- Circumscribing circle size

These parameters are interrelated in their effect on the extrusion design and its application.

Shape Configuration

The designer's first priority is to satisfy a specific need, and aluminum extrusion allows you to design the shape that best meets your structural and aesthetics requirements. Since extrusion dies are relatively inexpensive, designers can afford to use several different shapes, if that's the best way to achieve their objectives.

Extrusions can be designed to aid in assembly, improve product appearance, reduce or eliminate forming and welding operations, and achieve many other purposes.

Extruded shapes are described in three general categories—solid, semihollow, and hollow. Dies to produce solid shapes are the least complex. The difference between a solid shape and a semihollow shape may not be obvious at first glance. It's easier to describe and understand all three categories by working in reverse, starting with hollow shapes.

A hollow shape is simply an extruded shape which, anywhere in its cross section, completely encloses a void. The void itself may have any sort of shape, and the complete profile may include a variety of other forms; but if any part of it encloses a void, it's classified as a "hollow."

Tube and Pipe are specific forms of hollow shapes. "Tube" is a hollow section that is long in comparison to its cross-sectional size. It is symmetrical and has uniform wall thickness except as affected by corners. It may be round or elliptical, or square, rectangular, hexagonal, or octagonal. "Extruded tube," as the name indicates, is tube produced by hot extrusion; "drawn tube" is produced by drawing through a die.

"Pipe" is a tube with certain standardized combinations of outside diameter and wall thickness. These are commonly designated by "Nominal Pipe Sizes" and by "ANSI (American National Standards Institute) Schedule Numbers."

A semihollow shape is one that partially encloses a void – for example, a circle or rectangle with a gap in one side; but a solid shape can also partially enclose a void, and the difference may not be obvious. It is defined mathematically, by comparing the area of the partially enclosed void to the size of the gap (actually, to the mathematical square of the gap size). If that ratio is larger than a certain number, the shape is classified as semihollow; if the ratio is smaller, the shape is considered a solid.

The dies required to make semihollow shapes are moderately more expensive than solid shape dies, and the output of those dies tends to approach tolerance limits. Tooling life and productivity are both improved with decreasing ratios, thus reducing cost.

A solid extruded shape is any shape that is not a hollow or a semihollow. This covers a wide range including, for example, compact cross-sections with or without projections; angular or curved shapes; and those wrap-around shapes whose void area/gap^2 ratios are too low for the semihollow-class.

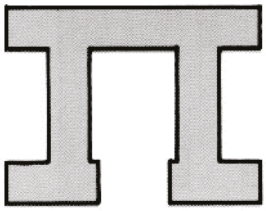

Figure 5-1
EXAMPLE OF A SOLID SHAPE

Extruded rod is a solid shape with a round cross-section at least 0.375 in. in diameter.

Extruded bar is a solid shape whose cross-section is square, rectangular, hexagonal or octagonal, and whose width between parallel faces is a least 0.375 inches.

If the dimension across any of these rod- or bar-type shapes is less than 0.375 in., it is classified as wire.

Tolerances

In many applications in which the extrusion will be part of an assembly of components, tolerances are critical. A designer should be aware of the standard dimensional tolerances to which extrusions are commercially produced. These tolerances generally cover such characteristics as straightness, flatness, and twist, and such cross-sectional dimensions as thickness, angles, contours and corner or fillet radii. Both standard and precision tolerances for extrusions are given in *Aluminum Standards and Data,* Section 11.

Aluminum extrusions are often designed to minimize or eliminate the need for machining. If desired, many extrusions can be produced to the recently introduced "precision tolerances" or to closer-than-standard custom tolerances, generating cost savings in secondary operations; such savings may range from modest to very large, depending on circumstances. The designer should consider his requirements carefully and order special tolerances only where they are really needed.

If extruded parts are to interlock in any manner, the designer should work with the supplier to make sure that tolerances will provide a proper fit.

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Surface Finish

One advantage of aluminum extrusions is the variety of ways the surface can be finished, and this offers another range of choices to the designer.

As-extruded, or "mill," finish can range from "structural," on which minor surface imperfections are acceptable, to "architectural," presenting uniformly good appearance. It should be understood that under normal circumstances aluminum may be marred because it is a relatively soft metal and that special care is required if a blemish free surface is desired.

Other finishes include scratch finishing, satin finishing and buffing. Aluminum can also be finished by clear or colored anodizing, or by painting or other coatings.

If a product will have surfaces that are exposed in use, where normal processing marks may be objectionable, the extruders should be told which surfaces are critical. They can design a die that orients the shape to protect those surfaces during the extrusion process; they can also select packaging that will protect the product during shipment.

Alloy Selection

Aluminum extrusions are made in a wide variety of alloys and tempers to meet a broad spectrum of needs. Selection is made to meet the specific requirements in strength, weldability, forming characteristics, finish, corrosion resistance, machinability, and sometimes other properties.

The complete list of registered aluminum alloys is quite long, but in practice a few alloys are chosen repeatedly for extrusion because of their versatility and highly suitable characteristics. Extruders generally stock the three or four most frequently used alloys. When their specialized markets justify it, individual companies include in their inventories additional alloys that will vary with the needs of their major customers. Thus, a substantial variety of extrusion alloy/temper products is regularly available.

The 6xxx-series of aluminum alloys is selected for nearly 75 percent of extrusion applications. Of those, alloys 6063, 6061, and 6005A are used most frequently.

6063 is used for a broad range of solid and hollow products. It is easily welded, and it has a pleasing natural finish and excellent corrosion resistance. 6063 is used in architecture and in many moderate-stress applications.

6061 combines good strength with good corrosion resistance, weldability, and machining characteristics. Alloy 6061 is used in many structural applications.

6005A in a T61 has the same minimum strengths as 6061-T6 temper and is preferred over 6061 for extrudability. Its corrosion resistance, weldability, and machining characteristics are similar to 6061.

Many other alloys are used for extrusions to meet particular requirements. To mention a few:

Characteristics	**Alloys**
High strength	6082, 7005
High corrosion resistance	1100, 3003
High electrical conductivity	6101

Designers should consult alloy and temper tables and discuss specific needs with extruders.

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Circumscribing Circle Size

One measurement of the size of an extrusion is the diameter of the smallest circle that will entirely enclose its cross-section – its "circumscribing circle." This dimension is one factor in the economics of an extrusion. In general, extrusions are most economical when they fit within medium-sized circumscribing circles: that is, one with a diameter between 1 and 10 inches.

The example shown in Figure 5-2 would be classified as a 3 to 4 in. circle size shape.

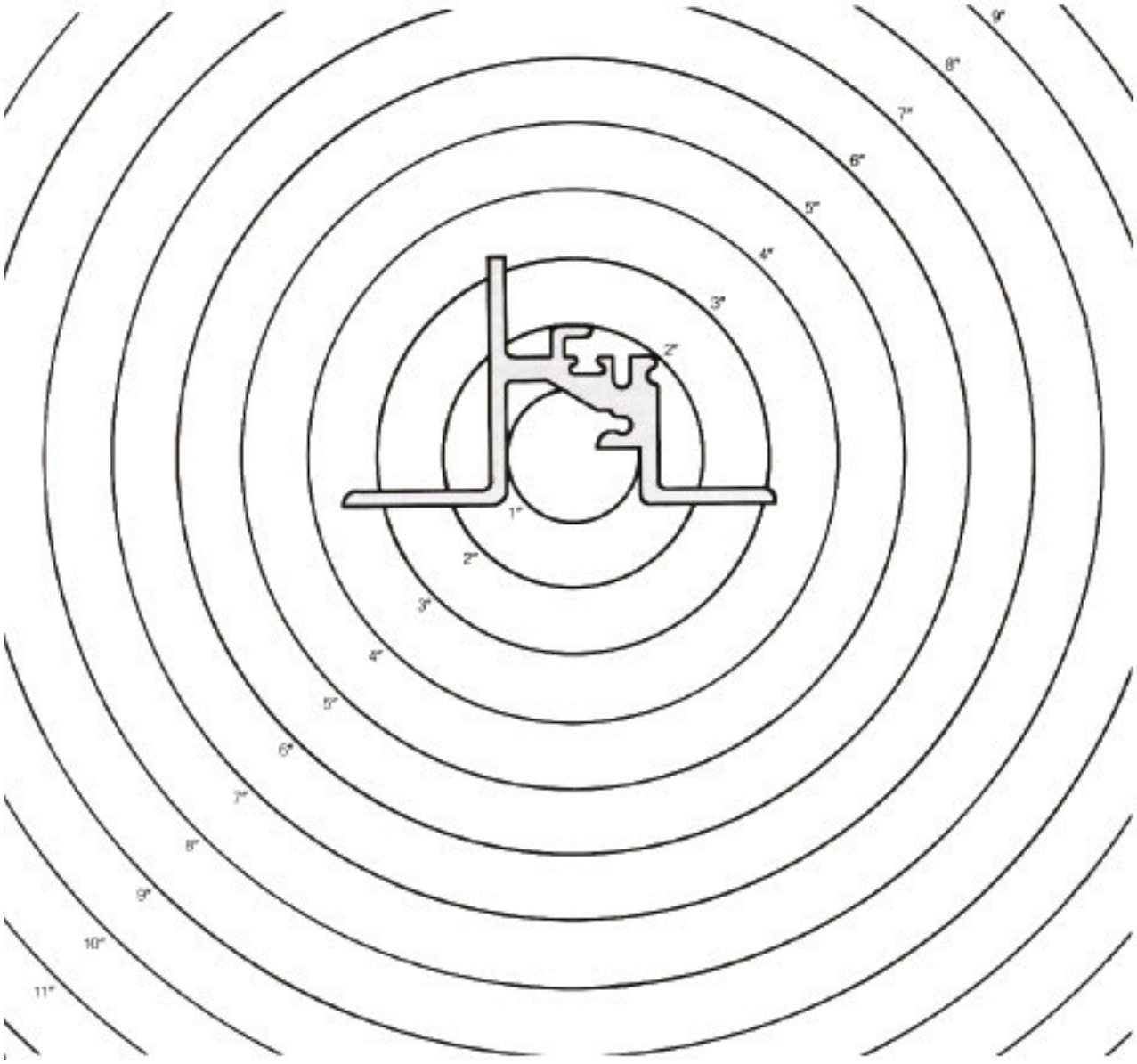

Figure 5-2

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5.3 Design Guidelines

Good Extrusion Design Practices

At this stage in the development of an extruded product, the designer has determined its functional shape and size, and considered appropriate tolerances, surface finishes and alloys.

Before proceeding, it makes sense to review the extruder's available standard shapes. It may be possible to adapt a standard shape to the needs of the product, with little or no modification.

If a standard shape is not readily adaptable, the design can be completed as a custom shape perfectly suited to the requirements of the product.

Here are a few tips on good practices in custom-designing aluminum extrusions:

Specify the Most Appropriate Metal Thicknesses

Specify metal thicknesses that are just heavy enough to meet your structural requirements. Even in low stress areas, however, keep sufficient thickness to avoid risking distortion or damage. Some shapes tend to invite distortion during the extrusion process (such as an asymmetric profile or thin details at the end of a long flange). Such tendencies exert more influence on thin-walled shapes than on those with normal metal thickness.

Keep Metal Thickness as Uniform As Possible

Extrusion allows you to put extra metal where it is needed—in high-stress areas, for example—and still save material by using normal dimensions elsewhere in the same piece. Adjacent wall thickness ratios of less than 2-to-1 are extruded without difficulty. However, large contrasts between thick and thin areas may create uneven conditions during extrusion. It is best to maintain near uniform metal thickness throughout a shape if possible. When a design combines thick and thin dimensions, streamline the transitions with a radius (a curve, rather than a sharp angle) at junctions where the thickness changes sharply. Rounded corners ease the flow of metal.

Visualize the Die and the Metal Flow

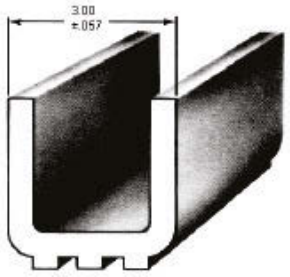
Remember what an extrusion die does: while it lets metal flow through its shaped aperture, it must hold back metal all around that aperture against great force. When you design a shape for extrusion, you are simultaneously designing a die aperture and you must take extrusion forces and metal flow into account.

For example, a U-shaped channel in an extrusion corresponds to a solid "tongue" in the die, attached at only one end. Flexibility in this tongue can alter the aperture slightly under the pressure of extrusion; the deeper you make the channel, the longer you make the tongue and the more difficult it becomes to regulate the extruded dimensions. On the other hand, rounding corners at the base and tip of the tongue can ease metal flow and so help to keep the extruded dimensions more uniform. Even corners rounded to only 1/64 in. radius can facilitate extruding.

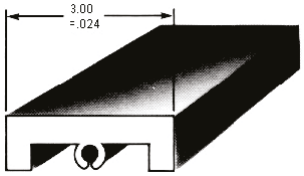
Visualize the shape of the die that must produce your design, and try to minimize shapes that would weaken the die or impede metal flow.

Use Metal Dimensions for Best Tolerance

Dimensions measured across solid metal are easier to produce to closer tolerances than those measured across a gap or angle (see Figure 5-3). So rely on metal dimensions as much as possible when designing close-fitted mating parts or other shapes requiring closer tolerances. Standard industry dimensional tolerances are entirely adequate for many applications, but special tolerances can be specified if necessary.



An Open Space Dimension is more difficult to hold to close tolerances.



A Metal Dimension can be extruded to close tolerances

Figure 5-3

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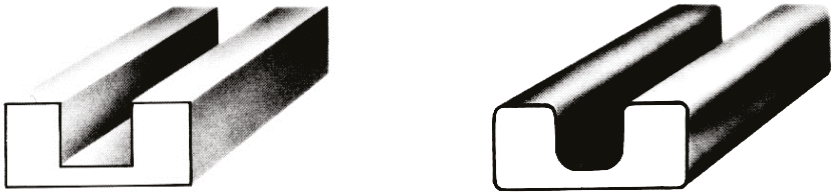
Instead of This

Consider This

Smooth All Transitions

Transitions should be streamlined by a generous radius at any thick-thin junction.



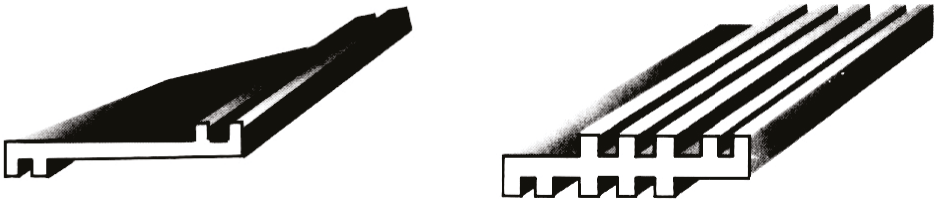
Keep Wall Thickness Uniform

The preceding shape can be further improved by maintaining uniform wall thickness.

In addition to using more metal, thick-thin junctions give rise to distortion, die breakage or surface defects on the extrusion.

Ribs Help Straightening Operation

Wide, thin sections can be hard to straighten after extrusion. Ribs help to reduce twisting and to improve flatness.



Symmetry Preferred in Semi-Hollow Areas

When designing, visualize the die and tongue that will be necessary to produce a semi-hollow shape. By keeping the void symmetrical you lessen the chances that the die tongue may break.

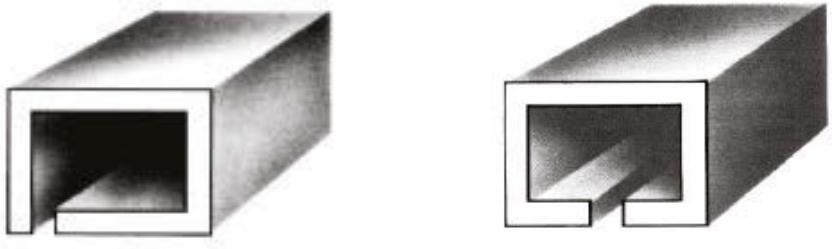


Figure 5-4

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5.4 Design for Assembly

Aluminum extrusions can be designed for joining by a wide variety of assembly methods such as riveting, bolting, welding, brazing, soldering and adhesive bonding.

They can also be designed to fit, hook or snap together with mating parts. Hinges or slides can often by "designed-in" as integral parts of extrusions, eliminating the need for additional assembly and moving parts.

Five types of extruded joints are discussed in this section:

- Nesting Joints
- Interlocking Joints
- Snap-Fit Joints
- Screw Slots
- Screw Chases

Nesting Joints

Nesting joints, which include lap joints and tongue-and-groove joints, have mating elements that are shaped to be assembled with little or no self-locking action.

They serve primarily to align adjoining parts, and they usually depend on rivets, bolts, adhesives, confinement within a rigid frame, or other fasteners to hold them together.

Lap joints, shown in Figure 5-5, are the simplest nesting joints.

Interlocking Joints

The interlocking joint is, in effect, a modified tongue-and-groove. But instead of being straight, the two mating elements are curved and so cannot be assembled or (more to the point) disassembled by simple straight-line motion. They are assembled by a rotating motion and will not separate without a corresponding counter-rotation. As long as the parts are held in their assembled position, they strongly resist separation and misalignment in both the horizontal and the vertical directions.

The amount of rotation required for interlocking assembly depends on the geometry of the design. It can be made more or less than 45°, as long as the design allows enough clearance for the required rotation.

Interlocking joints can be secured in at least five ways, all based on preventing counter-rotation.

- Fastening the elements to structural cross-members.
- Restraining the assembly within a rigid frame.
- Restraining the assembly with channel end-closures.
- Fastening the joint with rivets, welds, adhesives or other devices.
- Providing a folding, locking flange as shown in Figure 5-6.

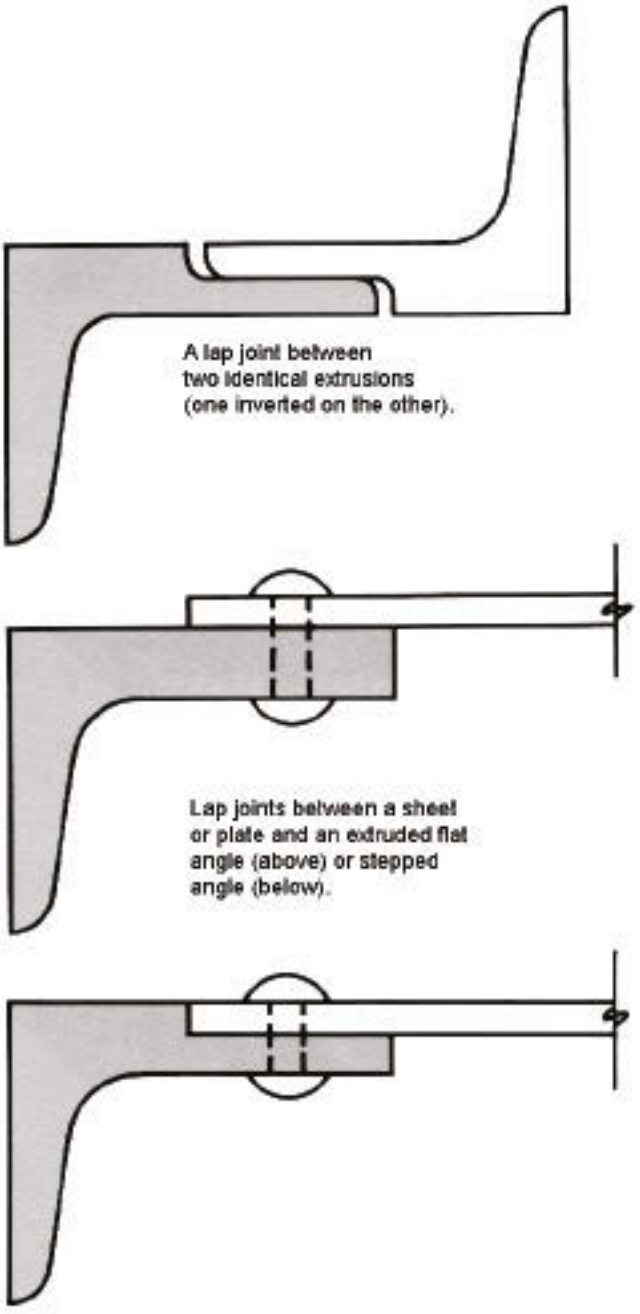

Figure 5-5

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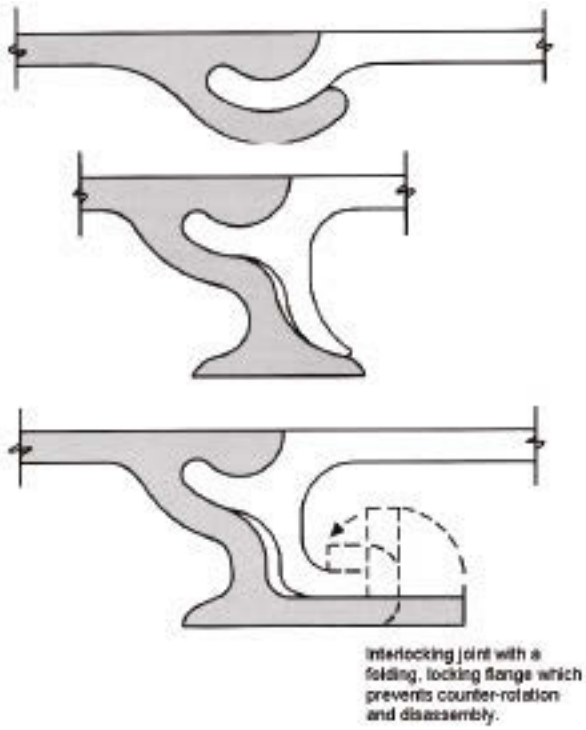

Figure 5-6

Snap-Fit Joints

A "snap-fit" or "snap-lock" joint (see Figure 5-7) is o which is self-locking and requires no additional fasteners hold the joint together.

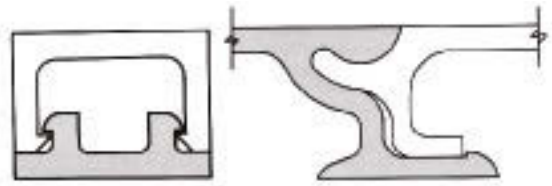

Figure 5-7

The mating parts of a snap-fit joint exert a cam action on each other, flexing until one part slips past a raised lip on the other part. Once past this lip, the flexed parts snap back to their normal shape and the lip prevents them from separating. After it is snapped together, this joint cannot be disassembled unintentionally.

This joint's strength can be increased by applying adhesive to the mating surfaces before assembly. Even short lengths of an adhesively bonded, snap-fit joint cannot be easily slid apart.

Precise dimensions are critical in a snap-fit joint. Experienced extrusion designers who are fully conversant with snap-fit production requirements can determine the precise final dimensions.

Screw Slots

Screw slots are often used to facilitate the assembly of aluminum extrusions. Standard screw slots are illustrated in Part I Figure J.5.1 and should always be used with tapping screws.

The screw slot should be designed so that the area of the void and the metal thickness surrounding it is symmetrical about the center line of the gap.

The type F tapping screw is recommended for use with the extruded screw slot. This screw has threads which approximate machine screw threads plus a blunt point that will stay within the screw slot.

Sheet metal type screws are not recommended since their thread projects to the end of the screw and thereby can "walk" through the slot opening. The pull-out strength of a screw in a screw slot is given in Specification Section J.5.4.1.2.

The pull-out strength of a screw in a screw slot is given in Specification Section J.5.4.1.2.

Screw Chases

Extrusions may have screw chases as shown in Figure 5-8. A screw chase provides a means of attaching a fastener to an extrusion in a direction perpendicular to the extruded direction. Different chase configurations are used – some have ribbed walls and some have flat walls. Table 5-1 suggests dimensions for screw chases with flat walls.

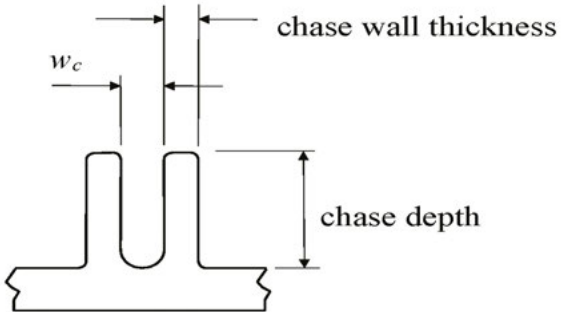

Figure 5-8

Table 5-1 Screw Chase Dimensions

Screw size	Screw nominal diameter (in.) D	Chase inside width (in.) w_c	Chase inside width tolerance (in.)
No. 8	0.164	0.122	0.006
No. 10	0.190	0.142	0.006
No. 12	0.216	0.162	0.008
1/4"	0.250	0.188	0.008

A screw chase should be wide enough so that the screw won't break during installation and narrow enough so the screw won't strip out too easily. These considerations are affected by the screw strength, which is a function of screw material, screw thread type, and screw chase side height and thickness.

The pull-out strength of a ¼" diameter screw in a screw chase is given in Specification Section J.5.4.1.3.

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6. Corrosion

A great deal of technology and experience exists for successful corrosion resistance in assemblies and structures. The following information has been adapted from Hatch (1984).

The following measures can be used to provide corrosion resistance:

- Alloy and temper selection
- Design
- Joints
- Inhibitors
- Protective coatings
- Cathodic protection

Alloy and temper selection: Alloys of the 1xxx, 3xxx, 5xxx, and 6xxx series generally have very good corrosion resistance in natural environments and can often be used without corrosion protection. Temper selection for the 1xxx, 3xxx, and 6xxx series alloys and for the 5xxx series alloys containing up to 3% magnesium (e.g. 5005, 5050, 5052, and 5454) may be based on factors other than corrosion. For 5xxx series sheet and plate alloys containing more than 3% magnesium (e.g., 5083, 5086, and 5456) for applications with service temperatures exceeding 150°F or in marine environments, the temper should be limited to H116 or H321 and material should comply with ASTM B928 to guard against intergranular and exfoliation corrosion.

Alloys of the 2xxx and 7xxx series alloys have relatively poor corrosion resistance and require corrosion protection. Temper selection for the 2xxx and 7xxx series alloys can significantly affect exfoliation and stress corrosion resistance. For these alloys, consideration should also be given to stress corrosion cracking (SCC). SCC can occur when residual or assembly stresses occur in the through-thickness or short transverse direction. This can be minimized by considering temper selection, residual stresses from fabrication (e.g. forming, machining, and thermal treatments), and fit up details.

Design: Factors that may affect corrosion resistance can be more cost-effectively considered during the design phase rather than after the design is finalized:

- Avoid contact with dissimilar metals (galvanic corrosion protection is discussed below).
- Avoid crevices, especially at joints (crevice corrosion protection is discussed below).
- Avoid intermittent welds.
- Avoid standing moisture and poultice catchments.
- Avoid placing absorbent materials, such as open-cell gaskets, insulation, and soundproofing, against aluminum.
- Avoid direct impingement by fluid streams, especially sharp pipe bends.
- Avoid heat transfer hot spots.
- Avoid corrosive conditions when locating parts and joints.
- Avoid sharp edges where coatings will be used.

Joints: A key area for corrosion protection is joints. Joints may involve aluminum and other metals. Galvanic corrosion can occur when aluminum is joined to other metals and the joint is connected by a conductive fluid. Joints designed so that they remain dry in service or where the dissimilar metals are not electrically connected, even by a remote path, will be free from galvanic corrosion. A common tool for predicting which metal will corrode (anode) in a given couple is the galvanic series, which is environment-specific (see Table 6-1 for an example in sodium chloride solution). In Table 6-1 the metal in a galvanic couple that is toward the active end of the galvanic series will corrode, and the other metal in the couple which is toward the noble end of the series will not corrode. The galvanic series is useful only as a predictive tool as to location of corrosion in a galvanic couple, not corrosion rate. However, selection of couple members that are close together in the galvanic series minimizes galvanic corrosion. Aluminum can be coupled to magnesium, zinc, cadmium, and passive stainless steel in most environments without galvanic corrosion. In most other galvanic couples aluminum will experience galvanic corrosion.

Where dissimilar metals must be joined, creating an undesirable galvanic couple, several steps can be taken to minimize corrosion. The exposed area of the more noble or cathodic metal should be minimized by design and by application of protective coatings (e.g. paint, gasket, or tape). At bolted or riveted galvanic joints (e.g. aluminum to steel) the fasteners (the smaller exposed surface area) should be the more noble material, such as steel or 3xx series stainless steel rather than aluminum. If steel fasteners are used, consider coating the fasteners with a zinc (galvanizing) or other suitable coating.

Where galvanic couples have only a few points of electrical contact, it may be possible to control corrosion by electrical insulation. Insulation can be effective only when all points of electrical contact are broken. Insulation can be achieved by inserting nonmetallic, non-wicking bushings, gaskets, sleeves, or tapes into joints. Such insulation is difficult to achieve in large, complex structures where remote electrical paths may exist.

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Crevices are inevitable in structures. When crevices trap foreign matter, accelerated corrosion may result. Often joints can be located or oriented to minimize moisture ingress and retention. Adhesives, sealants, and nonabsorbent gaskets can prevent the ingress of moisture into crevices. Continuous welds are more desirable than intermittent welds because they leave no crevices. A type of crevice corrosion known as poultice corrosion can occur under foreign materials, such as mud, paper, or cloth. Poultice corrosion can often be minimized by avoiding catchments and pockets during design of a structure.

TABLE 6-1
GALVANIC SERIES IN SODIUM CHLORIDE SOLUTION
(similar to sea water)

Magnesium	Anode
Zinc	
Aluminum alloy 7072 (used in Alclad products)	
5xxx aluminum alloys	
7xxx structural aluminum alloys	
1xxx, 3xxx, 6xxx aluminum alloys	
Cadmium	
2xxx aluminum alloys	
Iron and steel	
Lead	
Tin	
Brass	
Copper	
Stainless steel (3xx, passive)	
Nickel	Cathode

Inhibitors: In fluid-carrying systems where piping of aluminum and other metals are joined, a thick-walled, replaceable aluminum nipple should be used at the joint. In closed loop, mixed metal fluid-carrying systems, such as automotive cooling systems, it may be possible to control galvanic corrosion with a mixed metal corrosion inhibitor. Mixed metal fluid-carrying systems that include aluminum and cannot be treated with inhibitors should not contain copper.

Protective Coatings: When surface treatments such as anodizing, organic coating, or plating are used on aluminum to provide consistent appearance or improve corrosion resistance, the quality of the treatment is extremely important. If flaws or points of damage occur which expose the substrate aluminum surface, accelerated localized pitting corrosion may result. See Part I and Part II Section M.7 for additional information on contact with dissimilar materials.

Cathodic Protection: For aluminum structures that are buried or immersed in aqueous environments, corrosion may be controlled by application of the electrochemical process known as cathodic protection.

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7. Fire Protection

Aluminum alloys are non-combustible when tested in accordance with ASTM E136. The behavior of aluminum and steel members exposed to fire are compared below.

1. Both aluminum and steel members are noncombustible.
2. The cross sectional areas of aluminum members are usually about 40% larger than those of steel.
3. The thermal conductivity of aluminum is about 2.7 times that of steel.
4. Aluminum's strength degrades at much lower temperatures than that of steel.

These issues affect the relative performance of the two materials in a fire. Aluminum parts exposed to fire would be expected to reach a lower temperature than steel, but aluminum's strength relative to that at room temperature is more degraded compared to that for steel. Aluminum members thus need more insulation than steel members to resist the effects of fire.

Kaufman and Kasser (1963) tested fire protection for aluminum members. The criteria for establishing the fire protection for aluminum were:

1. To ensure that strength during a fire will at least equal the allowable stresses at room temperature, the aluminum temperature should be limited to 500°F.
2. To ensure that there will be no substantial change in properties after a fire, the aluminum temperature should be limited to 375°F.

Light weight vermiculite plaster was used in the tests, and specimens were as indicated on Figure 7-1. The relative thicknesses of protection required for various periods of time are shown below.

Part I Appendix 4 and Eurocode 9, Part 1-2 address aluminum structural design for fire conditions.

RELATIVE THICKNESS OF VERMICULITE

REQUIRED FOR FIRE PROTECTION OF STRUCTURAL ALUMINUM MEMBERS

Fire Protection Period (hours)	Ratio of Aluminum Member's Insulation Thickness to Steel Member's Insulation Thickness
1	1.7
2	1.9
3	1.8
4	1.7

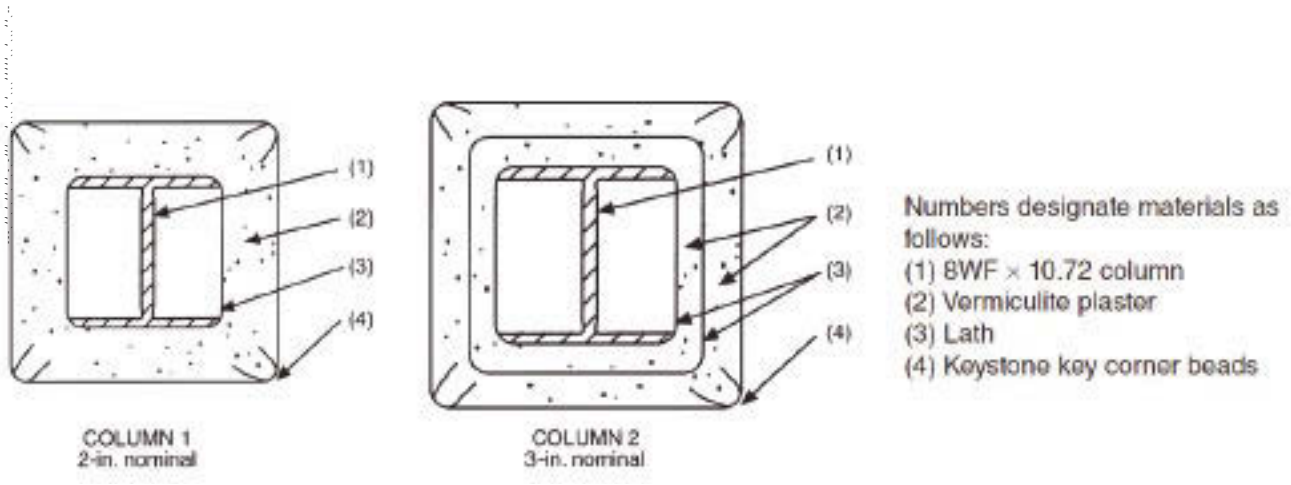

Figure 7-1
SPECIMENS FOR FIRE PROTECTION TESTS

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8. Sustainability

8.1 Reflectance and Emittance

In warm climates, the more roofs reflect and radiate the sun's radiation, the more energy they save by reducing buildings' cooling requirements. Solar reflectance, also called albedo, measures a material's ability to reflect sunlight — including visible, infrared, and ultraviolet wavelengths — on a scale of 0 to 1 and can be expressed as a decimal fraction or a percentage. Thermal emittance is the fraction of energy a material radiates away after it is absorbed. Emittance is the ability to release absorbed heat and is also expressed as a decimal fraction or a percentage.

Reflectance is determined using ASTM E1918 or C1549; emittance is determined according to ASTM E408 or C1371.

Cooling energy requirements are significantly reduced by roofing materials with high reflectance and emittance. For prepainted metal roofing, the substrate has little or no influence on the exterior surface reflectance and emittance. The emittance of painted metal is about 0.8 to 0.9. The reflectance is a function of paint color and type.

Reflectance and emittance of bare aluminum is affected by surface roughness, oxides, and cleanliness. Typical total solar reflectance is 0.6 to 0.8. Mill finish aluminum can have very low emittance (0.02 to 0.10), although this increases slightly as natural oxides form. Aluminum is often anodized to create a durable layer of aluminum oxide that is much thicker than that which occurs naturally. Anodized aluminum has significantly higher emittance (0.6 to 0.9).

8.2 Recycling

Aluminum can be recycled indefinitely without loss of properties. Aluminum is 100% recyclable, and recycling aluminum saves approximately 92% of the energy required to produce aluminum from bauxite.

A 2008 survey of aluminum producers indicated that the total recycled content of domestically produced flat rolled products for the building and construction market was approximately 85%. On average, 60% of the total product content was from post-consumer sources. To determine the recycled content of specific aluminum products, consult the supplier.

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PART IV
MATERIAL PROPERTIES

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

PART IV

Material Properties

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IV
Material Properties

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The information in Part IV is excerpted from Aluminum Standards and Data 2017 and Aluminum Standards and Data 2017 Metric SI.

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General Characteristics of Aluminum

A unique combination of properties makes aluminum one of our most versatile engineering and construction materials. A mere recital of its characteristics is impressive. It is light in mass, yet some of its alloys have strengths greater than that of structural steel. It has high resistance to corrosion under the majority of service conditions, and no colored salts are formed to stain adjacent surfaces or discolor products with which it comes into contact, such as fabrics in the textile industry and solutions in chemical equipment. It has no toxic reaction. It has good electrical and thermal conductivities and high reflectivity to both heat and light. The metal can easily be worked into any form and readily accepts a wide variety of surface finishes.

Lightness is one of aluminum's most useful characteristics. The specific gravity is about 2.7. The mass ("weight") of aluminum is roughly 35 percent that of iron and 30 percent that of copper.

Commercially pure aluminum has a tensile strength of about 13,000 pounds per square inch. Thus its usefulness as a structural material in this form is somewhat limited. By working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminum with small percentages of one or more other elements such as manganese, silicon, copper, magnesium or zinc. Like pure aluminum, the alloys are also made stronger by cold working. Some of the alloys are further strengthened and hardened by heat treatments so that today aluminum alloys having tensile strengths approaching 100,000 pounds per square inch are available.

A wide variety of mechanical characteristics, or tempers, is available in aluminum alloys through various combinations of cold work and heat treatment. In specifying the temper for any given product, the fabricating process and the amount of cold work to which it will subject the metal should be kept in mind. In other words, the temper specified should be such that the amount of cold work the metal will receive during fabrication will develop the desired characteristics in the finished products.

Aluminum and its alloys lose part of their strength at elevated temperatures, although some alloys retain good strength at temperatures from 400˚F to 500˚F. At subzero temperatures, however, their strength increases without loss of ductility, so that aluminum is a particularly useful metal for low-temperature applications.

When aluminum surfaces are exposed to the atmosphere, a thin invisible oxide skin forms immediately, which protects the metal from further oxidation. This self-protecting characteristic gives aluminum its high resistance to corrosion. Unless exposed to some substance or condition that destroys this protective oxide coating, the metal remains fully protected against corrosion. Aluminum is highly resistant to weathering, even in industrial atmospheres that often corrode other metals. It is also corrosion resistant to many acids. Alkalis are among the few substances that attack the oxide skin and therefore are corrosive to aluminum. Although the metal can safely be used in the presence of certain mild alkalis with the aid of inhibitors, in general, direct contact with alkaline substances should be avoided.

Some alloys are less resistant to corrosion than others, particularly certain high-strength alloys. Such alloys in some forms can be effectively protected from the majority of corrosive influences, however, by cladding the exposed surface or surfaces with a thin layer of either pure aluminum or one of the more highly corrosion-resistant alloys.

A word of caution should be mentioned in connection with the corrosion-resistant characteristics of aluminum. Direct contacts with certain other metals should be avoided in the presence of an electrolyte; otherwise galvanic corrosion of the aluminum may take place in the vicinity of the contact area. Where other metals must be fastened to aluminum, the use of a bituminous paint coating or insulating tape is recommended.

The fact that aluminum is nontoxic was discovered in the early days of the industry. It is this characteristic that permits the metal to be used in cooking utensils without any harmful effect on the body, and today we find also a great deal of aluminum equipment in use by food processing industries. The same characteristic permits aluminum foil wrapping to be used safely in direct contact with food products.

Aluminum is one of the two common metals having an electrical conductivity high enough for use as an electric conductor. The conductivity of electric conductor grade (1350) is about 62 percent that of the International Annealed Copper Standard. Because aluminum has less than one-third the specific gravity of copper, however, a pound of aluminum will go about twice as far as a pound of copper when used for this purpose. Alloying lowers the conductivity somewhat, so that wherever possible alloy 1350 is used in electric conductor applications.

The high thermal conductivity of aluminum came prominently into play in the very first large-scale commercial application of the metal in cooking utensils. This characteristic is important wherever the transfer of thermal energy from one medium to another is involved, either heating or cooling. Thus aluminum heat exchangers are commonly used in the food, chemical, petroleum, aircraft and other industries. Aluminum is also an excellent reflector of radiant energy through the entire range of wavelengths, from ultraviolet, through the visible spectrum to infrared and heat waves, as well as electromagnetic waves of radio and radar.

Aluminum has a light reflectivity of over 80 percent, which has led to its wide use in lighting fixtures. Aluminum roofing reflects a high percentage of the sun's heat, so that buildings roofed with this material are cooler in summer.

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The ease with which aluminum may be fabricated into any form is one of its most important assets. Often it can compete successfully with cheaper materials having a lower degree of workability. The metal can be cast by any method known to foundrymen; it can be rolled to any desired thickness down to foil thinner than paper; aluminum sheet can be stamped, drawn, spun or roll-formed. The metal also may be hammered or forged. Aluminum wire, drawn from rolled rod, may be stranded into cable of any desired size and type. There is almost no limit to the different profiles in which the metal may be extruded.

The ease and speed with which aluminum may be machined is one of the important factors contributing to the low cost of finished aluminum parts. The metal may be turned, milled, bored, or machined in other manners at the maximum speeds of which the majority of machines are capable. Another advantage of its flexible machining characteristics is that aluminum rod and bar may readily be employed in the high-speed manufacture of parts by automatic screw machines.

Almost any method of joining is applicable to aluminum: riveting, welding, brazing or soldering. A wide variety of mechanical aluminum fasteners simplifies the assembly of many products. Adhesive bonding of aluminum parts is widely employed, particularly in joining aircraft components.

For the majority of applications, aluminum needs no protective coating. Mechanical finishes such as polishing, sand blasting or wire brushing meet the majority of needs. In many instances, the surface finish supplied is entirely adequate without further finishing. Where the plain aluminum surface does not suffice, or where additional protection is required, any of a wide variety of surface finishes may be applied. Chemical, electrochemical and paint finishes are all used. Many colors are available in both chemical and electrochemical finishes. If paint, lacquer or enamel is used, any color possible with these finishes may be applied. Vitreous enamels have been developed for aluminum, and the metal may also be electroplated.

Aluminum sheet, because of its superior corrosion resistance and smooth continuous surface, is an excellent base for the high quality paints used in producing painted sheet. The chemical pretreatment plus the application of high quality thermally cured paint assures a finish that will exhibit no cracking, blistering, or peeling. Accidental damage to products made of painted aluminum sheet will not result in unsightly rust areas or streaks. Experience has shown that paint in the quality used for this product, properly formulated, applied and cured, will show little change in color or loss of gloss after one year's service in the adverse climatic conditions of south-central Florida.

Highly industrialized areas may cause some color change due to atmospheric contaminants.

Proper maintenance can extend the service life considerably—even the finest automobiles require occasional washing and polishing if they are to retain their original appearance.

Even after many years of service most advantages of the painted sheet remain. It can be repainted with any good grade of house paint with no danger of cracking or peeling, such as is often experienced when paint is applied to other types of base materials.

Painted sheet and the products made from it should be handled with care to avoid damage to the paint film. Repair of large damaged areas is not recommended, but for repair of small areas air drying touch-up paint intended for brush application is available from paint suppliers. Your painted sheet supplier should be contacted for precise information. This touch-up paint cannot be expected to exhibit the same weathering and other characteristics as the original painted sheet, and touched-up areas will present appearance differences after weather exposure. For this reason, use of touch-up paint should be held to a minimum.

Many types of paint systems are used, and it is difficult to establish reasonable and meaningful standards for all of them. Specific applications require consideration of life expectancy, forming requirements and methods, economics, and so forth. Paint systems generally in use exhibit general characteristics as shown on pages 7–31 to 7–33, but for specific applications consult the painted sheet supplier.

These are the characteristics that give aluminum its extreme versatility. In the majority of applications, two or more of these characteristics come prominently into play—for example, light weight combined with strength in airplanes, railroad cars, trucks and other transportation equipment. High resistance to corrosion and high thermal conductivity are important in equipment for the chemical and petroleum industries; these properties combine with non-toxicity for food processing equipment.

Attractive appearance together with high resistance to weathering and low maintenance requirements have led to extensive use in buildings of all types. High reflectivity, excellent weathering characteristics, and light weight are all important in roofing materials. Light weight contributes to low handling and shipping costs, whatever the application.

Many applications require the extreme versatility that only aluminum has. Almost daily its unique combination of properties is being put to work in new ways. The metal now serves as a basic raw material for more than 20,000 businesses scattered throughout the country.

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Alloy and Temper Designation Systems for Aluminum (ANSI H35.1 / H35.1(M)-2017)

Information Note: The Aluminum Association is the registrar under ANSI H35.1 / H35.1(M) with respect to the designation and composition of aluminum alloys and tempers registered in the United States, and is also the registrar under an international accord on the composition and designation of registered wrought aluminum alloys. Since there is no international accord on designation and registration of tempers for wrought aluminum alloys and wrought aluminum alloy products, reference to ANSI H35.1 / H35.1(M) properties and characteristics of wrought aluminum alloy tempers registered with the Aluminum Association under ANSI H35.1 / H35.1(M) may not always reflect actual properties and characteristics associated with the particular aluminum alloy temper. The user may wish to confirm that expected properties denoted by specific temper designation(s) are furnished.

Note: The user of this Aluminum Standards and Data manual should be aware that the alloy and temper designation systems, as reprinted from ANSI H35.1 / H35.1(M), are those in effect at the time of this manual's publication but are subject to supersession by subsequent revisions of this ANSI standard as it is updated.

1. Scope

This standard provides systems for designating wrought aluminum and wrought aluminum alloys, aluminum and aluminum alloys in the form of castings and foundry ingot, and the tempers in which aluminum and aluminum alloy wrought products and aluminum alloy castings are produced. Specific limits for chemical compositions and for mechanical and physical properties to which conformance is required are provided by applicable product standards.

NOTE: A numerical designation assigned in conformance with this standard should only be used to indicate an aluminum or an aluminum alloy having chemical composition limits identical to those registered with the Aluminum Association and, for wrought aluminum and wrought aluminum alloys, with the signatories of the Declaration of Accord on an International Alloy Designation System for Wrought Aluminum and Wrought Aluminum Alloys.

2. Wrought Aluminum and Aluminum Alloy Designation System ① ② ③ ④ ⑬

A system of four-digit numerical designations is used to identify wrought aluminum and wrought aluminum alloys. The first digit indicates the alloy group as follows:

Aluminum alloys grouped by major alloying elements

Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and silicon	6xxx
Zinc	7xxx
Other element	8xxx
Unused series	9xxx

The designation assigned shall be in the 1xxx group whenever the minimum aluminum content is specified as 99.00 percent or higher. The alloy designation in the 2xxx through 8xxx groups is determined by the alloying element (Mg_2Si for 6xxx alloys) present in the greatest mean percentage, except in cases in which the alloy being registered qualifies as a modification or variation of a previously registered alloy. If the greatest mean percentage is common to more than one alloying element, choice of group shall be in order of group sequence Cu, Mn, Si, Mg, Mg_2Si, Zn or others.

The last two digits identify the aluminum alloy or indicate the aluminum purity. The second digit indicates modifications of the original alloy or impurity limits.

① Chemical composition limits and designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum and aluminum alloy castings and foundry ingot may be registered with the Aluminum Association provided: (1) the aluminum or aluminum alloy is offered for sale, (2) the complete chemical composition limits are registered, and (3) the composition is significantly different from that of any aluminum or aluminum alloy for which a numerical designation already has been assigned.

② For codification purposes an alloying element is any element that is intentionally added for any purpose other than grain refinement and for which minimum and maximum limits are specified.

③ Standard limits for alloying elements and impurities are expressed to the following places:

Less than 0.001 percent	0.000X
0.001 but less than 0.01 percent	0.00X
0.01 but less than 0.10 percent	
Unalloyed aluminum made by a refining process	0.0XX
Alloys and unalloyed aluminum not made by a refining process	0.0X
0.10 through 0.55 percent (It is customary to express limits of 0.30 percent through 0.55 percent as 0.X0 or 0.X5)	0.XX
Over 0.55 percent (except that combined Si + Fe limits for 1xxx designations must be expressed as 0.XX or 1.XX)	0.X,X.X, etc.
Aluminum, 99.00 percent and greater	1XXX

④ Standard limits for alloying elements and impurities are expressed in the following sequence: Silicon; Iron; Copper; Manganese; Magnesium; Chromium; Nickel; Zinc; Titanium (see Note 1); Other (see Note 2) Elements, Each; Other (see Note 2) Elements, Total; Aluminum (see Note 3).

Note 1—Additional specified elements having limits are inserted in alphabetical order according to their chemical symbols between Titanium and Other Elements, Each, or are listed in footnotes.

Note 2—"Other" includes listed elements for which no specific limit is shown as well as unlisted metallic elements. "Total" is the sum of those "Others" metallic elements 0.010 or more each, expressed to the second decimal before determining the sum. The producer may analyze samples for trace elements not specifi ed in the registration or specification. However, such analysis is not required and may not cover all metallic "other" elements. Should any analysis by the producer or the purchaser establish that an "other" element exceeds the limit of "Each" or that the aggregate of several "other" elements exceeds the limit of "Total", the material shall be considered non-conforming.

Note 3—Aluminum is specified as minimum for unalloyed aluminum, and as a remainder for aluminum alloys.

⑬ Individual element limits (i.e. a maximum limit or a range) are required for elements having a combined maximum limit in excess of 0.10%. Individual element limits are not required for elements having a combined maximum limit of 0.10% or less.

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2.1 Aluminum

In the 1xxx group for minimum aluminum purities of 99.00 percent and greater, the last two of the four digits in the designation indicate the minimum aluminum percentage ⑤. These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01 percent. The second digit in the designation indicates modifications in impurity limits or alloying elements. If the second digit in the designation is zero, it indicates unalloyed aluminum having natural impurity limits; integers 1 through 9, which are assigned consecutively as needed, indicate special control of one or more individual impurities or alloying elements.

2.2 Aluminum Alloys

In the 2xxx through 8xxx alloy groups the last two of the four digits in the designation have no special significance but serve only to identify the different aluminum alloys in the group. The second digit in the alloy designation indicates original alloy and alloy modifications. If the second digit in the designation is zero, it indicates the original alloy; integers 1 through 9, which are assigned consecutively, indicate alloy modifications. A modification of the original alloy is limited to any one or a combination of the following:

(a) Change of not more than the following amounts in arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element or both.

Arithmetic Mean of Limits for Alloying Elements in Original Alloy	*Maximum Change*
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

(b) Addition or deletion of not more than one alloying element with limits having an arithmetic mean of not more than 0.30 percent or addition or deletion of not more than one combination of elements expressed as an alloying element with limits having a combined arithmetic mean of not more than 0.40 percent.

(c) Substitution of one alloying element for another element serving the same purpose.

(d) Change in limits for impurities expressed singly or as a combination.

(e) Change in limits for grain refining elements.

(f) Maximum iron or silicon limits of 0.12 percent and 0.10 percent, or less, respectively, reflecting use of high purity base metal.

An alloy shall not be registered as a modification if it meets the requirements for a variation.

2.3 Experimental Alloys

Prior to July/2015, experimental alloys were designated in accordance with this system, but they were indicated by the prefix "X". The practice of registering experimental alloys has been discontinued and new experimental alloy designations shall not be granted. Previously registered and subsequently inactivated experimental alloy compositions can only be reactivated with removal of the experimental alloy status and prefix "X".

2.4 Variations

Variations of wrought aluminum and wrought aluminum alloys registered in accordance with this system are identified by a serial letter after the numerical designation. The serial letters are assigned in alphabetical sequence starting with A but omitting I, O and Q.

A variation has composition limits that are similar but not identical to a modification or an original alloy, with differences such as:

(a) Change of not more than the following amounts in arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element, or both:

Arithmetic Mean of Limits for Alloying Elements in Original Alloy or Modification	*Maximum Change*
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

5 The aluminum content for unalloyed aluminum made by a refining process is the difference between 100.00 percent and the sum of all other metallic elements together with silicon present in amounts of 0.0010 percent or more each, expressed to the third decimal before determining the sum, which is rounded to the second decimal before subtracting; for unalloyed aluminum not made by a refining process it is the difference between 100.00 percent and the sum of all other analyzed metallic elements together with silicon present in amounts of 0.010 percent or more each, expressed to the second decimal before determining the sum. For unalloyed aluminum made by a refining process, when the specified maximum limit is 0.0XX, an observed value or a calculated value greater than 0.0005 but less than 0.0010% is rounded off and shown as "less than 0.001"; for alloys and unalloyed aluminum not made by a refining process, when the specified maximum limit is 0.XX, an observed value or a calculated value greater than 0.005 but less than 0.010% is rounded off and shown as "less than 0.01".

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(b) Substitution of one alloying element for another element serving the same purpose.

(c) Change in limits of impurities expressed singly or as a combination except for low iron. Iron maximum of 0.12 percent, or less, reflecting high purity base metal, should be considered as an alloy modification.

(d) Change in limits on grain refining elements.

(e) Inclusion of a minimum limit for iron or silicon, or both, without a change in the maximum limit.

An alloy shall not be registered as a new alloy or alloy modification if it meets the requirements for a variation.

3. Cast Aluminum and Aluminum Alloy Designation System ① ② ③ ④

A system of four digit numerical designations is used to identify aluminum and aluminum alloys in the form of castings and foundry ingot. The first digit indicates the alloy group as follows:

Aluminum, 99.00 percent minimum and greater	1xx.x
Aluminum alloys grouped by major alloying elements	
Copper	2xx.x
Silicon, with added copper and/or magnesium	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x
Other element	9xx.x
Unused series	6xx.x

The alloy group in the 2xx.x through 9xx.x excluding 6xx.x alloys is determined by the alloying element present in the greatest mean percentage, except in cases in which the alloy being registered qualified as a modification of a previously registered alloy. If the greatest mean percentage is common to more than one alloying element, the alloy group will be determined by the sequence shown above.

The second two digits identify the aluminum alloy or indicate the aluminum purity. The last digit, which is separated from the others by a decimal point, indicates the product form: that is, castings or ingot. A modification of the original alloy or impurity limits is indicated by a serial letter before the numerical designation. The serial letters are assigned in alphabetical sequence starting with A but omitting I, O, Q and X.

A modification of the original alloy is limited to any one or a combination of the following:

(a) Change of not more than the following amounts in the arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element or both:

Arithmetic Mean of Limits for Alloying Elements in Original Alloy or Modification	*Maximum Change*
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

(b) Addition or deletion of not more than one alloying element with limits having an arithmetic mean of not more than 0.30 percent or addition or deletion of not more than one combination of elements expressed as an alloying element with limits having a combined arithmetic mean of not more than 0.40 percent.

(c) Substitution of one alloying element for another element serving the same purpose.

(d) Change in limits for impurities expressed singly or as a combination.

(e) Change in limits for grain refining elements.

(f) Iron or silicon maximum limits of 0.12 percent and 0.10 percent, or less, respectively, reflecting use of high purity base metal.

3.1 Aluminum Castings and Ingot

In the 1xx.x group for minimum aluminum purities of 99.00 percent and greater, the second two of the four digits in the designation indicate the minimum aluminum percentage.⑤These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01 percent. The last digit, which is to the right of the decimal point, indicates the product form: 1xx.0 indicates castings, and 1xx.1 indicates ingot.

3.2 Aluminum Alloy Castings and Ingot

In the 2xx.x through 9xx.x alloy groups the second two of the four digits in the designation have no special significance but serve only to identify the different aluminum alloys in the group. The last digit, which is to the right of the decimal point, indicates the product form: xxx.0 indicates castings, xxx.1 indicates ingot that has chemical composition limits conforming to 3.2.1, and xxx.2 indicates ingot that has chemical composition limits that differ but fall within the limits of xxx.1 ingot.

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3.2.1 Limits for Alloying Elements and Impurities

Limits for alloying elements and impurities for xxx.1 ingot are the same as for the alloy in the form of castings, except grain refining elements and except for the following:

Maximum Iron Percentage:

For All Forms of Castings	*For Ingot, Fe Shall be At Least*
Up thru 0.15	0.03 less than castings
Over 0.15 thru 0.25	0.05 less than castings
Over 0.25 thru 0.6	0.10 less than castings
Over 0.6 thru 1.0	0.2 less than castings
Over 1.0	0.3 less than castings

Minimum Magnesium Percentage*:

For All Forms of Castings	*For Ingot*
Less than 0.50	0.05 more than castings
0.50 and greater	0.1 more than castings

Maximum Zinc Percentage:

For Die Castings	*For Ingot*
Over 0.25 thru 0.6	0.10 less than castings
Over 0.6	0.1 less than castings

*Applicable only if magnesium is an alloying element (i.e. has a registered minimum and maximum percentage).

3.2.2 Identifiers for 3xx.x and 4xx.x Foundry Ingot Containing Structure Modifiers

One of the applicable suffixes in the table below should be added to the registered alloy designation whenever a structure modifier is intentionally added to that alloy.

Alloy Designation Suffix	Structure Modifying Element	Chemical Composition Limits	
		Minimum (%)	Maximum (%)
N	Na	0.003	0.08
S	Sr	0.005	0.08
C	Ca	0.005	0.15
P	P	—	0.060

(a) The letter suffix follows and is separated from the registered foundry ingot designation by a hyphen (e.g., "A356.1-S").

(b) In cases where more than one modifier is intentionally added, only the modifier of greater concentration shall be identified by suffix letter affixed to the registered alloy designation.

(c) Where foundry alloy is sold with a suffix added to its alloy designation, the modifying element's concentration is not to be included in "Others, Each" or "Others, Total".

(d) It is not intended that these structure modifier identifiers be treated as new alloy registration, nor should these designations be listed in the Registration Record.

4. Temper Designation System ⑥

The temper designation system is used for all forms of wrought and cast aluminum and aluminum alloys except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter.

⑥ ***Temper designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum alloy castings may be registered with the Aluminum Association provided: (1) the temper is used or is available for use by more than one user, (2) mechanical property limits are registered, (3) the characteristics of the temper are significantly different from those of all other tempers that have the same sequence of basic treatments and for which designations already have been assigned for the same alloy and product, and (4) the following are also registered if characteristics other than mechanical properties are considered significant: (a) test methods and limits for the characteristics or (b) the specific practices used to produce the temper***

These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.

4.1 Basic Temper Designations

F **as fabricated**. Applies to the products of shaping processes in which no special control over thermal conditions or strain hardening is employed. For wrought products, there are no mechanical property limits.

O **annealed**. Applies to wrought products that are annealed to obtain the lowest strength temper, and to cast products that are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.

H **strain-hardened (wrought products only)**. Applies to products that have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.

W **solution heat-treated**. An unstable temper applicable only to alloys that spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated; for example: W ½ hr.

T **precipitation hardened to produce stable tempers other than F, O or H**. Applies to products that are precipitation hardened, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits..

4.2 Subdivisions of Basic Tempers

4.2.1 Subdivision of H Temper: Strain-hardened

(a) The first digit following the H indicates the specific combination of basic operations, as follows:

H1 **strain-hardened only**. Applies to products that are strain- hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

H2 **strain-hardened and partially annealed**. Applies to products that are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

H3 **strain-hardened and stabilized**. Applies to products that are strain-hardened and whose mechanical properties are stabilized either by a low temperature thermal treatment or as a result of heat introduced during fabrication. Stabilization usually improves ductility. This designation is applicable only to those alloys that, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment.

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H4 strain-hardened and lacquered or painted. Applies to products which are strain-hardened and which are subjected to some thermal operation during the subsequent painting or lacquering operation. The number following this designation indicates the degree of strain-hardening remaining after the product has been thermally treated, as part of painting/lacquering cure operation. The corresponding H2X or H3X mechanical property limits apply.

(b) The digit following the designation H1, H2, H3, and H4 indicates the degree of strain-hardening as identified by the minimum value of the ultimate tensile strength. Numeral 8 has been assigned to the hardest tempers normally produced. The minimum tensile strength of tempers HX8 may be determined from Table 1 and is based on the minimum tensile strength of the alloy in the annealed temper. However, temper registrations prior to 1992 that do not conform to the requirements of Table 1 shall not be revised and registrations of intermediate or modified tempers for such alloy/temper systems shall conform to the registration requirements that existed prior to 1992.

Table 1

US Customary Units

Minimum tensile strength in annealed temper ksi	Increase in tensile strength to HX8 temper ksi
up to 6	8
7 to 9	9
10 to 12	10
13 to 15	11
16 to 18	12
19 to 24	13
25 to 30	14
31 to 36	15
37 to 42	16
43 and over	17

Metric Units

Minimum tensile strength in annealed temper MPa	Increase in tensile strength to HX8 temper MPa
up to 40	55
45 to 60	65
65 to 80	75
85 to 100	85
105 to 120	90
125 to 160	95
165 to 200	100
205 to 240	105
245 to 280	110
285 to 320	115
325 and over	120

Tempers between O (annealed) and HX8 are designated by numerals 1 through 7.

—Numeral 4 designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX8 tempers;

—Numeral 2 designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX4 tempers;

—Numeral 6 designates tempers whose ultimate tensile strength is approximately midway between that of the HX4 tempers and that of the HX8 tempers;

—Numerals 1, 3, 5 and 7 designate, similarly, tempers intermediate between those defined above.

—Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the HX8 tempers by 2 ksi or more. (For Metric Units by 10 MPa or more).

The ultimate tensile strength of the odd numbered intermediate (-HX1, -HX3, -HX5, and HX7) tempers, determined as described above, shall be rounded to the nearest multiple of 0.5 ksi. (For Metric Units when not ending in 0 or 5, shall be rounded to the next higher 0 or 5 MPa.)

(c) The third digit ⑦, when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties or both differ from, but are close to, that (or those) for the two-digit H temper designation to which it is added, or when some other characteristic is significantly affected. (See Appendix for assigned three-digit H tempers.)

NOTE: The minimum ultimate tensile strength of a three-digit H temper must be at least as close to that of the corresponding two-digit H temper as it is to the adjacent two-digit H tempers. Products in the H temper whose mechanical properties are below H_1 shall be variations of H_1.

4.2.2 Subdivision of T Temper: Precipitation Hardened

(a) Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows ⑧:

T1 cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition. Applies to products that are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T2 cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition. Applies to products that are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

⑦ Numerals 1 through 9 may be arbitrarily assigned as the third digit and registered with the Aluminum Association for an alloy and product to indicate a variation of a two-digit H temper (see note ③).

⑧ A period of natural aging at room temperature may occur between or after the operations listed for the T tempers. Control of this period is exercised when it is metallurgically important.

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T3 **solution heat-treated⑨, cold worked, and naturally aged to a substantially stable condition.** Applies to products that are cold worked to improve strength after solution heat-treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T4 **solution heat-treated⑨ and naturally aged to a substantially stable condition.** Applies to products that are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T5 **cooled from an elevated temperature shaping process and then artificially aged.** Applies to products that are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T6 **solution heat-treated⑨and then artificially aged.** Applies to products that are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T7 **solution heat-treated⑨ and overaged/stabilized.** Applies to wrought products that are artificially aged after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some significant characteristic . Applies to cast products that are artificially aged after solution heat-treatment to provide dimensional and strength stability.

T8 **solution heat-treated⑨,cold worked, and then artificially aged.** Applies to products that are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T9 **solution heat-treated⑨,artificially aged, and then cold worked.** Applies to products that are cold worked to improve strength.

T10 **cooled from an elevated temperature shaping process, cold worked, and then artificially aged.** Applies to products that are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

(b) Additional digits⑪, the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment that significantly alters the product characteristics that are or would be obtained using the basic treatment. (See Appendix for specific additional digits for T tempers.)

4.3 Variations of O Temper: Annealed

4.3.1 A digit following the O, when used, indicates a product in the annealed condition having special characteristics. NOTE: As the O temper is not part of the strain-hardened (H) series, variations of O temper shall not apply to products that are strain-hardened after annealing and in which the effect of strain-hardening is recognized in the mechanical properties or other characteristics. (See Appendix for specific additional digits for O tempers.)

⑨ Solution heat treatment is achieved by heating cast or wrought products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution and cooling rapidly enough to hold the constituents in solution. Some 6xxx series and some 7xxx series alloys attain the same specified mechanical properties whether furnace solution heat treated or cooled from an elevated temperature shaping process at a rate rapid enough to hold constituents in solution. In such cases the temper designations T3, T4, T6, T7, T8, and T9 are used to apply to either process and are appropriate designations.

⑩ For this purpose, *characteristic* is something other than mechanical properties. the test method and limit used to evaluate material for this characteristic are specified at the time of the temper registration.

⑪ Additional digits may be arbitrarily assigned and registered with The Aluminum Association for an alloy and product to indicate a variation of tempers T1 through T10 even though the temper representing the basic treatment has not been registered (see note ⑥). Variations in treatment that do not alter the characteristics of the product are considered alternate treatments for which additional digits are not assigned.

APPENDIX

A1 Three-Digit H Tempers

(a) The following three-digit H temper designations have been assigned for wrought products in all alloys:

H_11 Applies to products that incur sufficient strain hardening after the final anneal that they fail to qualify as annealed but not so much or so consistent an amount of strain hardening that they qualify as H_1.

H112 Applies to products that may acquire some temper from working at an elevated temperature and for which there are mechanical property limits.

(b) The following three-digit H temper designations have been assigned for:

pattern or embossed sheet	fabricated from
H114	O temper
H124, H224, H324	H11, H21, H31 temper, respectively
H134, H234, H334	H12, H22, H32 temper, respectively
H144, H244, H344	H13, H23, H33 temper, respectively
H154, H254, H354	H14, H24, H34 temper, respectively
H164, H264, H364	H15, H25, H35 temper, respectively
H174, H274, H374	H16, H26, H36 temper, respectively
H184, H284, H384	H17, H27, H37 temper, respectively
H194, H294, H394	H18, H28, H38 temper, respectively
H195, H295, H395	H19, H29, H39 temper, respectively

(c) The following three-digit H temper designations have been assigned only for wrought products in the 5xxx series, for which the magnesium content is 3% nominal or more:

H116 Applies to products manufactured from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are strain hardened at the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. They are suitable for continuous service at temperature no greater than 150° F (66°C). Corrosion tests include inter-granular and exfoliation.

H1_8 Applies to products manufactured from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are strain hardened at the last operation to specified stable tensile property limits and are capable of meeting specified levels of corrosion resistance in accelerated type corrosion tests after a thermal treatment that is intended to demonstrate improved corrosion performance in ambient conditions. They are suitable for continuous service at temperature no greater than 150°F (66°C). Corrosion tests include inter-granular and exfoliation.

H321 Applies to products from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are thermally stabilized at the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. They are suitable for continuous service at temperatures no greater than 150° F (66°C). Corrosion tests include inter-granular and exfoliation.

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A2 Additional Digits for T Tempers

A2.1 Assigned Additional Digits for Stress-Relieved Tempers

The following specific additional digits have been assigned for stress-relieved tempers of wrought products:

A2.1.1 Stress relieved by stretching⑫

T_51 Applies to plate and rolled or cold-finished rod or bar, die or ring forgings and rolled rings when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. The products receive no further straightening after stretching.

Plate. . . . . 1½% to 3% permanent set.

Rolled or Cold-Finished
Rod and Bar . . . . . 1% to 3% permanent set.

Die or Ring Forgings
and Rolled Rings . . . . . 1% to 5% permanent set.

T_510 Applies to extruded rod, bar, profiles (shapes) and tube and to drawn tube when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. These products receive no further straightening after stretching.

Extruded Rod
Bar, Profiles (Shapes)
and Tube . . . . . 1% to 3% permanent set.

Drawn Tube. . . . . ½% to 3% permanent set.

T_511 Applies to extruded rod, bar, profiles (shapes) and tube and to drawn tube when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. These products may receive minor straightening after stretching to comply with standard tolerances.

Extruded Rod, Bar,
Profiles (Shapes)
and Tube . . . . . 1% to 3% permanent set.

Drawn Tube. . . . . ½% to 3% permanent set.

2.1.2 Stress relieved by compressing ⑫

T_52 Applies to products that are stress-relieved by compressing after solution heat treatment or cooling from an elevated temperature shaping process to produce a permanent set of 1 percent to 5 percent.

A2.1.3 Stressed relieved by combined stretching and compressing⑫

T_54 Applies to die forgings that are stress relieved by re-striking cold in the finish die.

A2.2 Assigned Additional Digits for T7 Temper Variations

The following temper designations have been assigned to wrought products which are artificially overaged to obtain a good compromise among exfoliation corrosion resistance, stress corrosion resistance, fracture toughness, and tensile strength.

These designations shall be applied when standardizing new alloy-temper-product combinations.

T79 Very limited overaging to achieve some improved corrosion resistance with limited reduction in strength as compared to the T6 Temper.

T76 Limited overaged condition to achieve moderate corrosion resistance with some reduction in strength. The T76 temper has lower strength and better corrosion resistance than the T79 temper.

T74 Overaged condition to achieve good corrosion resistance with a greater reduction in strength than the T76 temper. The T74 temper strength and corrosion resistance properties are between those of the T73 and T76 tempers.

T73 Fully overaged condition to achieve the best corrosion resistance of the T7X tempers with a greater reduction in strength than the T74 temper.

T77 Aged condition which provides strength at or near T6 temper and corrosion resistance similar to T76 temper.

The evolution of material properties from temper T79 to T73 is illustrated in Figure 1.*

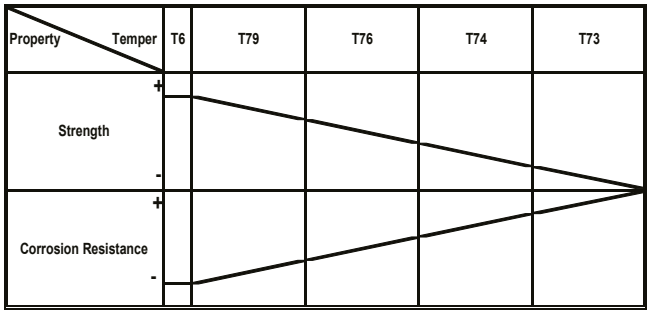

Figure 1

* The T77 temper does not fall within the continuous progression of the T7X tempers depicted in Figure 1.

⑫ The same digits (51, 510, 511, 52, 54) may be added to the designation W to indicate unstable solution heat-treated and stress-relieved tempers.

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A2.3 Assigned Temper Designations for Producer/Supplier and Purchaser/User Heat Treatment

A2.3.1 Temper Designations for Producer/Supplier Laboratory Demonstration of Response to Heat Treatment

The following temper designations have been assigned for wrought products test material, furnace heat-treated from annealed (O, O1, etc.) or F temper, to demonstrate response to heat-treatment.

T42 Solution heat-treated from annealed or F temper and naturally aged to a substantially stable condition.

T62 Solution heat-treated from annealed or F temper and artificially aged.

T7_2 Solution heat-treated from annealed or F temper and artificially overaged to meet the mechanical properties and corrosion resistance limits of the T7_ temper.

A2.3.2 Temper Designations for Producer/Supplier Demonstration of Response to Temper Conversion

Temper designation T_2 shall be used to indicate wrought product test material, which has undergone furnace heat-treatment for capability demonstration of temper conversion. When the purchaser requires capability demonstrations from T-temper, the seller shall note "Capability Demonstration" adjacent to the specified and ending tempers. Some examples are:

(a) "T3 to T82 Capability Demonstration for response to aging";

(b) "T4 to T62 Capability Demonstration for response to aging";

(c) "T4 to T762 Capability Demonstration for response to overaging";

(d) "T6 to T732 Capability Demonstration for response to overaging";

(e) "T351 to T42 Capability Demonstration for response to re-solution heat-treatment".

A2.3.3 Temper Designation for Purchaser/User Heat-treatment

Temper designation T_2 should also be applied to wrought products heat-treated by the purchaser/user, in accordance with the applicable heat treatment specification, to achieve the properties applicable to the final temper.

A3 Assigned O Temper Variations

The following temper designations have been assigned for:

A3.1 Wrought Products High Temperature Annealed to Accentuate Ultrasonic Response and Provide Dimensional Stability

O1 Thermally treated at approximately the same time and temperature required for solution heat treatment and slow cooled to room temperature. Applicable to products that are to be machined prior to solution heat treatment by the user. Mechanical property limits are not applicable.

A3.2 Temper Designation for Producer Laboratory Demonstration of Response to Annealing

O2 Wrought product test material, furnace annealed from the F temper, to determine the minimum limits upon which H temper designations are assigned.

A4 Designation of Unregistered Tempers

The letter P has been assigned to denote H, T and O temper variations that are negotiated between manufacturer and purchaser. The letter P immediately follows the temper designation that most nearly pertains. Specific examples where such designation may be applied include the following:

(a) The use of the temper is sufficiently limited so as to preclude its registration. (Negotiated H temper variations were formerly indicated by the third digit zero.)

(b) The test conditions (sampling location, number of samples, test specimen configuration, etc.) are different from those required for registration with the Aluminum Association.

(c) The mechanical property limits are not established on the same basis as required for registration with the Aluminum Association.

(d) For products such as Aluminum Metal Matrix Composites which are not included in any registration records.

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Metallurgical Aspects

In high-purity form aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys, which singly or in combination impart strength to the metal. Further strengthening is possible by means that classify the alloys roughly into two categories, non-heat-treatable and heat-treatable.

non-heat-treatable alloys—The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1xxx, 3xxx, 4xxx, or 5xxx series. Since these alloys are work-hardenable, further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called stabilizing to ensure stability of properties.

heat-treatable alloys—The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc, and silicon. Since these elements singly or in various combinations show increasing solid solubility in aluminum with increasing temperature, it is possible to subject them to thermal treatments that will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated-temperature process designed to put the soluble element or elements in solid solution. This is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and for a short time renders the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below freezing temperatures until they are ready to form them. At room or elevated temperatures the alloys are not stable after quenching, however, and precipitation of the constituents from the super-saturated solution begins. After a period of several days at room temperature, termed aging or room-temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for long periods of time at room temperature.

By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

clad alloys—The heat-treatable alloys in which copper or zinc are major alloying constituents are less resistant to corrosive attack than the majority of non-heat-treatable alloys.

To increase the corrosion resistance of these alloys in sheet and plate form, they are often clad with high- purity aluminum, a low magnesium-silicon alloy, or an alloy containing 1 percent zinc. The cladding, usually from 2½ percent to 5 percent of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance but also exerts a galvanic effect, which further protects the core material.

Special composites may be obtained such as clad non-heat-treatable alloys for extra corrosion protection, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons, and on an experimental basis extrusions also have been clad.

annealing characteristics—All wrought aluminum alloys are available in annealed form. In addition, it may be desirable to anneal an alloy from any other initial temper, after working, or between successive stages of working such as in deep drawing.

Effect of Alloying Elements

1xxx series—Aluminum of 99 percent or higher purity has many applications, especially in the electrical and chemical fields. These compositions are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain-hardening. Iron and silicon are the major impurities.

2xxx series—Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties; in the heat treated condition mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances artificial aging is employed to further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not so great. The alloys in the 2xxx series do not have as good corrosion resistance as most other aluminum alloys, and under certain conditions they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet are usually clad with a high-purity alloy or a magnesium-silicon alloy of the 6xxx series, which provides galvanic protection to the core material and thus greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

3xxx series—Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5 percent, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, which is widely used as a general purpose alloy for moderate-strength applications requiring good workability.

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4xxx series—The major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminum-silicon alloys are used in welding wire and as brazing alloys where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark gray when anodic oxide finishes are applied, and hence are in demand for architectural applications.

5xxx series—Magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element or with manganese, the result is a moderate to high strength non-heat-treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8 percent magnesium being equal to 1.25 percent manganese, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in marine atmosphere. However, certain limitations should be placed on the amount of cold work and on the safe operating temperatures permissible for the higher magnesium content alloys (over about 3½ percent for operating temperatures above about 150°F) to avoid susceptibility to stress corrosion.

6xxx series—Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. The major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most of the 2xxx or 7xxx alloys, the magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the T4 temper (solution heat-treated but not artificially aged) and then reach full T6 properties by artificial aging.

7xxx series—Zinc is the major alloying element in this group, and when coupled with a smaller percentage of magnesium results in heat-treatable alloys of very high strength. Usually other elements such as copper and chromium are also added in small quantities. The outstanding member of this group is 7075, which is among the highest strength alloys available and is used in air-frame structures and for highly stressed parts.

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Table 1

COMPARATIVE CHARACTERISTICS AND APPLICATIONS

Alloy and Temper	Resistance to Corrosion		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	Weldability ⑥			Some Applications of Alloys
	General ①	Stress Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
1060-O	A	A	A	E	A	A	A	B	Chemical equipment, railroad tank cars
H12	A	A	A	E	A	A	A	A	
H14	A	A	A	D	A	A	A	A	
H16	A	A	B	D	A	A	A	A	
H18	A	A	B	D	A	A	A	A	
1100-O	A	A	A	E	A	A	A	B	Sheet metal work, spun hollowware, fin stock
H12	A	A	A	E	A	A	A	A	
H14	A	A	A	D	A	A	A	A	
H16	A	A	B	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
1350-O	A	A	A	E	A	A	A	B	Electrical conductors
H12, H111	A	A	A	E	A	A	A	A	
H14, H24	A	A	A	D	A	A	A	A	
H16, H26	A	A	B	D	A	A	A	A	
H18	A	A	B	D	A	A	A	A	
2011-T3	D③	D	C	A	D	D	D	D	Screw machine products
T4, T451	D③	D	B	A	D	D	D	D	
T8	D	B	D	A	D	D	D	D	
2014-O	. .	. .	. .	D	D	D	D	B	Truck frames, aircraft structures
T3, T4, T451	D③	C	C	B	D	D	B	B	
T6, T651, T6510, T6511	D	C	D	B	D	D	B	B	
2017-T4, T451	D③	C	C	B	D	D	B	B	Screw machine products, fittings
2018-T61	. .	. .	. .	B	D	D	C	B	Aircraft engine cylinders, heads and pistons
2024-O	. .	. .	. .	D	D	D	D	D	Truck wheels, screw machine products, aircraft structures
T4, T3, T351, T3510, T3511	D③	C	C	B	D	C	B	B	
T361	D③	C	D	B	D	D	C	B	
T6	D	B	C	B	D	D	C	B	
T861, T81, T851, T8510, T8511	D	B	D	B	D	D	C	B	
2025-T6	D	C	. .	B	D	D	B	B	Forgings, aircraft propellers
2036-T4	C	. .	B	C	D	C	B	B	Auto body panel sheet
2117-T4	C	A	B	C	D	D	B	B	Rivets
2124-T851	D	B	D	B	D	D	C	B	Aircraft structures
2218-T61	D	C	. .	. .	D	D	C	B	Jet engine impellers and rings
T72	D	C	. .	B	D	D	C	B	
2219-O	. .	. .	. .	. .	D	D	A	B	Structural uses at high temperatures (to 600°F) High strength weldments
T31, T351, T3510, T3511	D③	C	C	B	D	A	A	A	
T37	D③	C	D	B	D	A	A	A	
T81, T851, T8510, T8511	D	B	D	B	D	A	A	A	
T87	D	B	D	B	D	A	A	A	
2618-T61	D	C	. .	B	D	D	C	B	Aircraft engines
3003-O	A	A	A	E	A	A	A	B	Cooking utensils, chemical equipment, pressure vessels, sheet metal work, builder's hardware, storage tanks
H12	A	A	A	E	A	A	A	A	
H14	A	A	B	D	A	A	A	A	
H16	A	A	C	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
H25	A	A	B	D	A	A	A	A	

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Table 1

COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Continued)

Alloy and Temper	Resistance to Corrosion		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	Weldability ⑥			Some Applications of Alloys
	General ①	Stress Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
3004-O	A	A	A	D	B	A	A	B	Sheet metal work, storage tanks
H32	A	A	B	D	B	A	A	A	
H34	A	A	B	C	B	A	A	A	
H36	A	A	C	C	B	A	A	A	
H38	A	A	C	C	B	A	A	A	
3105-O	A	A	A	E	A	A	A	B	Residential siding, mobile homes, rain carrying goods, sheet metal work
H12	A	A	B	E	A	A	A	A	
H14	A	A	B	D	A	A	A	A	
H16	A	A	C	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
H25	A	A	B	D	A	A	A	A	
4032-T6	C	B	. .	B	D	D	B	C	Pistons
5005-O	A	A	A	E	B	A	A	B	Appliances, utensils, architectural, electrical conductor
H12	A	A	A	E	B	A	A	A	
H14	A	A	B	D	B	A	A	A	
H16	A	A	C	D	B	A	A	A	
H18	A	A	C	D	B	A	A	A	
H32	A	A	A	E	B	A	A	A	
H34	A	A	B	D	B	A	A	A	
H36	A	A	C	D	B	A	A	A	
H38	A	A	C	D	B	A	A	A	
5050-O	A	A	A	E	B	A	A	B	Builder's hardware, refrigerator trim, coiled tubes
H32	A	A	A	D	B	A	A	A	
H34	A	A	B	D	B	A	A	A	
H36	A	A	C	C	B	A	A	A	
H38	A	A	C	C	B	A	A	A	
5052-O	A	A	A	D	C	A	A	B	Sheet metal work, hydraulic tube, appliances
H32	A	A	B	D	C	A	A	A	
H34	A	A	B	C	C	A	A	A	
H36	A	A	C	C	C	A	A	A	
H38	A	A	C	C	C	A	A	A	
5056-O	A④	B④	A	D	D	C	A	B	Cable sheathing, rivets for magnesium, screen wire, zipper
H111	A④	B④	A	D	D	C	A	A	
H12, H32	A④	B④	B	D	D	C	A	A	
H14, H34	A④	B④	B	C	D	C	A	A	
H18, H38	A④	C④	C	C	D	C	A	A	
H192	B④	D④	D	B	D	C	A	A	
H392	B④	D④	D	B	D	C	A	A	
5083-O	A④	A④	B	D	D	C	A	B	Unfired, welded pressure vessels, marine, auto aircraft cryogenics, TV towers, drilling rigs, transportation equipment, missile components
H32⑧	A④	A④	C	D	D	C	A	A	
H321⑧	A④	A④	C	D	D	C	A	A	
H111	A④	B④	C	D	D	C	A	A	
H116 ⑧	A④	A④	C	D	D	C	A	A	

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Table 1

COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Continued)

Alloy and Temper	Resistance to Corrosion		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	Weldability ⑥			Some Applications of Alloys
	General ①	Stress Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
5086-O	A④	A④	A	D	D	C	A	B	
H32⑧	A④	A④	B	D	D	C	A	A	
H34	A④	B④	B	C	D	C	A	A	Unfired, welded pressure vessels, marine, auto aircraft cryogenics, TV towers, drilling rigs, transportation equipment, missile components
H36	A④	B④	C	C	D	C	A	A	
H111	A④	A④	B	D	D	C	A	A	
H116⑧	A④	A④	B	D	D	C	A	A	
5154-O	A④	A④	A	D	D	C	A	B	Welded structures, storage tanks, pressure vessels, salt water service
H32	A④	A④	B	D	D	C	A	A	
H34	A④	A④	B	C	D	C	A	A	
H36	A④	A④	C	C	D	C	A	A	
H38	A④	A④	C	C	D	C	A	A	
5252-H24	A	A	B	D	C	A	A	A	Automotive and appliance trim
H25	A	A	B	C	C	A	A	A	
H28	A	A	C	C	C	A	A	A	
5254-O	A④	A④	A	D	D	C	A	B	Hydrogen peroxide and chemical storage vessels
H32	A④	A④	B	D	D	C	A	A	
H34	A④	A④	B	C	D	C	A	A	
H36	A④	A④	C	C	D	C	A	A	
H38	A④	A④	C	C	D	C	A	A	
5454-O	A	A	A	D	D	C	A	B	Welded structures, pressure vessels, marine service
H32	A	A	B	D	D	C	A	A	
H34	A	A	B	C	D	C	A	A	
H111	A	A	B	D	D	C	A	A	
5456-O	A④	B④	B	D	D	C	A	B	
H32⑧	A④	B④	C	D	D	C	A	A	High strength welded structures, pressure vessels, marine applications, storage tanks
H321⑧	A④	B④	C	D	D	C	A	A	
H116⑧	A④	B④	C	D	D	C	A	A	
5457-O	A	A	A	E	B	A	A	B	
5657-H241	A	A	A	D	B	A	A	A	Anodized auto and appliance trim
H25	A	A	B	D	B	A	A	A	
H26	A	A	B	D	B	A	A	A	
H28	A	A	C	D	B	A	A	A	
6005-T1, T5	B	A	. .	. .	A	A	A	A	Truck, marine, railroad car
6005A-T1, T5	B	A	B	C	A	A	A	A	Extruded profiles, structures, ladders, construction
6005A-T61	B	A	C	C	A	A	A	A	
6053-O	. .	. .	. .	E	B	A	A	B	Wire and rod for rivets
T6, T61	A	A	. .	C	B	A	A	A	
6061-O	B	A	A	D	A	A	A	B	Heavy-duty structures requiring good corrosion resistance, truck and marine, railroad cars, furniture, pipelines
T4, T451, T4510, T4511	B	B	B	C	A	A	A	A	
T6, T651, T652, T6510, T6511	B	A	C	C	A	A	A	A	

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Table 1

COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Concluded)

Alloy and Temper	Resistance to Corrosion		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	Weldability ⑥			Some Applications of Alloys
	General ①	Stress Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
6063-T1	A	A	B	D	A	A	A	A	Pipe railing, furniture, architectural extrusions
T4	A	A	B	D	A	A	A	A	
T5, T52	A	A	B	C	A	A	A	A	
T6	A	A	C	C	A	A	A	A	
T83, T831, T832	A	A	C	C	A	A	A	A	
6066-O	C	A	B	D	D	D	B	B	Forgings and extrusion for welded structures
T4, T4510, T4511	C	B	C	C	D	D	B	B	
T6, T6510, T6511	C	B	C	B	D	D	B	B	
6070-T4, T4511	B	B	B	C	D	A	A	A	Heavy duty welded structures, pipelines
T6	B	B	C	C	D	A	A	A	
6082-T6, T6511	B	A	C	C	A	A	A	A	Heavy-duty structures requiring good corrosion resistance, truck and marine, railroad cars, furniture, pipelines
6101-T6, T63	A	A	C	C	A	A	A	A	High strength bus conductors
T61, T64	A	A	B	D	A	A	A	A	
6151-T6, T652	. .	. .	. .	. .	B	. .	. .	. .	Moderate strength, intricate forgings for machine and auto parts
6201-T81	A	A	. .	C	A	A	A	A	High strength electric conductor wire
6262-T6, T651, T6510, T6511	B	A	C	B	B	B	B	A	Screw machine products
T9	B	A	D	B	B	B	B	A	
6351-T1	. .	. .	C	C	C	B	A	B	Extruded profiles, structurals, pipe and tube
T4	A	. .	C	C	C	B	A	B	
T5	A	. .	C	C	C	B	A	A	
T6	A	. .	C	C	C	B	A	A	
6360-T5	A	A	B	C	A	A	A	A	Architectural extrusion, furniture, extruded profiles, pipe
T6	A	A	C	C	A	A	A	A	
6463-T1	A	A	B	D	A	A	A	A	Extruded architectural and trim sections
T5	A	A	B	C	A	A	A	A	
T6	A	A	C	C	A	A	A	A	
6560-T5	A	A	B	C	A	A	A	A	Architectural extrusion, furniture, extruded profiles, pipe
T6	A	A	C	C	A	A	A	A	
6951-T42, T62	. .	. .	. .	. .	A	A	A	A	
7005-T53	. .	. .	. .	. .	B	C	A	A	
7049-T73, T7352	C	B	D	B	D	D	D	B	Aircraft forgings
7050-T73510, T73511, T74⑦, T7451⑦, T74510⑦, T74511⑦, T7452⑦, T7651, T76510, T76511	C	B	D	B	D	D	D	B	Aircraft and other structures
7075-O	. .	. .	. .	D	D	D	D	B	Aircraft and other structures
T6, T651, T652, T6510, T6511	C③	C	D	B	D	D	D	B	
T73, T7351	C	B	D	B	D	D	D	B	
7175-T74, T7452, T7454	C	B	D	B	D	D	C	B	
7475-O	. .	. .	. .	. .	D	D	D	B	Shell Casings, Aircraft & Other Structures
7475-T61, -T651	C	C	D	B	D	D	B	B	
7475-T761, T7351	C	B	D	B	D	D	D	B	
8017-H12, H22, H221	A	A	A	D	A	A	A	A	Electrical conductors
8030-H12, H221	A	A	A	E	A	A	A	A	Electrical conductors
8176-H14, H24	A	A	A	D	A	A	A	A	Electrical conductors
8177-H13, H23, H221	A	A	A	E	A	A	A	A	Electrical conductors

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Footnotes for Table 1

① Ratings A through E are relative ratings in decreasing order of merit, based on exposures to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial and seacoast atmospheres without protection. Alloys with C, D and E ratings generally should be protected at least on faying surfaces.

② Stress-corrosion cracking ratings are based on service experience and on laboratory tests of specimens exposed to the 3.5% sodium chloride alternate immersion test.

A = No known instance of failure in service or in laboratory tests.

B = No known instance of failure in service; limited failures in laboratory tests of short transverse specimens.

C = Service failures with sustained tension stress acting in short transverse direction relative to grain structure; limited failures in laboratory tests of long transverse specimens.

D = Limited service failures with sustained longitudinal or long transverse areas.

These ratings are neither product specific nor test direction specific and

therefore indicate only the general level of stress-corrosion cracking resis

tance. For more specific information on certain alloys, see ASTM G64.

③ In relatively thick sections the rating would be E.

④ This rating may be different for material held at elevated temperature for long periods.

⑤ Ratings A through D for Workability (cold), and A through E for Machinability, are relative ratings in decreasing order of merit.

⑥ Ratings A through D for Weldability and Brazeability are relative ratings defined as follows:

A = Generally weldable by all commercial procedures and methods.

B = Weldable with special techniques or for specific applications that justify preliminary trials or testing to develop welding procedure and weld performance.

C = Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D = No commonly used welding methods have been developed.

⑦ T74 type tempers, although not previously registered, have appeared in various literature and specifications as T736 type tempers.

⑧ 5xxx products in the -H116 and H32X tempers have similar properties and have the same testing requirements, but are produced by different practices. The -H116 and -H321 tempers are typically used in marine and other applications requiring demonstrations of intergranular and exfoliation corrosion resistance. Products in the -H32 temper have similar tensile properties and while production methods may be similar, corrosion testing requirements are different, therefore, -H32 temper products shall not be substituted for -H116 or -H321 products.

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Table 2

MECHANICAL PROPERTY LIMITS FOR RIVET AND COLD HEADING WIRE ①

ALLOY AND TEMPER	SPECIFIED DIAMETER in.	TENSILE STRENGTH ksi min.		ELONGATION ② percent min. in. 2 in. or 4D ③	ULTIMATE SHEAR ④ STRENGTH ksi min.
		ULTIMATE	YIELD ②		
2017-T4	0.063–1.000	55.0	32.0	12	33.0
2024-T42	0.063–0.124	62.0	. .	. .	37.0
	0.125–1.000	62.0	40.0	10	37.0
2117-T4	0.063–1.000	38.0	18.0	18	26.0
2219-T6	0.063–1.000	55.0	35.0	6	30.0
6053-T61	0.063–1.000	30.0	20.0	14	20.0
6061-T6	0.063–1.000	42.0	35.0	10	25.0
7050-T7	0.063–1.000	70.0	58.0	10	39.0
7075-T6	0.063–1.000	77.0	66.0	7	42.0
7075-T73	0.063–1.000	68.0	56.0	10	41.0

① Rivet and cold heading wire and rod, and the fasteners produced from it, shall upon proper heat treatment (T4 and T42 tempers) or heat treatment and aging (T6, T61, T7 and T73 tempers) be capable of developing the properties presented in Table 10.4. Tensile tests are preferred for the rivet and cold heading wire and rod, and shear tests for the fasteners made from it.
② The measurement of elongation and yield strength is not required for wire less than 0.125 inch in thickness or diameter.
③ D represents specimen diameter.
④ The ultimate shear strength is either a directly measured value or a derived value calculated from a known relationship with the ultimate tensile strength.

Table 2M

MECHANICAL PROPERTY LIMITS FOR RIVET AND COLD HEADING WIRE ①

ALLOY AND TEMPER	SPECIFIED DIAMETER mm	TENSILE STRENGTH MPa min		ELONGATION ② ③ percent min. mm		ULTIMATE SHEAR ④ STRENGTH MPa min.
		ULTIMATE	YIELD ②	50mm	5D ($5.65\sqrt{A}$)	
2017-T4	1.60–25.00	380	220	12	10	225
2024-T42	1.60–3.15	425	. .	. .	. .	255
	3.16–25.00	425	275	10	9	255
2117-T4	1.60–25.00	260	125	18	16	180
2219-T6	1.60–25.00	380	240	6	5	205
6053-T61	1.60–25.00	205	135	14	12	135
6061-T6	1.60–25.00	290	240	10	9	170
7050-T7	1.60–25.00	485	400	10	9	270
7075-T6	1.60–25.00	530	455	7	6	290
7075-T73	1.60–25.00	470	385	10	9	280

① Rivet and cold heading wire and rod, and the fasteners produced from it, shall upon proper heat treatment (T4 and T42 tempers) or heat treatment and aging (T6, T61, T7 and T73 tempers) be capable of developing the properties presented in Table 10.4. Tensile tests are preferred for the rivet and cold heading wire and rod, and shear tests for the fasteners made from it.
② The measurement of elongation and yield strength is not required for wire 3.20 mm and less in thickness or diameter.
③ Elongations in 50 mm apply to rectangular bar up through 12.50 mm thickness from which a standard rectangular tension test specimen is machined. The 5D ($5.65\sqrt{A}$) requirements, where D and A are the diameter and cross-sectional area, respectively, apply to round specimens tested in full section or to standard or proportional round machined tension test specimens.
④ The ultimate shear strength is either a directly measured value or a derived value calculated from a known relationship with the ultimate tensile strength.

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Table 3

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 77°F	Electrical Conductivity at 68°F Percent of International Annealed Copper Standard		Electrical Resistivity at 68°F
	68 to 212°F per °F	°F		English Units④	Equal Volume	Equal Weight	Ohm–Cir. Mil/Foot
1060	13.1	1195–1215	O	1625	62	204	17
			H18	1600	61	201	17
1100	13.1	1190–1215	O	1540	59	194	18
			H18	1510	57	187	18
1350	13.2	1195–1215	All	1625	62	204	17
2011	12.7	1005–1190 ⑥	T3	1050	39	123	27
			T8	1190	45	142	23
2014	12.8	945–1180 ⑤	O	1340	50	159	21
			T4	930	34	108	31
			T6	1070	40	127	26
2017	13.1	955–1185 ⑤	O	1340	50	159	21
			T4	930	34	108	31
2018	12.4	945–1180 ⑥	T61	1070	40	127	26
2024	12.9	935–1180 ⑤	O	1340	50	160	21
			T3, T4, T361	840	30	96	35
			T6, T81, T861	1050	38	122	27
2025	12.6	970–1185 ⑤	T6	1070	40	128	26
2036	13.0	1030–1200 ⑥	T4	1100	41	135	25
2117	13.2	1030–1200 ⑥	T4	1070	40	130	26
2124	12.7	935–1180 ⑤	T851	1055	38	122	27
2218	12.4	940–1175 ⑤	T72	1070	40	126	26
2219	12.4	1010–1190 ⑤	O	1190	44	138	24
			T31, T37	780	28	88	37
			T6, T81, T87	840	30	94	35
2618	12.4	1020–1180	T6	1020	37	120	28
3003	12.9	1190–1210	O	1340	50	163	21
			H12	1130	42	137	25
			H14	1100	41	134	25
			H18	1070	40	130	26
3004	13.3	1165–1210	All	1130	42	137	25
3105	13.1	1175–1210	All	1190	45	148	23
4032	10.8	990–1060 ⑤	O	1070	40	132	26
			T6	960	35	116	30
4043	12.3	1065–1170	O	1130	42	140	25
4045	11.7	1065–1110	All	1190	45	151	23
4343	12.0	1070–1135	All	1250	47	158	25
5005	13.2	1170–1210	All	1390	52	172	20
5050	13.2	1155–1205	All	1340	50	165	21
5052	13.2	1125–1200	All	960	35	116	30
5056	13.4	1055–1180	O	810	29	98	36
			H38	750	27	91	38

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Table 3

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL (Continued) ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

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Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 77°F	Electrical Conductivity at 68°F Percent of International Annealed Copper Standard		Electrical Resistivity at 68°F
	68 to 212°F per °F	°F		English Units④	Equal Volume	Equal Weight	Ohm–Cir. Mil/Foot
5083	13.2	1095–1180	O	810	29	98	36
5086	13.2	1085–1185	All	870	31	104	33
5154	13.3	1100–1190	All	870	32	107	32
5252	13.2	1125–1200	All	960	35	116	30
5254	13.3	1100–1190	All	870	32	107	32
5356	13.4	1060–1175	O	810	29	98	36
5454	13.1	1115–1195	O	930	34	113	31
			H38	930	34	113	31
5456	13.3	1055–1180	O	810	29	98	36
5457	13.2	1165–1210	All	1220	46	153	23
5657	13.2	1180–1215	All	1420	54	180	19
6005	13.0	1125–1210 ⑥	T1	1250	47	155	22
			T5	1310	49	161	21
6005A	13.0	1110–1200	T1	1220	47	155	22
6005A	13.0	1110–1200	T5	1340	50	165	21
6005A	13.0	1110–1200	T61	1310	49	161	21
6053	12.8	1070–1205 ⑥	O	1190	45	148	23
			T4	1070	40	132	26
			T6	1130	42	139	25
6061	13.1	1080–1205 ⑥	O	1250	47	155	22
			T4	1070	40	132	26
			T6	1160	43	142	24
6063	13.0	1140–1210	O	1510	58	191	18
			T1	1340	50	165	21
			T5	1450	55	181	19
			T6, T83	1390	53	175	20
6066	12.9	1045–1195 ⑤	O	1070	40	132	26
			T6	1020	37	122	28
6070	. .	1050–1200 ⑤	T6	1190	44	145	24
6082	12.8	1070–1200	T6, T6511	1190	44	145	24
6101	13.0	1150–1210	T6	1510	57	188	18
			T61	1540	59	194	18
			T63	1510	58	191	18
			T64	1570	60	198	17
			T65	1510	58	191	18
6105	13.0	1110–1200 ⑥	T1	1220	46	151	23
			T5	1340	50	165	21
6151	12.9	1090–1200 ⑥	O	1420	54	178	19
			T4	1130	42	138	25
			T6	1190	45	148	23

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Table 3

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL (Concluded) ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 77°F	Electrical Conductivity at 68°F Percent of International Annealed Copper Standard		Electrical Resistivity at 68°F
	68 to 212°F per °F	°F		English Units④	Equal Volume	Equal Weight	Ohm–Cir. Mil/Foot
6201	13.0	1125–1210 ⑥	T81	1420	54	180	19
6262	13.0	1080–1205 ⑥	T9	1190	44	145	24
6351	13.0	1030–1200	T6	1220	46	151	23
6360	13.0	1140–1210	T5	1300	52	172	20
	13.0		T6	1320	53	175	20
6463	13.0	1140–1210 ⑥	T1	1340	50	165	21
			T5	1450	55	181	19
			T6	1390	53	175	20
6560	12.8	1140-1220	T5	1320	53	175	20
	12.8		T6	1300	52	172	20
6951	13.0	1140–1210	O	1480	56	186	19
			T6	1370	52	172	20
7049	13.0	890–1175	T73	1070	40	132	26
7050	12.8	910–1165	T74 ⑧	1090	41	135	25
7072	13.1	1185–1215	O	1540	59	193	18
7075	13.1	890–1175 ⑦	T6	900	33	105	31
7175	13.0	890–1175 ⑦	T74	1080	39	124	26
7475	12.9	890–1175	T61, T651	960	35	116	30
			T76, T761	1020	40	132	26
			T7351	1130	42	139	25
8017	13.1	1190–1215	H12, H22	. .	59	193	18
			H212	. .	61	200	17
8030	13.1	1190–1215	H221	1600	61	201	17
8176	13.1	1190–1215	H24	. .	61	201	17

① Coefficient to be multiplied by 10^{-6}. Example: $12.2 \times 10^{-6} = 0.0000122$.
② Melting ranges shown apply to wrought products of ¼ inch thickness or greater.
③ Based on typical composition of the indicated alloys.
④ English units = btu-in./ft²hr°F.
⑤ Eutectic melting is not eliminated by homogenization.
⑥ Eutectic melting can be completely eliminated by homogenization.
⑦ Homogenization may raise eutectic melting temperature 20–40°F but usually does not eliminate eutectic melting.
⑧ Although not formerly registered, the literature and some specifications have used T736 as the designation for this temper.

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Table 3M

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 25°C	Electrical Conductivity at 20°F At 20° MS/m ⑧		Electrical Resistivity at 20°C
	20 to 100°C per °C	°C		W/m ·K	Equal Volume	Equal Mass	Ohm·mm²/m
1060	23.6	645–655	O	234	36	118	0.028
			H18	230	35	117	0.029
1100	23.6	640–655	O	222	34	113	0.029
			H18	218	33	108	0.030
1350	23.6	645–655	All	234	36	118	0.028
2011	22.9	540–645 ⑤	T3	151	23	71	0.043
			T8	172	26	82	0.038
2014	23.0	505–635 ④	O	193	29	92	0.034
			T4	134	20	63	0.050
			T6	155	23	74	0.043
2017	23.6	510–640 ④	O	193	29	92	0.034
			T4	134	20	63	0.050
2018	22.3	505–640 ⑤	T61	155	23	74	0.043
2024	23.2	500–635 ④	O	193	29	93	0.034
			T3, T4, T361	121	17	56	0.059
			T6, T81, T861	151	22	71	0.045
2025	22.7	520–640 ④	T6	155	23	74	0.043
2036	23.4	555–650 ⑤	T4	159	24	78	0.042
2117	23.8	550–650 ⑤	T4	155	23	75	0.043
2124	22.9	500–635 ④	T851	152	22	71	0.045
2218	22.3	505–635 ④	T72	155	23	73	0.043
2219	22.3	545–645 ④	O	172	26	80	0.038
			T31, T37	113	16	57	0.062
			T6, T81, T87	121	17	58	0.059
2618	22.3	550–640	T6	146	21	70	0.048
3003	23.2	640–655	O	193	29	92	0.034
			H12	163	24	78	0.042
			H14	159	24	78	0.042
			H18	155	23	74	0.043
3004	23.9	630–655	All	163	24	79	0.042
3105	23.6	635–655	All	172	26	86	0.038
4032	19.4	530–570 ④	O	155	23	77	0.043
			T6	138	20	67	0.050
4043	22.0	575–630	O	163	24	81	0.041
4045	21.1	575–600	All	171	26	88	0.038
4343	21.6	575–615	All	180	27	92	0.037
5005	23.8	630–655	All	201	30	100	0.033
5050	23.8	625–650	All	193	29	96	0.034
5052	23.8	605–650	All	138	20	67	0.050
5056	24.1	565–640	O	117	17	57	0.059
			H38	109	16	53	0.062
5083	23.8	580–640	O	117	17	57	0.059
5086	23.8	585–640	All	126	18	60	0.056
5154	23.9	590–645	All	126	19	62	0.053
5252	23.8	605–650	All	138	20	67	0.050
5254	23.9	590–645	All	126	19	62	0.053
5356	24.1	575–635	O	117	17	57	0.059

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Table 3M

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL (Continued) ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 25°C	Electrical Conductivity at 20°F At 20° MS/m ⑧		Electrical Resistivity at 20°C
	20 to 100°C per °C	°C		W/m ·K	Equal Volume	Equal Mass	Ohm·mm²/m
5454	23.6	600–645	O	134	20	66	0.050
			H38	134	20	66	0.050
5456	23.9	570–640	O	117	17	57	0.059
5457	23.8	630–655	All	176	27	89	0.037
5657	23.8	635–655	All	205	31	104	0.032
6005	23.6	605–655 ⑤	T1	180	27	90	0.037
			T5	188	28	93	0.036
6005A	23.6	600–650	T1	176	27	90	0.037
6005A	23.6	600–650	T5	193	29	96	0.034
6005A	23.6	600–650	T61	188	28	93	0.036
6053	23.0	575–650 ⑤	O	172	26	86	0.038
			T4	155	23	77	0.042
			T6	167	24	81	0.041
6061	23.6	580–650 ⑤	O	180	27	90	0.037
			T4	155	23	77	0.043
			T6	167	25	82	0.040
6063	23.4	615–655	O	218	34	111	0.029
			T1	193	29	96	0.034
			T5	209	32	105	0.031
			T6, T83	201	31	102	0.032
6066	23.2	560–645 ④	O	155	23	77	0.043
			T6	146	21	71	0.048
6070	. .	565–650 ④	T6	172	26	84	0.038
6082	23.0	575-650	T6, T6511	172	26	84	0.040
6101	23.4	620–655	T6	218	33	109	0.030
			T61	222	34	113	0.029
			T63	218	34	111	0.029
			T64	226	35	115	0.029
			T65	218	34	111	0.029
6105	23.4	600–650 ⑤	T1	176	27	88	0.037
			T5	193	29	96	0.034
6151	23.2	590–650 ⑤	O	205	31	103	0.032
			T4	163	24	80	0.042
			T6	172	26	86	0.038
6201	23.4	610–655 ⑤	T81	205	31	104	0.032
6262	23.4	580–650 ⑤	T9	172	26	84	0.038
6351	23.4	555–6506	T6	176	27	88	0.038
6360	23.4	615-655	T5	187	30	100	0.033
	23.4		T6	189	31	102	0.032
6463	23.4	615–655 ⑤	T1	193	29	96	0.034
			T5	209	32	105	0.031
			T6	201	31	102	0.032
6560	23.0	615–660	T5	189	31	102	0.032
	23.0		T6	187	30	100	0.033
6951	23.4	615–655	O	213	32	108	0.031
			T6	197	30	100	0.033

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Table 3M

TYPICAL PHYSICAL PROPERTIES - THERMAL AND ELECTRICAL (Concluded) ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size.

These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

Alloy	Average① Coefficient of Thermal Expansion	Melting Range② ③ Approx.	Temper	Thermal Conductivity at 25°C	Electrical Conductivity at 20°F At 20° MS/m ⑧		Electrical Resistivity at 20°C
	20 to 100°C per °C	°C		W/m ·K	Equal Volume	Equal Mass	Ohm·mm²/m
7049	23.4	475–635	T73	155	23	77	0.043
7050	23.0	490–630	T74 ⑦	157	24	78	0.042
7072	23.6	640–655	O	222	34	112	0.029
7075	23.6	475–635 ⑥	T6	130	19	61	0.053
7175	23.4	475–635 ⑥	T74	157	23	72	0.043
7475	23.2	475–635	T61, T651	138	20	69	0.050
			T76, T761	146	23	77	0.043
			T7351	163	24	81	0.041
8017	23.6	645–655	H12, H22	. .	34	113	0.029
			H212	. .	35	117	0.029
8030	23.6	645–655	H221	230	35	117	0.029
8176	23.6	645–655	H24	230	35	117	0.029

① Coefficient to be multiplied by 10^{-6}. Example: $23.6 \times 10^{-6} = 0.0000236$.
② Melting ranges shown apply to wrought products of 6 mm thickness or greater.
③ Based on typical composition of the indicated alloys.
④ Eutectic melting is not eliminated by homogenization.
⑤ Eutectic melting can be completely eliminated by homogenization.
⑥ Homogenization may raise eutectic melting temperature 10-20°C but usually does not eliminate eutectic melting.
⑦ Although not formerly registered, the literature and some specifications have used T736 as the designation for this temper.
⑧ MS/m = 0.58 x %IACS.

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Table 4

NOMINAL DENSITIES OF ALUMINUM AND ALUMINUM ALLOYS

Density and specific gravity are dependent upon composition, and variations are discernible from one cast to another for most alloys. The nominal values shown below should not be specified as engineering requirements but are used in calculating typical values for weight per unit length, weight per unit area, covering area, etc. The density values are derived from the metric and subsequently rounded. These values are not to be converted to the metric. X.XXX0 and X.XXX5 density values and X.XX0 and X.XX5 specific gravity values are limited to 99.35 percent or higher purity aluminum.

Alloy	Density (lbs/cu. in.)	Specific Gravity
1050	0.0975	2.705
1060	0.0975	2.705
1100	0.098	2.71
1145	0.0975	2.700
1200	0.098	2.70
1230	0.098	2.70
1235	0.0975	2.705
1345	0.0975	2.705
1350	0.0975	2.705
2011	0.102	2.83
2014	0.101	2.80
2017	0.101	2.79
2018	0.102	2.82
2024	0.100	2.78
2025	0.101	2.81
2036	0.100	2.75
2117	0.099	2.75
2124	0.100	2.78
2218	0.101	2.81
2219	0.103	2.84
2618	0.100	2.76
3003	0.099	2.73
3004	0.098	2.72
3005	0.098	2.73
3105	0.098	2.72
4032	0.097	2.68
4043	0.097	2.69
4045	0.096	2.67
4047	0.096	2.66
4145	0.099	2.74
4343	0.097	2.68
4643	0.097	2.69
4943	0.097	2.69
5005	0.098	2.70
5050	0.097	2.69
5052	0.097	2.68
5056	0.095	2.64
5083	0.096	2.66
5086	0.096	2.66
5154	0.096	2.66
5183	0.096	2.66

Alloy	Density (lbs/cu. in.)	Specific Gravity
5252	0.096	2.67
5254	0.096	2.66
5356	0.096	2.64
5454	0.097	2.69
5456	0.096	2.66
5457	0.097	2.69
5554	0.097	2.69
5556	0.096	2.66
5654	0.096	2.66
5657	0.097	2.69
6003	0.097	2.70
6005	0.097	2.70
6005A	0.098	2.70
6053	0.097	2.69
6061	0.098	2.70
6063	0.097	2.70
6066	0.098	2.72
6070	0.098	2.71
6082	0.098	2.70
6101	0.097	2.70
6105	0.097	2.69
6151	0.098	2.71
6162	0.097	2.70
6201	0.097	2.69
6262	0.098	2.72
6360	0.098	2.70
6351	0.098	2.71
6463	0.097	2.69
6560	0.098	2.70
6951	0.098	2.70
7005	0.100	2.78
7049	0.103	2.84
7050	0.102	2.83
7072	0.098	2.72
7075	0.101	2.81
7175	0.101	2.80
7475	0.101	2.81
8017	0.098	2.71
8030	0.098	2.71
8176	0.098	2.71
8177	0.098	2.70

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PART V
SECTION PROPERTIES

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

PART V

Section Properties

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Section Properties

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Table 1

NOMENCLATURE

Symbol	Property	Units
A	area	in^2
b	width	in.
C_w	warping constant	in^6
d	depth	in.
d_1	distance between flange fillets on a web	in.
I	moment of inertia	in^4
J	torsion constant	in^4
r	radius of gyration	in.
r_o	polar radius of gyration about the shear center	in.
R	radius	in.
R_b	mid-thickness radius of a pipe or tube	in.
S	elastic section modulus	in^3
t	thickness	in.
t_f	flange thickness	in.
t_w	web thickness	in.
W_t	weight per unit length	lb/ft
X	location of the major axis	in.
x_o	x coordinate of shear center	in.
Y	location of the minor axis	in.
y_o	y coordinate of shear center	in.
Z	plastic section modulus	in^3

x and y subscripts denote the axis about which the property is taken. The x axis is the major axis. The y axis is the minor axis.

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Table 2

SECTION DESIGNATIONS

Section	Designation	Example	Description
Aluminum Association Standard Channels	AC *Depth* × *Wt*	AC 4 × 2.33	C-shapes with flat flanges; designed for structural efficiency
MC-Shapes	MC *Depth* × *Wt*	MC 3 × 2.23	C-shapes with flat flanges
C-Shapes	C *Depth* × *Wt*	C 2 × 1.22	C-shapes with flanges with a 1:6 slope on the inner surface
Aluminum Association Standard W-Shapes	AW *Depth* × *Wt*	AW 12 × 11.7	I-shapes with flat flanges; designed for structural efficiency
W-Shapes	W *Nominal Depth* × *Wt*	W 12 × 13.8	I-shapes with flat flanges
S-Shapes	S *Depth* × *Wt*	S 10 × 12.1	I-shapes with flanges with a 1:6 slope on the inner surface
Angles	L *long leg* × *short leg* × *thickness*	L 3 × 2 × ¼	L shaped product with a fillet at the junction of the legs and radii on the inside tips of the legs
Square End Angles	LS *long leg* × *short leg* × *thickness*	LS 3 × 3 × 1/8	L shaped product with small radii at the corners
Tees	T *Depth* × *Width* × *Wt*	T 2.50 × 2.50 × 1.91	T shapes
Zees	Z *Depth* × *Width* × *Wt*	Z 4.00 × 3.19 × 4.32	Z shapes
Plates	PL *Thickness* × *Width*	PL 0.375 × 60	Rolled product with a rectangular cross section at least 0.25 in. thick
Rods	RD *Diameter*	RD 0.500	Solid product with a circular cross section at least 0.375 in. in diameter
Square Bars	SQ *Side dimension*	SQ 4	Solid product with a square cross section at least 0.375 in. on a side
Pipes	NPS *size* × SCH *schedule no.*	NPS 4 × SCH 40	Tube in standardized outside diameters and wall thicknesses
Round Tubes	*Outside diameter* OD × *wall thickness* WALL	4 OD × 0.125 WALL	Hollow product with a circular cross section
Rectangular Tubes	RT *long side* × *short side* × *wall thickness*	RT 6 × 4 × ¼	Hollow product with a rectangular cross section (including square tube)

In the 2020 ADM, shape designations for channels and I-shapes changed. Channels with flanges sloped 1:6 are designated C-shapes, Aluminum Association standard channels are designated AC-shapes, and all other channels are designated MC-shapes. I-shapes with flanges sloped 1:6 are designated S-shapes, Aluminum Association standard I-shapes are designated AW-shapes, and all other I-shapes are designated W-shapes.

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Table 3

WEIGHTS PER SQUARE FOOT

The weight per square foot for an alloy with density of 0.100 lb/in^3 is shown for each thickness. The weights for other alloys can be calculated using the density given in Part IV Table 4. Commonly used thicknesses are shown **BOLD**.

Thickness (in.)		Weight (lb/ft^2)	Thickness (in.)		Weight (lb/ft^2)	Thickness (in.)		Weight (lb/ft^2)
Decimal	Fraction		Decimal	Fraction		Decimal	Fraction	
.006		0.086	.132		1.90	1.625	1 5/8	23.40
.007		0.101	.140		2.02	1.750	1 ¾	25.20
.008		0.115	.150		2.16	1.875	1 7/8	27.00
.009		0.130	**.160**		2.30	2.000	2	28.80
.010		0.144	.170		2.45	2.125	2 1/8	30.60
.011		0.158	**.180**		2.59	2.250	2 ¼	32.40
.012		0.173	.1875	3/16	2.70	2.375	2 3/8	34.20
.013		0.187	**.190**		2.74	2.500	2 ½	36.00
.014		0.202	.200		2.88	2.625	2 5/8	37.80
.016	1/64	0.230	.212		3.05	2.750	2 ¾	39.60
.018		0.259	.224		3.23	2.875	2 7/8	41.40
.019		0.274	.236		3.40	3.000	3	43.20
.020		0.288	**.250**	¼	3.60	3.250	3 ¼	46.80
.021		0.302	.266	17/64	3.83	3.500	3 ½	50.40
.022		0.317	.281	9/32	4.05	3.750	3 ¾	54.00
.024		0.346	.297	19/64	4.28	4.000	4	57.60
.025		0.360	**.313**	5/16	4.51	4.250	4 ¼	61.20
.026		0.374	.328	21/64	4.72	4.500	4 ½	64.80
.028		0.403	.344	11/32	4.95	4.750	4 ¾	68.40
.030		0.432	.359	23/64	5.17	5.000	5	72.00
.032		0.461	**.375**	3/8	5.40	5.250	5 ¼	75.60
.034		0.490	.391	25/64	5.63	5.500	5 ½	79.20
.036		0.518	.406	13/32	5.85	5.750	5 ¾	82.80
.038		0.547	.422	27/64	6.08	6.000	6	86.40
.040		0.576	.438	7/16	6.31			
.042		0.605	.453	29/64	6.52			
.045		0.648	.469	15/32	6.75			
.048		0.691	.484	31/64	6.97			
.050		0.720	**.500**	½	7.20			
.053		0.763	.531	17/32	7.65			
.056		0.806	.562	9/16	8.09			
.060		0.864	.594	19/32	8.55			
.063	1/16	0.907	**.625**	5/8	9.00			
.067		0.965	.656	21/32	9.45			
.071		1.02	.688	11/16	9.91			
.075		1.08	.719	23/32	10.35			
.080		1.15	**.750**	¾	10.80			
.085		1.22	.812	13/16	11.69			
.090		1.30	.875	7/8	12.60			
.095		1.37	.938	15/16	13.51			
.100		1.44	**1.000**	1	14.40			
.106		1.53	1.125	1 1/8	16.20			
.112		1.61	1.250	1 ¼	18.00			
.118		1.70	1.375	1 3/8	19.80			
.125	1/8	1.80	1.500	1 ½	21.60			

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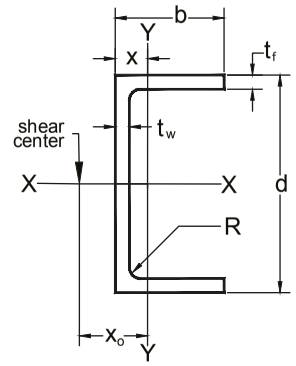

Table 4
ALUMINUM ASSOCIATION STANDARD CHANNELS

Designation	Depth	Width	Flange Thickness	Web Thickness	Fillet Radius	Area	Axis X-X				Axis Y-Y						
	d	b	t_f	t_w	R	A	I_x	S_x	Z_x	r_x	I_y	S_y	r_y	x	x_o	C_w	J
	in.	in.	in.	in.	in.	in^2	in^4	in^3	in^3	in.	in^4	in^3	in.	in.	in.	in^6	in^4
AC 2 X 0.577	2.000	1.000	0.130	0.130	0.100	0.490	0.288	0.288	0.345	0.766	0.0450	0.0639	0.303	0.296	0.577	0.0324	0.00289
AC 2 X 1.07	2.000	1.250	0.260	0.170	0.150	0.911	0.546	0.546	0.665	0.774	0.139	0.178	0.390	0.471	0.875	0.0894	0.0167
AC 3 X 1.14	3.000	1.500	0.200	0.130	0.250	0.965	1.41	0.940	1.09	1.21	0.217	0.215	0.474	0.494	1.00	0.332	0.0109
AC 3 X 1.60	3.000	1.750	0.260	0.170	0.250	1.36	1.97	1.31	1.54	1.20	0.417	0.368	0.554	0.617	1.22	0.626	0.0257
AC 4 X 1.74	4.000	2.000	0.230	0.150	0.250	1.48	3.91	1.95	2.25	1.63	0.601	0.446	0.638	0.653	1.35	1.65	0.0213
AC 4 X 2.33	4.000	2.250	0.290	0.190	0.250	1.98	5.21	2.60	3.02	1.62	1.02	0.692	0.717	0.775	1.57	2.76	0.0454
AC 5 X 2.21	5.000	2.250	0.260	0.150	0.300	1.88	7.88	3.15	3.61	2.05	0.975	0.642	0.720	0.731	1.53	4.17	0.0330
AC 5 X 3.09	5.000	2.750	0.320	0.190	0.300	2.63	11.1	4.45	5.10	2.06	2.05	1.14	0.884	0.955	1.97	8.70	0.0715
AC 6 X 2.83	6.000	2.500	0.290	0.170	0.300	2.41	14.4	4.78	5.49	2.44	1.53	0.896	0.798	0.788	1.66	9.52	0.0512
AC 6 X 4.03	6.000	3.250	0.350	0.210	0.300	3.43	21.0	7.01	8.00	2.48	3.76	1.76	1.05	1.12	2.32	23.1	0.1103
AC 7 X 3.21	7.000	2.750	0.290	0.170	0.300	2.73	22.1	6.31	7.22	2.85	2.10	1.10	0.878	0.842	1.81	17.8	0.0569
AC 7 X 4.72	7.000	3.500	0.380	0.210	0.300	4.01	33.8	9.65	11.0	2.90	5.13	2.23	1.13	1.20	2.51	43.0	0.147
AC 8 X 4.15	8.000	3.000	0.350	0.190	0.300	3.53	37.4	9.35	10.7	3.26	3.25	1.57	0.959	0.934	1.99	36.0	0.103
AC 8 X 5.79	8.000	3.750	0.410	0.250	0.350	4.92	52.7	13.2	15.1	3.27	7.12	2.82	1.20	1.22	2.57	78.5	0.212
AC 9 X 4.98	9.000	3.250	0.350	0.230	0.350	4.24	54.4	12.1	14.0	3.58	4.40	1.89	1.02	0.928	2.00	62.8	0.131
AC 9 X 6.97	9.000	4.000	0.440	0.290	0.350	5.93	78.3	17.4	20.1	3.63	9.60	3.49	1.27	1.25	2.63	135	0.296
AC 10 X 6.14	10.000	3.500	0.410	0.250	0.350	5.22	83.2	16.6	19.3	3.99	6.33	2.55	1.10	1.02	2. 19	111	0.211
AC 10 X 8.36	10.000	4.250	0.500	0.310	0.400	7.11	116	23.2	26.8	4.04	13.0	4.46	1.35	1.34	2.81	226	0.446
AC 12 X 8.27	12.000	4.000	0.470	0.290	0.400	7.04	160	26.6	30.9	4.77	11.0	3.85	1.25	1.14	2.45	281	0.371
AC 12 X 11.8	12.000	5.000	0.620	0.350	0.450	10.1	240	39.9	45.9	4.88	25.7	7.59	1.60	1.61	3.39	639	0.938
AC 14 x 13.9[1]	14.000	6.000	0.640	0.320	0.450	11.8	401	57.3	64.8	5.82	44.7	11.20	1.94	2.00	4.27	1511	1.16

1. New shape; check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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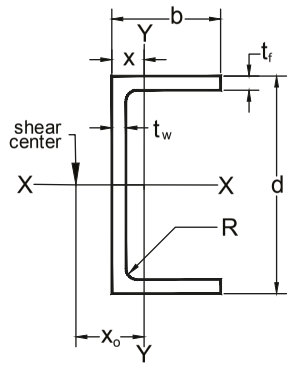

Notes:
1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

Table 5
MC-SHAPES

	Depth	Width	Flange Thickness	Web Thickness	Fillet Radius	Area	Axis X-X				Axis Y-Y						
	d	*b*	t_f	t_w	*R*	*A*	I_x	S_x	Z_x	r_x	I_y	S_y	r_y	*x*	x_o	C_w	*J*
Designation	in.	in.	in.	in.	in.	in^2	in^4	in^3	in^3	in.	in^4	in^3	in.	in.	in.	in^6	in^4
MC 2 X 0.706	2.000	1.500	0.125	0.125	0.125	0.600	0.391	0.391	0.447	0.807	0.137	0.136	0.477	0.493	1.011	0.0938	0.0031
MC 2.25 X 0.86	2.250	1.000	0.188	0.188	0.062	0.730	0.505	0.449	0.553	0.832	0.062	0.090	0.292	0.303	0.534	0.0589	0.0086
MC 3 X 1.48	3.000	1.500	0.250	0.188	0.312	1.26	1.72	1.15	1.33	1.17	0.268	0.265	0.461	0.489	0.937	0.415	0.021
MC 3 X 1.85	3.000	1.500	0.312	0.250	0.312	1.57	2.03	1.35	1.61	1.14	0.321	0.322	0.452	0.502	0.902	0.501	0.043
MC 3 X 2.18	3.000	2.000	0.312	0.250	0.188	1.86	2.56	1.71	2.03	1.17	0.730	0.568	0.627	0.714	1.362	1.09	0.053
MC 3 X 2.78	3.000	2.000	0.375	0.375	0.188	2.36	2.98	1.98	2.44	1.12	0.868	0.670	0.606	0.706	1.231	1.33	0.110
MC 4 X 1.90	4.000	1.620	0.281	0.188	0.375	1.62	3.95	1.98	2.25	1.56	0.396	0.355	0.495	0.504	0.983	1.11	0.032
MC 4 X 2.24	4.000	1.750	0.281	0.250	0.375	1.90	4.41	2.21	2.57	1.52	0.514	0.417	0.520	0.519	0.976	1.49	0.044
MC 4 X 2.02	4.000	2.000	0.250	0.188	0.375	1.72	4.36	2.18	2.45	1.59	0.667	0.486	0.623	0.627	1.266	1.84	0.029
MC 4 X 2.53	4.000	2.000	0.312	0.250	0.375	2.15	5.21	2.60	3.01	1.56	0.810	0.595	0.613	0.638	1.229	2.25	0.058
MC 4 X 2.90	4.000	2.500	0.312	0.250	0.375	2.46	6.27	3.14	3.59	1.60	1.52	0.919	0.786	0.842	1.671	4.13	0.068
MC 5 X 2.51	5.000	2.000	0.312	0.188	0.375	2.13	8.45	3.38	3.83	1.99	0.832	0.607	0.625	0.630	1.273	3.59	0.050
MC 5 X 3.11	5.000	2.000	0.343	0.281	0.375	2.64	9.59	3.84	4.50	1.90	0.942	0.669	0.597	0.592	1.122	4.27	0.086
MC 5 x 3.05	5.000	2.500	0.312	0.218	0.437	2.60	10.5	4.18	4.70	2.01	1.60	0.944	0.786	0.801	1.629	6.86	0.066
MC 5 X 3.55	5.000	2.500	0.375	0.250	0.437	3.02	12.0	4.79	5.46	1.99	1.86	1.11	0.784	0.830	1.649	7.89	0.110
MC 6 X 3.60	6.000	2.000	0.375	0.281	0.437	3.06	15.8	5.26	6.16	2.27	1.06	0.740	0.588	0.569	1.078	7.04	0.109
MC 6 X 3.51	6.000	2.500	0.312	0.250	0.437	2.99	16.4	5.47	6.24	2.34	1.74	0.978	0.764	0.719	1.461	11.2	0.079
MC 6 X 5.81	6.000	3.000	0.375	0.500	0.375	4.94	24.2	8.08	9.77	2.22	3.64	1.67	0.858	0.824	1.499	25.1	0.324
MC 6 X 6.42	6.000	3.500	0.500	0.375	0.437	5.46	30.9	10.3	12.0	2.38	6.62	2.87	1.10	1.19	2.348	40.3	0.380
MC 7 X 3.90	7.000	2.500	0.375	0.218	0.437	3.32	25.8	7.37	8.34	2.79	2.02	1.16	0.781	0.759	1.562	17.3	0.109
MC 7 X 4.61	7.000	3.000	0.375	0.250	0.500	3.92	30.8	8.79	9.89	2.80	3.47	1.67	0.941	0.921	1.901	29.5	0.138
MC 8 X 4.65	8.000	2.750	0.375	0.250	0.437	3.96	39.0	9.74	11.1	3.14	2.83	1.44	0.846	0.781	1.620	32.2	0.134
MC 8 X 5.56	8.000	3.000	0.437	0.281	0.500	4.73	47.3	11.8	13.5	3.16	4.10	1.95	0.931	0.900	1.840	46.1	0.220
MC 10 X 6.23	10.000	3.000	0.437	0.281	0.500	5.29	79.9	16.0	18.4	3.89	4.39	2.01	0.911	0.819	1.701	79.3	0.234
MC 10 X 7.58	10.000	3.500	0.500	0.312	0.562	6.44	101	20.1	22.9	3.95	7.59	3.07	1.09	1.03	2.126	134	0.383
MC 10 X 19.0	10.000	4.000	1.250	0.812	0.500	16.2	223	44.5	55.2	3.71	23.3	8.94	1.20	1.39	2.375	402	6.547
MC 12 X 10.3	12.000	4.000	0.562	0.375	0.625	8.74	192	32.0	36.8	4.69	13.1	4.56	1.22	1.13	2.329	338	0.665

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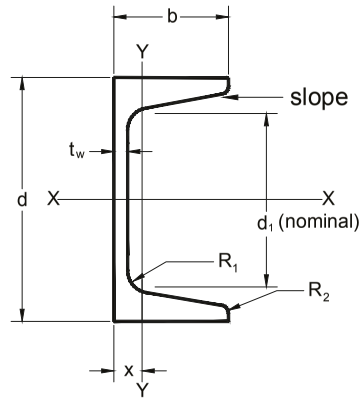

Table 6
C-SHAPES

Designation	Depth d in.	Width b in.	Flange Tip Thickness t_f in.	Average Flange Thickness t in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	Axis X-X			Axis Y-Y			y-axis Location
										I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	x in.
C 2 × 1.22	2.000	1.410	0.170	0.273	0.170	0.270	0.100	0.75	1.04	0.622	0.622	0.774	0.172	0.188	0.407	0.49
C 3 × 1.42	3.000	1.410	0.170	0.273	0.170	0.270	0.100	1.75	1.21	1.66	1.10	1.17	0.20	0.20	0.40	0.44
C 3 × 1.73	3.000	1.498	0.170	0.273	0.258	0.270	0.100	1.75	1.47	1.85	1.24	1.12	0.21	0.21	0.41	0.44
C 3 × 2.07	3.000	1.596	0.170	0.273	0.356	0.270	0.100	1.75	1.76	2.07	1.38	1.08	0.31	0.27	0.42	0.46
C 4 × 1.85	4.000	1.580	0.180	0.297	0.180	0.280	0.110	2.75	1.57	3.83	1.92	1.56	0.32	0.28	0.45	0.46
C 4 × 2.16	4.000	1.647	0.180	0.297	0.247	0.280	0.110	2.75	1.84	4.19	2.10	1.51	0.37	0.31	0.45	0.45
C 4 × 2.50	4.000	1.720	0.180	0.297	0.320	0.280	0.110	2.75	2.13	4.58	2.29	1.47	0.43	0.34	0.45	0.46
C 5 × 2.32	5.000	1.750	0.190	0.320	0.190	0.290	0.110	3.75	1.97	7.49	3.00	1.95	0.48	0.38	0.49	0.48
C 5 × 3.11	5.000	1.885	0.190	0.320	0.325	0.290	0.110	3.75	2.64	8.90	3.56	1.83	0.63	0.45	0.49	0.48
C 5 × 3.97	5.000	2.032	0.190	0.320	0.472	0.290	0.110	3.75	3.38	10.4	4.17	1.76	0.81	0.53	0.49	0.51
C 6 × 2.83	6.000	1.920	0.200	0.343	0.200	0.300	0.120	4.50	2.40	13.1	4.37	2.34	0.69	0.49	0.54	0.51
C 6 × 3.00	6.000	1.945	0.200	0.343	0.225	0.300	0.120	4.50	2.55	13.6	4.52	2.31	0.73	0.51	0.54	0.51
C 6 × 3.63	6.000	2.034	0.200	0.343	0.314	0.300	0.120	4.50	3.09	15.2	5.06	2.22	0.87	0.56	0.50	0.50
C 6 × 4.50	6.000	2.157	0.200	0.343	0.438	0.300	0.120	4.50	3.83	17.4	5.80	2.13	1.05	0.64	0.52	0.51
C 7 × 3.54	7.000	2.110	0.210	0.367	0.230	0.310	0.130	5.50	3.01	21.8	6.24	2.69	1.01	0.64	0.58	0.54
C 7 × 4.23	7.000	2.194	0.210	0.367	0.314	0.310	0.130	5.50	3.60	24.2	6.93	2.60	1.17	0.70	0.57	0.52
C 7 × 5.10	7.000	2.299	0.210	0.367	0.419	0.310	0.130	5.50	4.33	27.2	7.78	2.51	1.38	0.78	0.56	0.53
C 7 × 5.96	7.000	2.404	0.210	0.367	0.524	0.310	0.130	5.50	5.07	30.3	8.64	2.44	1.59	0.86	0.56	0.55

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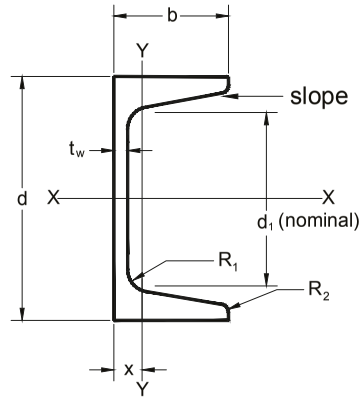

Table 6
C-SHAPES (CONTINUED)

Designation	Depth *d* in.	Width *b* in.	Flange Tip Thickness t_f in.	Average Flange Thickness *t* in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area *A* in^2	Axis X-X I_x in^4	Axis X-X S_x in^3	Axis X-X r_x in.	Axis Y-Y I_y in^4	Axis Y-Y S_y in^3	Axis Y-Y r_y in.	y-axis Location *x* in.
C 8 × 4.25	8.000	2.290	0.220	0.390	0.250	0.320	0.130	6.25	3.62	33.9	8.46	3.06	1.40	0.81	0.62	0.56
C 8 × 4.75	8.000	2.343	0.220	0.390	0.303	0.320	0.130	6.25	4.04	36.1	9.03	2.99	1.53	0.85	0.61	0.55
C 8 × 5.62	8.000	2.435	0.220	0.390	0.395	0.320	0.130	6.25	4.78	40.0	10.0	2.90	1.75	0.93	0.61	0.55
C 8 × 6.48	8.000	2.527	0.220	0.390	0.487	0.320	0.130	6.25	5.51	44.0	11.0	2.82	1.98	1.01	0.60	0.57
C 9 × 4.60	9.000	2.430	0.230	0.413	0.230	0.330	0.140	7.25	3.91	47.7	10.6	3.49	1.75	0.96	0.67	0.60
C 9 × 5.19	9.000	2.485	0.230	0.413	0.285	0.330	0.140	7.25	4.41	51.0	11.3	3.40	1.93	1.01	0.66	0.59
C 9 × 6.91	9.000	2.648	0.230	0.413	0.448	0.330	0.140	7.25	5.88	60.9	13.5	3.22	2.42	1.17	0.64	0.58
C 9 × 8.65	9.000	2.812	0.230	0.413	0.612	0.330	0.140	7.25	7.35	70.9	15.8	3.11	2.94	1.34	0.63	0.61
C 10 × 5.28	10.000	2.600	0.240	0.437	0.240	0.340	0.140	8.25	4.49	67.4	13.5	3.87	2.28	1.16	0.71	0.63
C 10 × 6.91	10.000	2.739	0.240	0.437	0.379	0.340	0.140	8.25	5.88	79.0	15.8	3.66	2.81	1.32	0.69	0.61
C 10 × 8.64	10.000	2.886	0.240	0.437	0.526	0.340	0.140	8.25	7.35	91.2	18.2	3.52	3.36	1.48	0.68	0.62
C 10 × 10.4	10.000	3.033	0.240	0.437	0.673	0.340	0.140	8.25	8.82	104	20.7	3.43	3.95	1.66	0.67	0.65
C 12 × 7.41	12.000	2.960	0.280	0.502	0.300	0.380	0.170	10.0	6.30	132	22.0	4.57	3.99	1.76	0.80	0.69
C 12 × 8.64	12.000	3.047	0.280	0.502	0.387	0.380	0.170	10.0	7.35	144	24.1	4.43	4.47	1.89	0.78	0.67
C 12 × 10.4	12.000	3.170	0.280	0.502	0.510	0.380	0.170	10.0	8.82	162	27.0	4.29	5.14	2.06	0.76	0.67
C 12 × 12.1	12.000	3.292	0.280	0.502	0.632	0.380	0.170	10.0	10.3	180	29.9	4.18	5.82	2.24	0.75	0.69
C 15 × 11.7	15.000	3.400	0.400	0.650	0.400	0.500	0.240	12.4	9.96	315	42.0	5.62	8.13	3.11	0.90	0.79
C 15 × 17.3	15.000	3.716	0.400	0.650	0.716	0.500	0.240	12.4	14.7	404	53.8	5.24	11.0	3.78	0.87	0.80

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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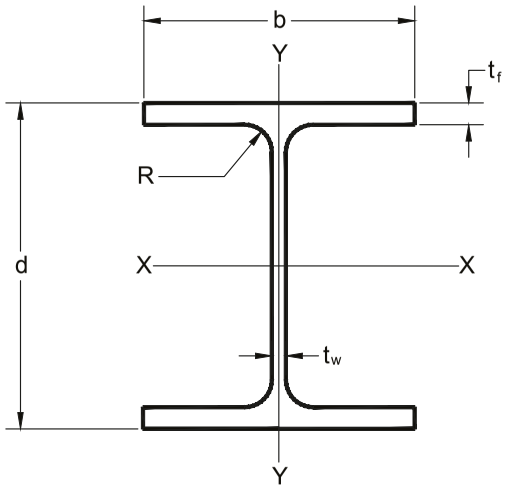

Table 7
ALUMINUM ASSOCIATION STANDARD W-SHAPES

Designation	*d*	*b*	t_f	t_w	*R*	*A*	Axis X-X				Axis Y-Y				C_w	*J*
							I_x	S_x	Z_x	r_x	I_y	S_y	Z_y	r_y		
	in.	in.	in.	in.	in.	in^2	in^4	in^3	in^3	in.	in^4	in^3	in^3	in.	in^6	in^4
AW 3 x 1.64	3.000	2.500	0.200	0.130	0.250	1.39	2.24	1.49	1.69	1.27	0.522	0.418	0.642	0.613	1.02	0.0192
AW 3 x 2.03	3.000	2.500	0.260	0.150	0.250	1.73	2.71	1.81	2.08	1.25	0.679	0.543	0.833	0.627	1.27	0.0374
AW 4 x 2.31	4.000	3.000	0.230	0.150	0.250	1.96	5.62	2.81	3.16	1.69	1.04	0.691	1.06	0.727	3.68	0.0333
AW 4 x 2.79	4.000	3.000	0.290	0.170	0.250	2.38	6.71	3.36	3.81	1.68	1.31	0.872	1.34	0.742	4.50	0.0608
AW 5 x 3.70	5.000	3.500	0.320	0.190	0.300	3.15	13.9	5.58	6.31	2.11	2.29	1.31	2.01	0.853	12.5	0.0984
AW 6 x 4.03	6.000	4.000	0.290	0.190	0.300	3.43	22.0	7.33	8.22	2.53	3.10	1.55	2.38	0.951	25.3	0.0888
AW 6 x 4.69	6.000	4.000	0.350	0.210	0.300	3.99	25.5	8.50	9.58	2.53	3.74	1.87	2.87	0.968	29.8	0.145
AW 7 x 5.80	7.000	4.500	0.380	0.230	0.300	4.93	42.9	12.3	13.8	2.95	5.78	2.57	3.94	1.08	63.3	0.206
AW 8 x 6.18	8.000	5.000	0.350	0.230	0.300	5.26	59.7	14.9	16.7	3.37	7.30	2.92	4.49	1.18	107	0.188
AW 8 x 7.02	8.000	5.000	0.410	0.250	0.300	5.97	67.8	16.9	19.1	3.37	8.55	3.42	5.25	1.20	123	0.286
AW 9 x 8.36	9.000	5.500	0.440	0.270	0.300	7.11	102	22.7	25.5	3.79	12.2	4.44	6.82	1.31	224	0.386
AW 10 x 8.65	10.000	6.000	0.410	0.250	0.400	7.35	132	26.4	29.5	4.24	14.8	4.93	7.55	1.42	340	0.360
AW 10 x 10.3	10.000	6.000	0.500	0.290	0.400	8.75	156	31.2	35.0	4.22	18.0	6.01	9.22	1.44	407	0.620
AW 12 x 11.7	12.000	7.000	0.470	0.290	0.400	9.92	256	42.6	47.5	5.07	26.9	7.69	11.8	1.65	894	0.621
AW 12 x 14.3	12.000	7.000	0.620	0.310	0.400	12.2	317	52.9	59.1	5.11	35.5	10.1	15.5	1.71	1149	1.26
AW 14 x 16.0[1]	14.000	8.000	0.600	0.300	0.400	13.6	489	69.9	77.5	6.00	51.2	12.8	19.5	1.94	2300	1.31

1. New shape; check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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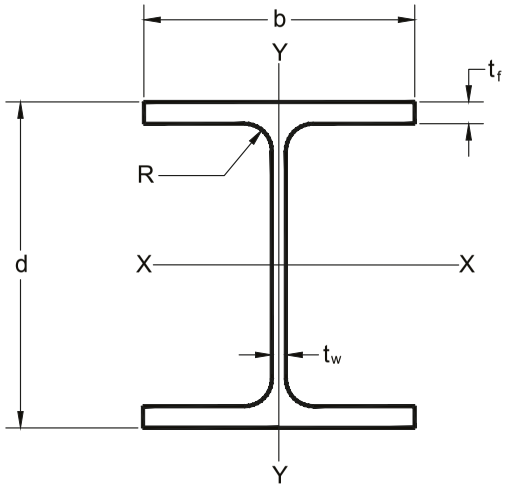

Table 8
W–SHAPES

Designation	d	b	t_f	t_w	R	A	Axis X-X				Axis Y-Y				C_w	J	r_0
							I_x	S_x	Z_x	r_x	I_y	S_y	Z_y	r_y			
	in.	in.	in.	in.	in.	in^2	in^4	in^3	in^3	in.	in^4	in^3	in^3	in.	in^6	in^4	in.
W 3 x 2.16	3.000	2.500	0.250	0.188	0.375	1.84	2.78	1.85	2.15	1.23	0.657	0.525	0.825	0.597	1.24	0.047	1.37
W 4 x 2.68	4.000	3.000	0.250	0.188	0.375	2.28	6.28	3.14	3.59	1.66	1.13	0.754	1.18	0.705	3.98	0.054	1.80
W 4 x 4.12	4.000	4.000	0.312	0.250	0.437	3.50	9.72	4.86	5.58	1.67	3.34	1.67	2.59	0.977	11.4	0.130	1.93
W 5 x 4.05	5.000	3.500	0.312	0.250	0.437	3.44	14.5	5.79	6.66	2.05	2.24	1.28	2.02	0.808	12.3	0.126	2.20
W 6 x 3.92	6.000	3.000	0.312	0.250	0.375	3.34	19.2	6.40	7.44	2.40	1.42	0.945	1.51	0.652	11.5	0.110	2.49
W 6 x 4.16	6.000	4.000	0.279	0.230	0.250	3.54	21.7	7.25	8.23	2.48	2.98	1.49	2.31	0.918	24.4	0.087	2.64
W 6 x 4.82	6.000	3.500	0.375	0.250	0.438	4.10	24.9	8.28	9.52	2.46	2.70	1.54	2.42	0.811	21.3	0.184	2.59
W 6 x 5.40	6.000	6.000	0.269	0.240	0.250	4.59	30.2	10.1	11.2	2.56	9.69	3.23	4.93	1.45	79.6	0.110	2.95
W 6 x 5.46	6.000	4.000	0.375	0.281	0.437	4.64	28.2	9.40	10.8	2.47	4.02	2.01	3.14	0.931	31.8	0.218	2.64
W 6 x 7.61	6.000	6.000	0.375	0.312	0.625	6.47	41.5	13.8	15.6	2.53	13.5	4.52	6.98	1.45	107	0.371	2.91
W 6 x 9.66	6.000	6.000	0.500	0.375	0.625	8.21	51.2	17.1	19.6	2.50	18.1	6.02	9.29	1.48	137	0.735	2.91
W 7 x 5.79	7.000	4.000	0.375	0.281	0.438	4.92	40.2	11.5	13.2	2.86	4.02	2.01	3.16	0.904	44.1	0.226	3.00
W 8 x 5.90	8.000	5.250	0.308	0.230	0.320	5.02	56.7	14.2	15.9	3.36	7.44	2.83	4.36	1.22	110	0.145	3.58
W 8 x 6.12	8.000	4.000	0.375	0.281	0.437	5.20	54.6	13.6	15.7	3.24	4.02	2.01	3.18	0.880	58.5	0.233	3.36
W 8 x 8.32	8.000	6.500	0.398	0.245	0.400	7.08	84.1	21.0	23.3	3.45	18.2	5.61	8.54	1.61	263	0.333	3.80
W 8 x 8.77	8.000	5.000	0.500	0.312	0.562	7.46	82.4	20.6	23.5	3.32	10.5	4.18	6.50	1.18	147	0.576	3.53
W 8 x 10.7	8.000	8.000	0.433	0.288	0.400	9.12	110	27.4	30.4	3.47	37.0	9.24	14.0	2.01	529	0.519	4.01
W 8 x 13.1	8.000	8.000	0.500	0.375	0.750	11.1	129	32.2	36.2	3.40	42.8	10.7	16.4	1.96	601	1.03	3.93

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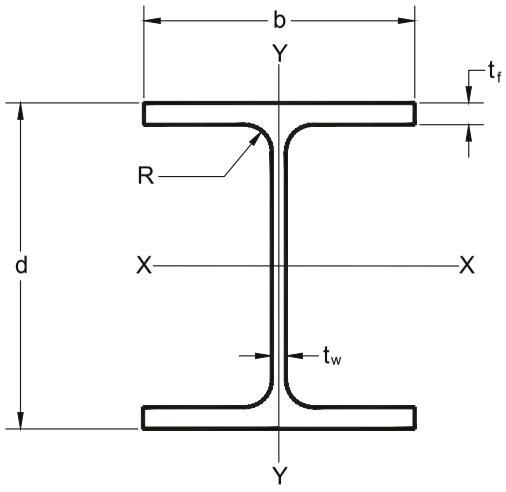

Table 8
W-SHAPES (Continued)

Designation	d	b	t_f	t_w	R	A	Axis X-X				Axis Y-Y				C_w	J	r_0
	in.	in.	in.	in.	in.	in^2	I_x in^4	S_x in^3	Z_x in^3	r_x in.	I_y in^4	S_y in^3	Z_y in^3	r_y in.	in^6	in^4	in.
W 10 x 7.30	9.900	5.750	0.340	0.240	0.312	6.21	107	21.6	24.2	4.15	10.8	3.75	5.77	1.32	246	0.205	4.35
W 10 x 9.83	10.000	5.000	0.500	0.343	0.562	8.36	139	27.8	31.9	4.08	10.5	4.19	6.60	1.12	236	0.637	4.23
W 10 x 11.3	10.000	6.000	0.500	0.375	0.562	9.65	163	32.7	37.3	4.12	18.1	6.02	9.40	1.37	408	0.769	4.34
W 10 x 11.4	9.750	7.964	0.433	0.292	0.500	9.71	171	35.0	38.8	4.20	36.5	9.16	14.0	1.94	792	0.564	4.62
W 12 x 12.5	12.000	5.500	0.562	0.375	0.625	10.6	252	42.0	48.2	4.88	15.7	5.70	8.99	1.22	513	0.991	5.03
W 12 x 13.8	11.940	8.000	0.516	0.294	0.600	11.8	310	51.9	57.5	5.13	44.1	11.0	16.8	1.94	1438	0.926	5.48
W 12 x 15.5	12.000	6.500	0.625	0.437	0.625	13.2	317	52.9	60.6	4.91	28.7	8.84	13.8	1.48	929	1.53	5.13
W 12 x 18.3	12.060	10.000	0.576	0.345	0.600	15.6	426	70.7	78.1	5.23	96.1	19.2	29.2	2.48	3167	1.54	5.79

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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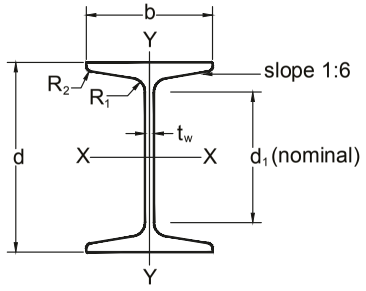

Table 9
S-SHAPES

Designation	Depth d in.	Width b in.	Flange Tip Thickness t_f in.	Avg Flange Thickness t in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	Axis X-X I_x in^4	Axis X-X S_x in^3	Axis X-X r_x in.	Axis Y-Y I_y in^4	Axis Y-Y S_y in^3	Axis Y-Y r_y in.
S 3 × 1.96	3.000	2.330	0.170	0.260	0.170	0.270	0.100	1.75	1.67	2.52	1.68	1.23	0.46	0.39	0.52
S 3 × 2.59	3.000	2.509	0.170	0.260	0.349	0.270	0.100	1.75	2.21	2.93	1.95	1.15	0.59	0.47	0.52
S 4 × 2.64	4.000	2.660	0.190	0.293	0.190	0.290	0.110	2.75	2.25	6.06	3.03	1.64	0.76	0.57	0.58
S 4 × 3.28	4.000	2.796	0.190	0.293	0.326	0.290	0.110	2.75	2.79	6.79	3.39	1.56	0.90	0.65	0.57
S 5 × 3.43	5.000	3.000	0.210	0.326	0.210	0.310	0.130	3.50	2.92	12.3	4.90	2.05	1.21	0.81	0.64
S 5 × 4.23	5.000	3.137	0.210	0.326	0.347	0.310	0.130	3.50	3.60	13.7	5.48	1.95	1.41	0.90	0.63
S 5 × 5.10	5.000	3.284	0.210	0.326	0.494	0.310	0.130	3.50	4.34	15.2	6.09	1.87	1.66	1.01	0.62
S 6 × 4.30	6.000	3.330	0.230	0.359	0.230	0.330	0.140	4.50	3.66	22.1	7.36	2.46	1.82	1.09	0.71
S 6 × 5.10	6.000	3.443	0.230	0.359	0.343	0.330	0.140	4.50	4.34	24.1	8.04	2.36	2.04	1.19	0.69
S 6 × 5.96	6.000	3.565	0.230	0.359	0.465	0.330	0.140	4.50	5.07	26.3	8.77	2.28	2.31	1.30	0.68
S 7 × 6.05	7.000	3.755	0.250	0.392	0.345	0.350	0.150	5.25	5.15	39.4	11.3	2.77	2.88	1.53	0.75
S 8 × 6.35	8.000	4.000	0.270	0.425	0.270	0.370	0.160	6.25	5.40	57.6	14.4	3.27	3.73	1.86	0.83
S 8 × 7.96	8.000	4.171	0.270	0.425	0.441	0.370	0.160	6.25	6.77	64.9	16.2	3.10	4.31	2.07	0.80
S 8 × 8.81	8.000	4.262	0.270	0.425	0.532	0.370	0.160	6.25	7.49	68.7	17.2	3.03	4.66	2.19	0.79
S 9 × 7.51	9.000	4.330	0.290	0.458	0.290	0.390	0.170	7.00	6.38	85.9	19.1	3.67	5.09	2.35	0.89
S 10 × 8.76	10.000	4.660	0.310	0.491	0.310	0.410	0.190	8.00	7.45	123	24.5	4.07	6.78	2.91	0.95
S 10 × 10.4	10.000	4.797	0.310	0.491	0.447	0.410	0.190	8.00	8.82	135	27.0	3.91	7.50	3.13	0.92
S 10 × 12.1	10.000	4.944	0.310	0.491	0.594	0.410	0.190	8.00	10.3	147	29.4	3.78	8.36	3.38	0.90
S 12 × 11.0	12.000	5.000	0.350	0.544	0.350	0.450	0.210	9.75	9.35	218	36.4	4.83	9.35	3.74	1.00
S 12 × 12.1	12.000	5.078	0.350	0.544	0.428	0.450	0.210	9.75	10.3	229	38.2	4.72	9.87	3.89	0.98
S 12 × 14.1	12.000	5.250	0.460	0.660	0.460	0.560	0.280	9.25	12.0	272	45.4	4.77	13.5	5.16	1.06
S 12 × 15.6	12.000	5.355	0.460	0.660	0.565	0.560	0.280	9.25	13.2	287	47.9	4.66	14.5	5.42	1.05
S 12 × 17.3	12.000	5.477	0.460	0.660	0.687	0.560	0.280	9.25	14.7	305	50.8	4.56	15.7	5.74	1.03

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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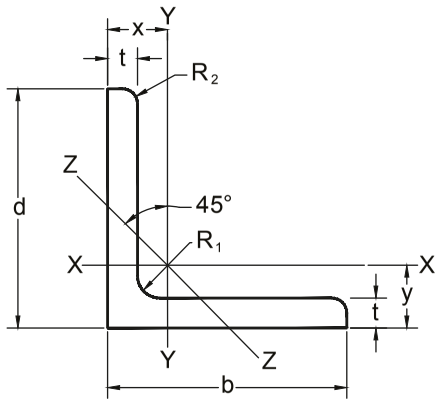

Table 10
ANGLES – EQUAL LEGS

Designation	Depth d in.	Width b in.	Thickness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	Axis X-X, Y-Y				Axis Z-Z	
								I_x, I_y in^4	S_x, S_y in^3	r_x, r_y in.	x, y in.	I_z in^4	r_z in.
L 1 1/2 × 1 1/2 × 1/8	1.500	1.500	0.125	0.188	0.125	0.42	0.360	0.0745	0.0684	0.455	0.411	0.0282	0.280
L 1 1/2 × 1 1/2 × 1/4	1.500	1.500	0.250	0.188	0.125	0.81	0.688	0.135	0.130	0.444	0.461	0.0556	0.284
L 1 3/4 × 1 3/4 × 1/8	1.750	1.750	0.125	0.188	0.125	0.50	0.423	0.121	0.0948	0.535	0.473	0.0462	0.330
L 1 3/4 × 1 3/4 × 1/4	1.750	1.750	0.250	0.188	0.125	0.96	0.813	0.223	0.182	0.523	0.524	0.0904	0.333
L 1 3/4 × 1 3/4 × 3/8	1.750	1.750	0.375	0.188	0.125	1.38	1.17	0.306	0.259	0.511	0.570	0.132	0.336
L 2 × 2 × 1/8	2.000	2.000	0.125	0.250	0.125	0.58	0.491	0.185	0.126	0.613	0.531	0.071	0.381
L 2 × 2 × 3/16	2.000	2.000	0.188	0.250	0.125	0.85	0.723	0.268	0.186	0.608	0.560	0.106	0.382
L 2 × 2 × 1/4	2.000	2.000	0.250	0.250	0.125	1.11	0.944	0.342	0.242	0.602	0.585	0.138	0.382
L 2 × 2 × 5/16	2.000	2.000	0.312	0.250	0.125	1.36	1.16	0.410	0.295	0.595	0.609	0.169	0.383
L 2 × 2 × 3/8	2.000	2.000	0.375	0.250	0.125	1.61	1.37	0.474	0.346	0.589	0.632	0.201	0.383
L 2 1/2 × 2 1/2 × 1/8	2.500	2.500	0.125	0.250	0.125	0.72	0.616	0.369	0.200	0.774	0.655	0.143	0.483
L 2 1/2 × 2 1/2 × 3/16	2.500	2.500	0.188	0.250	0.125	1.07	0.911	0.539	0.297	0.769	0.684	0.213	0.484
L 2 1/2 × 2 1/2 × 1/4	2.500	2.500	0.250	0.250	0.125	1.40	1.19	0.695	0.388	0.763	0.710	0.278	0.483
L 2 1/2 × 2 1/2 × 5/16	2.500	2.500	0.312	0.250	0.125	1.73	1.47	0.839	0.475	0.756	0.734	0.341	0.482
L 2 1/2 × 2 1/2 × 3/8	2.500	2.500	0.375	0.250	0.125	2.05	1.74	0.976	0.560	0.749	0.757	0.403	0.481
L 2 1/2 × 2 1/2 × 1/2	2.500	2.500	0.500	0.250	0.125	2.65	2.26	1.22	0.718	0.735	0.802	0.525	0.482
L 3 × 3 × 3/16	3.000	3.000	0.188	0.312	0.250	1.28	1.09	0.908	0.412	0.914	0.797	0.332	0.553
L 3 × 3 × 1/4	3.000	3.000	0.250	0.312	0.250	1.68	1.43	1.19	0.547	0.912	0.826	0.450	0.560
L 3 × 3 × 5/16	3.000	3.000	0.312	0.312	0.250	2.08	1.77	1.45	0.677	0.907	0.852	0.563	0.564
L 3 × 3 × 3/8	3.000	3.000	0.375	0.312	0.250	2.47	2.10	1.71	0.804	0.901	0.877	0.674	0.566
L 3 × 3 × 1/2	3.000	3.000	0.500	0.312	0.250	3.23	2.74	2.17	1.04	0.889	0.924	0.888	0.569
L 3 1/2 × 3 1/2 × 1/4	3.500	3.500	0.250	0.375	0.250	1.99	1.69	1.94	0.758	1.07	0.947	0.739	0.661
L 3 1/2 × 3 1/2 × 5/16	3.500	3.500	0.313	0.375	0.250	2.47	2.10	2.38	0.942	1.07	0.974	0.924	0.664
L 3 1/2 × 3 1/2 × 3/8	3.500	3.500	0.375	0.375	0.250	2.93	2.49	2.79	1.12	1.06	1.00	1.10	0.665
L 3 1/2 × 3 1/2 × 1/2	3.500	3.500	0.500	0.375	0.250	3.83	3.25	3.57	1.45	1.05	1.05	1.45	0.667

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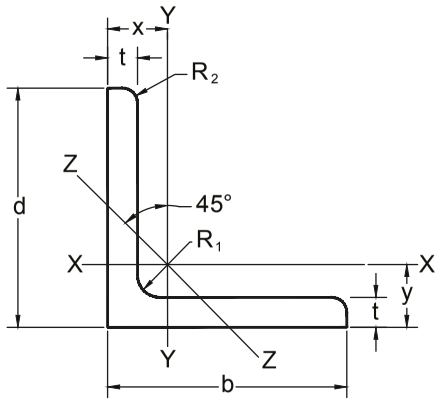

Table 10
ANGLES – EQUAL LEGS (Continued)

Designation	Depth d in.	Width b in.	Thickness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	Axis X-X, Y-Y I_x, I_y in^4	S_x, S_y in^3	r_x, r_y in.	x, y in.	Axis Z-Z I_z in^4	r_z in.
L 4 × 4 × 1/4	4.000	4.000	0.250	0.375	0.250	2.28	1.94	2.94	1.00	1.23	1.07	1.13	0.762
L 4 × 4 × 5/16	4.000	4.000	0.313	0.375	0.250	2.83	2.41	3.62	1.25	1.23	1.10	1.41	0.765
L 4 × 4 × 3/8	4.000	4.000	0.375	0.375	0.250	3.37	2.86	4.26	1.48	1.22	1.12	1.68	0.766
L 4 × 4 × 7/16	4.000	4.000	0.438	0.375	0.250	3.90	3.32	4.89	1.71	1.21	1.15	1.95	0.766
L 4 × 4 × 1/2	4.000	4.000	0.500	0.375	0.250	4.41	3.75	5.47	1.93	1.21	1.17	2.20	0.766
L 4 × 4 × 9/16	4.000	4.000	0.563	0.375	0.250	4.93	4.19	6.04	2.15	1.20	1.20	2.46	0.766
L 4 × 4 × 5/8	4.000	4.000	0.625	0.375	0.250	5.42	4.61	6.57	2.36	1.19	1.22	2.71	0.766
L 4 × 4 × 11/16	4.000	4.000	0.688	0.375	0.250	5.92	5.03	7.09	2.57	1.19	1.24	2.96	0.767
L 4 × 4 × 3/4	4.000	4.000	0.750	0.375	0.250	6.40	5.44	7.58	2.77	1.18	1.27	3.21	0.768
L 5 × 5 × 3/8	5.000	5.000	0.375	0.500	0.375	4.24	3.60	8.40	2.31	1.53	1.36	3.19	0.941
L 5 × 5 × 7/16	5.000	5.000	0.438	0.500	0.375	4.92	4.18	9.69	2.68	1.52	1.39	3.73	0.945
L 5 × 5 × 1/2	5.000	5.000	0.500	0.500	0.375	5.58	4.74	10.9	3.04	1.52	1.41	4.25	0.947
L 5 × 5 × 9/16	5.000	5.000	0.563	0.500	0.375	6.24	5.31	12.1	3.40	1.51	1.44	4.77	0.948
L 5 × 5 × 5/8	5.000	5.000	0.625	0.500	0.375	6.88	5.85	13.3	3.75	1.50	1.46	5.28	0.949
L 5 × 5 × 3/4	5.000	5.000	0.750	0.500	0.375	8.15	6.93	15.4	4.42	1.49	1.51	6.27	0.951
L 6 × 6 × 3/8	6.000	6.000	0.375	0.500	0.375	5.12	4.35	14.9	3.39	1.85	1.61	5.69	1.14
L 6 × 6 × 7/16	6.000	6.000	0.438	0.500	0.375	5.95	5.06	17.2	3.94	1.84	1.64	6.65	1.15
L 6 × 6 × 1/2	6.000	6.000	0.500	0.500	0.375	6.75	5.74	19.4	4.48	1.84	1.66	7.58	1.15
L 6 × 6 × 5/8	6.000	6.000	0.625	0.500	0.375	8.35	7.10	23.7	5.52	1.83	1.71	9.39	1.15
L 6 × 6 × 3/4	6.000	6.000	0.750	0.500	0.375	9.91	8.43	27.7	6.53	1.81	1.76	11.1	1.15
L 8 × 8 × 1/2	8.000	8.000	0.500	0.625	0.375	9.14	7.77	47.8	8.18	2.48	2.16	18.8	1.55
L 8 × 8 × 5/8	8.000	8.000	0.625	0.625	0.375	11.3	9.63	58.6	10.1	2.47	2.21	23.2	1.55
L 8 × 8 × 3/4	8.000	8.000	0.750	0.625	0.375	13.5	11.5	68.9	12.0	2.45	2.26	27.5	1.55
L 8 × 8 × 1	8.000	8.000	1.000	0.625	0.375	17.7	15.0	88.2	15.6	2.42	2.35	35.9	1.55

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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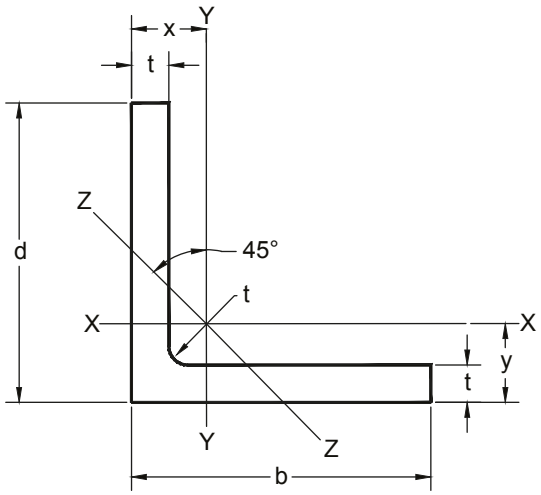

Table 11
SQUARE END ANGLES – EQUAL LEGS

Designation	Depth *d* in.	Width *b* in.	Thickness *t* in.	Weight lb/ft	Area *A* in^2	Axis X-X, Y-Y				Axis Z-Z	
						I_x, I_y in^4	S_x, S_y in^3	r_x, r_y in.	x, y in.	I_z in^4	r_z in.
LS 1 × 1 × 1/8	1.000	1.000	0.125	0.28	0.234	0.0217	0.0309	0.304	0.296	0.00896	0.196
LS 1 × 1 × 3/16	1.000	1.000	0.188	0.40	0.341	0.0300	0.0440	0.297	0.318	0.0129	0.195
LS 1 × 1 × 1/4	1.000	1.000	0.250	0.51	0.438	0.0369	0.0558	0.290	0.339	0.0168	0.196
LS 1 1/4 × 1 1/4 × 1/8	1.250	1.250	0.125	0.35	0.297	0.0439	0.0493	0.385	0.359	0.0179	0.246
LS 1 1/4 × 1 1/4 × 3/16	1.250	1.250	0.188	0.51	0.435	0.0616	0.0709	0.377	0.381	0.0258	0.244
LS 1 1/4 × 1 1/4 × 1/4	1.250	1.250	0.250	0.66	0.563	0.0767	0.0905	0.369	0.403	0.0333	0.243
LS 1 1/2 × 1 1/2 × 1/8	1.500	1.500	0.125	0.42	0.359	0.0778	0.0721	0.465	0.421	0.0315	0.296
LS 1 1/2 × 1 1/2 × 3/16	1.500	1.500	0.188	0.62	0.529	0.110	0.104	0.457	0.444	0.0455	0.293
LS 1 1/2 × 1 1/2 × 1/4	1.500	1.500	0.250	0.81	0.688	0.139	0.134	0.449	0.466	0.0586	0.292
LS 1 3/4 × 1 3/4 × 1/8	1.750	1.750	0.125	0.50	0.422	0.126	0.099	0.546	0.484	0.0507	0.347
LS 1 3/4 × 1 3/4 × 3/16	1.750	1.750	0.188	0.73	0.623	0.179	0.144	0.537	0.507	0.0734	0.343
LS 1 3/4 × 1 3/4 × 1/4	1.750	1.750	0.250	0.96	0.813	0.227	0.186	0.529	0.529	0.0947	0.341
LS 2 × 2 × 1/8	2.000	2.000	0.125	0.57	0.484	0.190	0.131	0.626	0.546	0.0766	0.398
LS 2 × 2 × 3/16	2.000	2.000	0.188	0.84	0.717	0.273	0.191	0.617	0.569	0.111	0.394
LS 2 × 2 × 1/4	2.000	2.000	0.250	1.10	0.938	0.348	0.247	0.609	0.592	0.143	0.391
LS 2 1/2 × 2 1/2 × 1/8	2.500	2.500	0.125	0.72	0.609	0.378	0.207	0.787	0.671	0.152	0.499
LS 2 1/2 × 2 1/2 × 3/16	2.500	2.500	0.188	1.06	0.905	0.548	0.303	0.778	0.695	0.222	0.495
LS 2 1/2 × 2 1/2 × 1/4	2.500	2.500	0.250	1.40	1.19	0.703	0.394	0.769	0.717	0.287	0.491
LS 2 1/2 × 2 1/2 × 5/16	2.500	2.500	0.312	1.72	1.46	0.847	0.481	0.761	0.739	0.350	0.489
LS 3 × 3 × 1/8	3.000	3.000	0.125	0.86	0.734	0.661	0.300	0.949	0.797	0.265	0.601
LS 3 × 3 × 3/16	3.000	3.000	0.188	1.28	1.09	0.964	0.442	0.939	0.820	0.388	0.596
LS 3 × 3 × 1/4	3.000	3.000	0.250	1.69	1.44	1.24	0.577	0.930	0.842	0.504	0.592
LS 3 × 3 × 5/16	3.000	3.000	0.312	2.09	1.77	1.51	0.706	0.922	0.865	0.616	0.589
LS 3 1/2 × 3 1/2 × 1/8	3.500	3.500	0.125	1.01	0.859	1.06	0.411	1.11	0.922	0.425	0.703
LS 4 × 4 × 1/8	4.000	4.000	0.125	1.16	0.984	1.59	0.539	1.27	1.05	0.638	0.805
LS 4 × 4 × 1/4	4.000	4.000	0.250	2.28	1.94	3.04	1.05	1.25	1.09	1.22	0.795

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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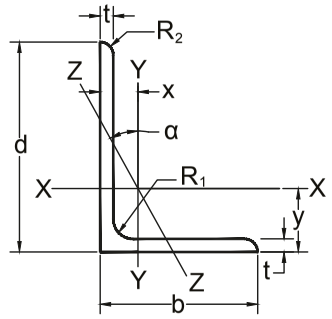

Table 12
ANGLES – UNEQUAL LEGS

Designation	Depth *d* in.	Width *b* in.	Thick-ness *t* in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area *A* in²	Axis X-X				Axis Y-Y				Axis Z-Z		
								I_x in⁴	S_x in³	r_x in.	*y* in.	I_y in⁴	S_y in³	r_y in.	*x* in.	I_z in⁴	r_z in.	α deg
L 1 3/4 × 1 1/4 × 1/8	1.750	1.250	0.125	0.188	0.125	0.42	0.360	0.109	0.0901	0.549	0.544	0.0460	0.0484	0.357	0.300	0.0238	0.257	27.12
L 1 3/4 × 1 1/4 × 3/16	1.750	1.250	0.188	0.188	0.125	0.62	0.530	0.157	0.133	0.544	0.572	0.0659	0.0713	0.353	0.326	0.0355	0.259	26.61
L 1 3/4 × 1 1/4 × 1/4	1.750	1.250	0.250	0.188	0.125	0.81	0.688	0.199	0.172	0.537	0.596	0.0830	0.0921	0.347	0.349	0.0465	0.260	26.09
L 2 × 1 × 3/16	2.000	1.000	0.188	0.188	0.125	0.62	0.530	0.211	0.166	0.631	0.728	0.0351	0.0459	0.257	0.236	0.0223	0.205	14.62
L 2 × 1 1/4 × 1/8	2.000	1.250	0.125	0.188	0.125	0.46	0.392	0.158	0.117	0.635	0.649	0.0477	0.0492	0.349	0.281	0.0265	0.260	21.87
L 2 × 1 1/4 × 1/4	2.000	1.250	0.250	0.188	0.125	0.88	0.751	0.291	0.224	0.623	0.702	0.0862	0.0937	0.339	0.330	0.0515	0.262	20.83
L 2 × 1 1/2 × 1/8	2.000	1.500	0.125	0.188	0.125	0.50	0.423	0.168	0.120	0.630	0.605	0.0810	0.0710	0.438	0.360	0.0407	0.310	29.38
L 2 × 1 1/2 × 3/16	2.000	1.500	0.188	0.188	0.125	0.73	0.624	0.243	0.178	0.625	0.633	0.117	0.105	0.433	0.386	0.0606	0.312	29.00
L 2 × 1 1/2 × 1/4	2.000	1.500	0.250	0.188	0.125	0.96	0.813	0.311	0.231	0.618	0.657	0.148	0.136	0.427	0.410	0.0792	0.312	28.62
L 2 × 1 1/2 × 3/8	2.000	1.500	0.375	0.188	0.125	1.38	1.17	0.428	0.330	0.604	0.704	0.202	0.193	0.415	0.455	0.116	0.314	27.74
L 2 × 1 3/4 × 1/4	2.000	1.750	0.250	0.250	0.125	1.04	0.882	0.328	0.237	0.610	0.617	0.233	0.185	0.514	0.494	0.109	0.352	36.91
L 2 1/4 × 1 1/2 × 1/4	2.250	1.500	0.250	0.250	0.125	1.04	0.882	0.435	0.292	0.702	0.758	0.153	0.138	0.417	0.389	0.0877	0.315	23.46
L 2 1/2 × 1 1/4 × 1/8	2.500	1.250	0.125	0.188	0.094	0.54	0.457	0.298	0.182	0.807	0.867	0.0515	0.0516	0.336	0.252	0.0320	0.265	15.16
L 2 1/2 × 1 1/2 × 1/8	2.500	1.500	0.125	0.250	0.125	0.58	0.491	0.314	0.186	0.800	0.806	0.0860	0.0728	0.418	0.320	0.0492	0.316	20.43
L 2 1/2 × 1 1/2 × 3/16	2.500	1.500	0.188	0.250	0.125	0.85	0.723	0.457	0.275	0.794	0.838	0.124	0.108	0.414	0.347	0.0727	0.317	20.07
L 2 1/2 × 1 1/2 × 1/4	2.500	1.500	0.250	0.250	0.125	1.11	0.944	0.586	0.358	0.787	0.864	0.158	0.140	0.408	0.372	0.0946	0.316	19.70
L 2 1/2 × 1 1/2 × 5/16	2.500	1.500	0.312	0.250	0.125	1.36	1.16	0.705	0.437	0.780	0.889	0.188	0.170	0.403	0.395	0.116	0.316	19.29
L 2 1/2 × 1 1/2 × 3/8	2.500	1.500	0.375	0.250	0.125	1.61	1.37	0.816	0.514	0.773	0.914	0.216	0.200	0.398	0.419	0.137	0.316	18.84
L 2 1/2 × 2 × 1/8	2.500	2.000	0.125	0.250	0.125	0.65	0.554	0.345	0.194	0.789	0.722	0.197	0.129	0.596	0.478	0.0955	0.415	32.51
L 2 1/2 × 2 × 3/16	2.500	2.000	0.188	0.250	0.125	0.96	0.817	0.503	0.288	0.784	0.752	0.286	0.191	0.592	0.506	0.142	0.416	32.30
L 2 1/2 × 2 × 1/4	2.500	2.000	0.250	0.250	0.125	1.26	1.07	0.646	0.375	0.778	0.778	0.366	0.249	0.585	0.531	0.185	0.416	32.09
L 2 1/2 × 2 × 5/16	2.500	2.000	0.312	0.250	0.125	1.54	1.31	0.780	0.459	0.770	0.802	0.440	0.304	0.579	0.555	0.226	0.415	31.85
L 2 1/2 × 2 × 3/8	2.500	2.000	0.375	0.250	0.125	1.83	1.55	0.905	0.541	0.763	0.826	0.509	0.358	0.572	0.578	0.267	0.415	31.59
L 3 × 1 1/2 × 1/4	3.000	1.500	0.250	0.312	0.125	1.27	1.08	0.980	0.510	0.954	1.08	0.165	0.142	0.391	0.343	0.106	0.313	14.59
L 3 × 2 × 3/16	3.000	2.000	0.188	0.312	0.188	1.07	0.910	0.821	0.400	0.949	0.947	0.292	0.190	0.567	0.459	0.158	0.416	24.25
L 3 × 2 × 1/4	3.000	2.000	0.250	0.312	0.188	1.40	1.19	1.06	0.526	0.944	0.976	0.377	0.249	0.562	0.485	0.209	0.418	23.95
L 3 × 2 × 5/16	3.000	2.000	0.312	0.312	0.188	1.73	1.47	1.29	0.647	0.938	1.00	0.456	0.306	0.557	0.510	0.257	0.419	23.64
L 3 × 2 × 3/8	3.000	2.000	0.375	0.312	0.188	2.05	1.74	1.51	0.765	0.931	1.03	0.529	0.361	0.551	0.534	0.305	0.419	23.32
L 3 × 2 × 1/2	3.000	2.000	0.500	0.312	0.188	2.65	2.26	1.90	0.987	0.918	1.08	0.659	0.464	0.541	0.580	0.399	0.421	22.61

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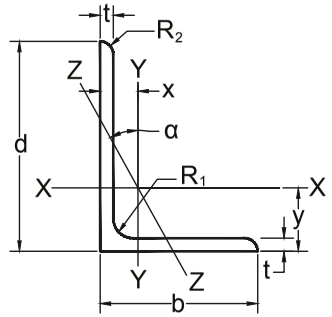

Table 12
ANGLES – UNEQUAL LEGS (Continued)

Designation	Depth d in.	Width b in.	Thick-ness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	Axis X-X I_x in^4	S_x in^3	r_x in.	y in.	Axis Y-Y I_y in^4	S_y in^3	r_y in.	x in.	Axis Z-Z I_z in^4	r_z in.	α deg
L 3 × 2 1/2 × 1/4	3.000	2.500	0.250	0.312	0.250	1.54	1.31	1.12	0.532	0.927	0.893	0.704	0.380	0.734	0.647	0.323	0.497	34.65
L 3 × 2 1/2 × 5/16	3.000	2.500	0.312	0.312	0.250	1.90	1.61	1.37	0.659	0.922	0.919	0.859	0.470	0.730	0.672	0.404	0.500	34.45
L 3 × 2 1/2 × 3/8	3.000	2.500	0.375	0.312	0.250	2.25	1.92	1.61	0.782	0.916	0.944	1.01	0.557	0.724	0.697	0.484	0.503	34.25
L 3 1/2 × 3 × 1/4	3.500	3.000	0.250	0.375	0.250	1.84	1.57	1.85	0.742	1.09	1.01	1.25	0.559	0.893	0.767	0.562	0.599	36.17
L 3 1/2 × 3 × 5/16	3.500	3.000	0.312	0.375	0.250	2.27	1.93	2.26	0.918	1.08	1.04	1.53	0.692	0.888	0.793	0.701	0.602	36.04
L 3 1/2 × 3 × 3/8	3.500	3.000	0.375	0.375	0.250	2.71	2.30	2.66	1.09	1.08	1.07	1.79	0.822	0.883	0.819	0.838	0.603	35.90
L 3 1/2 × 3 × 1/2	3.500	3.000	0.500	0.375	0.250	3.53	3.00	3.39	1.42	1.06	1.11	2.28	1.07	0.871	0.867	1.10	0.605	35.63
L 4 × 3 × 1/4	4.000	3.000	0.250	0.375	0.250	1.99	1.69	2.69	0.963	1.26	1.21	1.30	0.568	0.875	0.719	0.651	0.620	29.39
L 4 × 3 × 5/16	4.000	3.000	0.312	0.375	0.250	2.46	2.09	3.29	1.19	1.26	1.24	1.59	0.703	0.871	0.746	0.810	0.623	29.19
L 4 × 3 × 3/8	4.000	3.000	0.375	0.375	0.250	2.93	2.49	3.88	1.42	1.25	1.27	1.86	0.836	0.865	0.771	0.967	0.624	29.00
L 4 × 3 × 7/16	4.000	3.000	0.438	0.375	0.250	3.38	2.88	4.44	1.64	1.24	1.29	2.13	0.964	0.859	0.796	1.12	0.624	28.81
L 4 × 3 × 1/2	4.000	3.000	0.500	0.375	0.250	3.83	3.25	4.97	1.85	1.24	1.31	2.37	1.09	0.853	0.819	1.27	0.624	28.62
L 4 × 3 × 5/8	4.000	3.000	0.625	0.375	0.250	4.69	3.99	5.96	2.26	1.22	1.36	2.82	1.32	0.841	0.866	1.56	0.625	28.20
L 4 × 3 1/2 × 5/16	4.000	3.500	0.312	0.375	0.312	2.62	2.23	3.41	1.20	1.24	1.16	2.43	0.938	1.04	0.913	1.06	0.691	37.33
L 4 × 3 1/2 × 3/8	4.000	3.500	0.375	0.375	0.312	3.13	2.66	4.03	1.43	1.23	1.19	2.87	1.12	1.04	0.940	1.28	0.694	37.22
L 4 × 3 1/2 × 1/2	4.000	3.500	0.500	0.375	0.312	4.10	3.49	5.18	1.88	1.22	1.24	3.68	1.46	1.03	0.989	1.70	0.698	37.00
L 5 × 3 × 1/4	5.000	3.000	0.250	0.375	0.312	2.26	1.93	4.90	1.45	1.60	1.62	1.34	0.567	0.834	0.639	0.739	0.620	20.79
L 5 × 3 × 5/16	5.000	3.000	0.312	0.375	0.312	2.81	2.39	6.05	1.81	1.59	1.65	1.65	0.706	0.831	0.666	0.930	0.624	20.54
L 5 × 3 × 3/8	5.000	3.000	0.375	0.375	0.312	3.35	2.85	7.17	2.16	1.59	1.68	1.95	0.843	0.827	0.692	1.12	0.626	20.31
L 5 × 3 × 1/2	5.000	3.000	0.500	0.375	0.312	4.40	3.74	9.26	2.83	1.57	1.73	2.49	1.10	0.816	0.742	1.47	0.628	19.86

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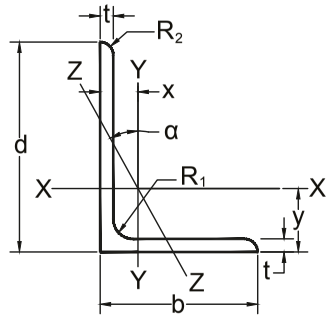

Table 12
ANGLES – UNEQUAL LEGS (Continued)

Designation	Depth *d* in.	Width *b* in.	Thick-ness *t* in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area *A* in^2	Axis X-X				Axis Y-Y				Axis Z-Z		
								I_x in^4	S_x in^3	r_x in.	*y* in.	I_y in^4	S_y in^3	r_y in.	*x* in.	I_z in^4	r_z in.	α deg
L 5 × 3 1/2 × 5/16	5.000	3.500	0.312	0.438	0.312	3.00	2.55	6.39	1.86	1.58	1.56	2.59	0.965	1.01	0.819	1.35	0.728	26.32
L 5 × 3 1/2 × 3/8	5.000	3.500	0.375	0.438	0.312	3.58	3.05	7.58	2.22	1.58	1.59	3.06	1.15	1.00	0.846	1.63	0.731	26.13
L 5 × 3 1/2 × 1/2	5.000	3.500	0.500	0.438	0.312	4.70	4.00	9.79	2.91	1.56	1.64	3.93	1.51	0.991	0.895	2.14	0.732	25.78
L 5 × 3 1/2 × 5/8	5.000	3.500	0.625	0.438	0.312	5.79	4.92	11.8	3.57	1.55	1.69	4.72	1.84	0.979	0.943	2.64	0.733	25.41
L 6 × 3 x 3/8	6.000	3.000	0.375	0.500	0.375	3.80	3.23	11.8	3.03	1.91	2.11	1.99	0.842	0.786	0.630	1.21	0.612	15.24
L 6 × 3 1/2 × 5/16	6.000	3.500	0.312	0.500	0.312	3.39	2.88	10.6	2.64	1.92	1.97	2.71	0.985	0.971	0.746	1.56	0.736	19.61
L 6 × 3 1/2 × 3/8	6.000	3.500	0.375	0.500	0.312	4.04	3.43	12.6	3.16	1.92	2.00	3.21	1.18	0.967	0.773	1.87	0.738	19.43
L 6 × 3 1/2 × 1/2	6.000	3.500	0.500	0.500	0.312	5.31	4.51	16.4	4.15	1.90	2.06	4.12	1.54	0.956	0.823	2.46	0.738	19.10
L 6 × 3 1/2 × 5/8	6.000	3.500	0.625	0.500	0.312	6.54	5.56	19.8	5.10	1.89	2.11	4.96	1.89	0.944	0.872	3.02	0.737	18.75
L 6 × 4 × 3/8	6.000	4.000	0.375	0.500	0.375	4.24	3.60	13.0	3.19	1.90	1.91	4.66	1.51	1.14	0.920	2.50	0.834	24.33
L 6 × 4 × 7/16	6.000	4.000	0.438	0.500	0.375	4.92	4.18	15.1	3.70	1.90	1.93	5.37	1.76	1.13	0.947	2.92	0.836	24.16
L 6 × 4 × 1/2	6.000	4.000	0.500	0.500	0.375	5.58	4.74	17.0	4.20	1.89	1.96	6.03	1.99	1.13	0.972	3.33	0.838	24.00
L 6 × 4 × 5/8	6.000	4.000	0.625	0.500	0.375	6.88	5.85	20.7	5.18	1.88	2.01	7.30	2.45	1.12	1.02	4.12	0.839	23.68
L 6 × 4 × 3/4	6.000	4.000	0.750	0.500	0.375	8.15	6.93	24.1	6.12	1.87	2.06	8.46	2.89	1.10	1.07	4.88	0.839	23.35
L 7 × 4 × 1/2	7.000	4.000	0.500	0.500	0.375	6.17	5.24	26.1	5.66	2.23	2.39	6.28	2.03	1.09	0.903	3.71	0.842	18.70
L 8 × 6 × 5/8	8.000	6.000	0.625	0.500	0.312	9.84	8.37	53.6	9.74	2.53	2.50	26.0	5.78	1.76	1.51	13.6	1.275	29.07
L 8 × 6 × 11/16	8.000	6.000	0.688	0.500	0.375	10.8	9.15	58.1	10.6	2.52	2.52	28.`0	6.27	1.75	1.53	14.7	1.266	29.03
L 8 × 6 × 3/4	8.000	6.000	0.750	0.500	0.375	11.7	9.93	62.6	11.5	2.51	2.55	30.2	6.79	1.74	1.55	15.9	1.265	28.94

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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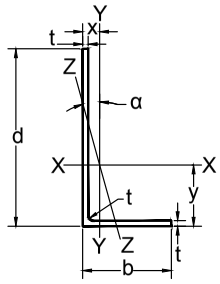

Table 13
SQUARE END ANGLES – UNEQUAL LEGS

Designation	Depth *d* in.	Width *b* in.	Thick-ness *t* in.	Weight lb/ft	Area *A* in^2	Axis X-X				Axis Y-Y				Axis Z-Z		
						I_x in^4	S_x in^3	r_x in.	y in.	I_y in^4	S_y in^3	r_y in.	x in.	I_z in^4	r_z in.	α deg
LS 1 × 3/4 × 1/8	1.000	0.750	0.125	0.24	0.203	0.0197	0.0295	0.312	0.332	0.00947	0.0174	0.216	0.207	0.00519	0.160	28.49
LS 1 1/4 × 1 × 1/8	1.250	1.000	0.125	0.31	0.266	0.0408	0.0477	0.392	0.393	0.0233	0.0318	0.296	0.268	0.0119	0.212	32.05
LS 1 1/2 × 3/4 × 1/8	1.500	0.750	0.125	0.31	0.266	0.0613	0.0644	0.480	0.548	0.0105	0.0183	0.199	0.173	0.00683	0.160	14.62
LS 1 1/2 × 1 × 1/8	1.500	1.000	0.125	0.35	0.297	0.0679	0.0677	0.478	0.497	0.0245	0.0325	0.287	0.247	0.0140	0.217	23.77
LS 1 1/2 × 1 × 3/16	1.500	1.000	0.188	0.51	0.435	0.0959	0.0979	0.470	0.520	0.0340	0.0465	0.280	0.270	0.0201	0.215	23.18
LS 1 1/2 × 1 1/4 × 1/8	1.500	1.250	0.125	0.39	0.328	0.0733	0.0702	0.473	0.455	0.0465	0.0505	0.376	0.330	0.0228	0.264	34.37
LS 1 3/4 × 1 × 1/8	1.750	1.000	0.125	0.39	0.328	0.104	0.0909	0.563	0.604	0.0255	0.0331	0.279	0.229	0.0156	0.218	18.50
LS 2 × 1 × 1/8	2.000	1.000	0.125	0.42	0.359	0.150	0.117	0.647	0.715	0.0263	0.0335	0.271	0.215	0.0168	0.216	14.95
LS 2 × 1 × 3/16	2.000	1.000	0.188	0.62	0.529	0.215	0.170	0.638	0.738	0.0366	0.0481	0.263	0.238	0.0240	0.213	14.45
LS 2 × 1 1/2 × 1/8	2.000	1.500	0.125	0.50	0.422	0.173	0.125	0.641	0.618	0.0847	0.0748	0.448	0.368	0.0447	0.326	29.16
LS 2 × 1 1/2 × 3/16	2.000	1.500	0.188	0.73	0.623	0.248	0.183	0.632	0.641	0.120	0.108	0.439	0.391	0.0645	0.322	28.84
LS 2 1/2 × 1 × 1/8	2.500	1.000	0.125	0.50	0.422	0.277	0.178	0.811	0.942	0.0276	0.0342	0.256	0.192	0.0187	0.210	10.54
LS 2 1/2 × 1 1/2 × 1/8	2.500	1.500	0.125	0.57	0.484	0.319	0.191	0.812	0.829	0.0899	0.0767	0.431	0.329	0.0532	0.331	20.36
LS 2 1/2 × 2 × 1/8	2.500	2.000	0.125	0.64	0.547	0.352	0.200	0.802	0.741	0.203	0.135	0.609	0.491	0.102	0.432	32.46
LS 2 1/2 × 2 × 3/16	2.500	2.000	0.188	0.95	0.811	0.510	0.294	0.793	0.764	0.292	0.197	0.600	0.514	0.148	0.427	32.26
LS 3 × 1 × 1/8	3.000	1.000	0.125	0.57	0.484	0.456	0.250	0.971	1.18	0.0286	0.0347	0.243	0.175	0.0201	0.204	7.94
LS 3 × 2 × 1/8	3.000	2.000	0.125	0.72	0.609	0.580	0.282	0.975	0.947	0.213	0.137	0.592	0.447	0.120	0.444	24.28
LS 3 × 2 × 1/4	3.000	2.000	0.250	1.40	1.19	1.09	0.542	0.957	0.993	0.392	0.260	0.574	0.493	0.225	0.435	23.77
LS 3 × 2 × 3/8	3.000	2.000	0.375	2.04	1.73	1.53	0.781	0.940	1.04	0.543	0.371	0.559	0.539	0.320	0.430	23.18
LS 3 × 2 1/2 × 1/4	3.000	2.500	0.250	1.54	1.31	1.17	0.561	0.945	0.911	0.743	0.404	0.753	0.661	0.366	0.528	34.37
LS 3 1/2 × 1 1/4 × 1/8	3.500	1.250	0.125	0.68	0.578	0.750	0.347	1.14	1.34	0.0570	0.0550	0.314	0.215	0.0392	0.261	8.98
LS 4 × 2 × 1/8	4.000	2.000	0.125	0.86	0.734	1.27	0.484	1.31	1.38	0.229	0.141	0.558	0.382	0.144	0.442	15.40
LS 4 × 2 × 1/4	4.000	2.000	0.250	1.69	1.44	2.41	0.936	1.29	1.43	0.421	0.268	0.541	0.429	0.269	0.432	14.95
LS 4 × 3 × 1/8	4.000	3.000	0.125	1.01	0.859	1.45	0.517	1.30	1.19	0.719	0.311	0.914	0.690	0.376	0.661	29.45
LS 5 × 3 × 1/8	5.000	3.000	0.125	1.16	0.984	2.66	0.784	1.64	1.61	0.762	0.319	0.880	0.610	0.447	0.674	20.67
LS 5 × 3 × 1/4	5.000	3.000	0.250	2.28	1.94	5.11	1.53	1.62	1.66	1.44	0.614	0.861	0.657	0.851	0.663	20.36
LS 5 × 4 × 1/8	5.000	4.000	0.125	1.30	1.11	2.92	0.820	1.62	1.44	1.70	0.554	1.24	0.936	0.847	0.874	32.63
LS 5 ¼ × 2 ¼ × 1/8	5.250	2.250	0.125	1.08	0.922	2.75	0.817	1.73	1.89	0.340	0.183	0.607	0.387	0.223	0.491	12.17

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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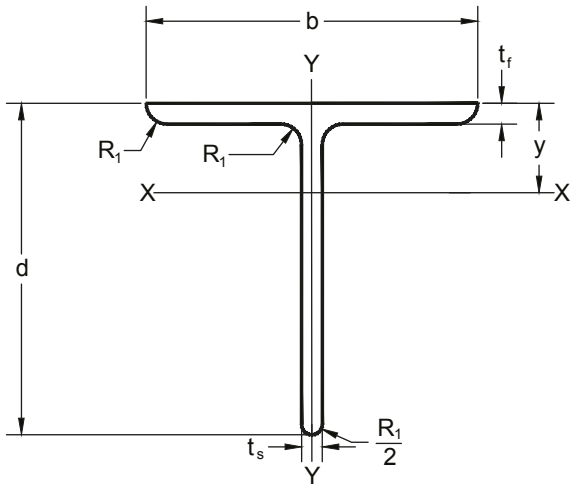

Table 14
TEES

Designation T $d \times b \times$ Wt in. in. lb/ft	Stem Thickness t_s in.	Flange Thickness t_f in.	Area A in^2	R_1 in.	Axis X-X I_x in^4	S_x in^3	r_x in.	y in.	Axis Y-Y I_y in^4	S_y in^3	r_y in.
T 1.25 × 1.50 × 0.384	0.125	0.125	0.326	0.125	0.045	0.049	0.371	0.327	0.032	0.043	0.314
T 1.63 × 1.75 × 0.476	0.125	0.125	0.405	0.125	0.100	0.83	0.496	0.434	0.052	0.059	0.357
T 1.00 × 2.00 × 0.421	0.125	0.125	0.358	0.125	0.025	0.032	0.266	0.212	0.078	0.078	0.466
T 1.75 × 2.00 × 0.531	0.125	0.125	0.451	0.125	0.128	0.098	0.532	0.451	0.078	0.078	0.415
T 1.25 × 2.50 × 0.652	0.156	0.156	0.554	0.125	0.062	0.063	0.333	0.265	0.188	0.151	0.583
T 2.00 × 2.50 × 0.789	0.156	0.156	0.671	0.125	0.241	0.161	0.599	0.500	0.189	0.151	0.530
T 2.00 × 3.00 × 0.881	0.156	0.156	0.749	0.125	0.254	0.164	0.582	0.456	0.330	0.220	0.663
T 2.50 × 3.00 × 1.17	0.188	0.188	0.995	0.188	0.565	0.302	0.753	0.632	0.393	0.262	0.629
T 3.00 × 4.00 × 1.50	0.188	0.188	1.28	0.188	1.03	0.448	0.897	0.708	0.947	0.474	0.861
T 4.00 × 4.00 × 2.27	0.250	0.250	1.93	0.250	2.98	1.02	1.24	1.08	1.24	0.619	0.801
T 5.00 × 4.00 × 2.57	0.250	0.250	2.18	0.250	5.54	1.57	1.59	1.47	1.24	0.620	0.754
T 3.00 × 6.00 × 3.24	0.312[4]	0.312	2.75	0.312[4]	1.83	0.77	0.81	0.62	5.63	1.88	1.43
T 4.00 × 6.00 × 3.88	0.375[4]	0.313	3.30	0.313[4]	4.78	1.59	1.20	1.00	5.65	1.88	1.31
T 4.00 × 6.00 × 4.79	0.375[4]	0.450	4.07	0.312[4]	5.02	1.61	1.11	0.88	8.12	2.71	1.41
T 7.50 × 7.50 × 9.46	0. 500[4]	0.750	8.04	0.625[4]	40.3	7.28	2.24	1.96	13.6	4.53	1.30
T 7.50 × 7.50 × 14.4	1.13[4]	0.750	12.3	0.625[4]	69.3	14.5	2.38	2.71	14.4	4.80	1.08
T 6.00 × 8.00 × 11.2	0.500[4]	0.860	9.56	0.500[4]	22.9	4.82	1.55	1.24	36.8	9.19	1.96

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.
4. Both flange and stem of these shapes have square ends. Fillet radius R_1 applies only to juncture of stem and flange.

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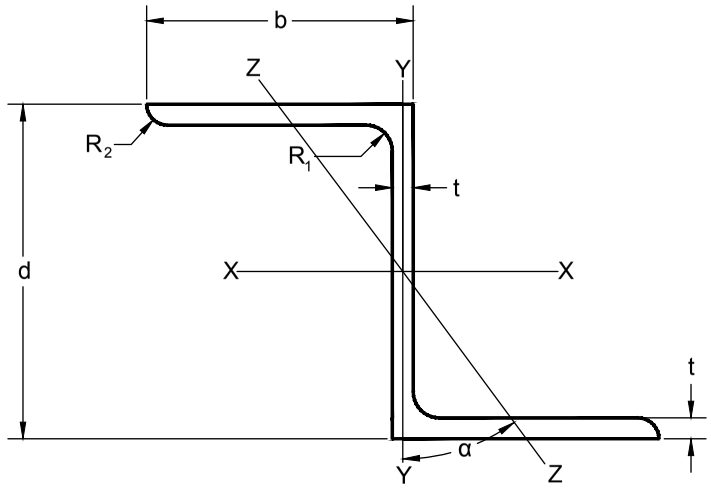

Table 15
ZEES

Designation	Depth *d* in.	Width *b* in.	Thickness *t* in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Area *A* in²	Axis X-X			Axis Y-Y			Axis Z-Z		
							I_x in⁴	S_x in³	r_x in.	I_y in⁴	S_y in³	r_y in.	I_z in⁴	r_z in.	α deg
Z 1 3/4 × 1 3/4 × 1.09	1.750	1.750	0.188	0.188	0.125	0.925	0.447	0.511	0.695	0.553	0.334	0.773	0.101	0.330	48.82
Z 2 × 1.25 × 0.922	2.000	1.250	0.188	0.188	0.125	0.784	0.459	0.459	0.765	0.186	0.161	0.488	0.0630	0.284	29.20
Z 2 3/8 × 1 1/4 × 1.00	2.375	1.250	0.188	0.188	0.125	0.854	0.695	0.586	0.902	0.187	0.161	0.467	0.0820	0.310	23.20
Z 3 × 2 11/16 × 2.33	3.000	2.688	0.250	0.312	0.250	1.98	2.89	1.92	1.21	2.64	1.03	1.15	0.590	0.545	43.40
Z 3 × 2 11/16 × 3.38	3.000	2.688	0.375	0.312	0.250	2.87	3.86	2.57	1.16	3.76	1.50	1.14	0.820	0.534	44.52
Z 4 × 3 1/16 × 2.85	4.000	3.062	0.250	0.312	0.250	2.42	6.31	3.16	1.61	4.01	1.36	1.29	1.08	0.668	36.78
Z 4 1/16 × 3 1/8 × 3.57	4.062	3.125	0.312	0.312	0.250	3.04	7.96	3.92	1.62	5.23	1.76	1.31	1.39	0.676	37.40
Z 4 1/8 × 3 3/16 × 4.32	4.125	3.188	0.375	0.312	0.250	3.67	9.66	4.69	1.62	6.54	2.18	1.33	1.72	0.684	37.92
Z 4 × 3 1/16 × 4.78	4.000	3.062	0.438	0.312	0.250	4.07	9.69	4.84	1.54	6.53	2.30	1.27	1.74	0.654	37.83
Z 4 1/8 × 3 3/16 × 6.22	4.125	3.188	0.563	0.312	0.250	5.29	12.8	6.19	1.55	9.06	3.12	1.31	2.41	0.675	38.68
Z 5 × 3 1/4 × 4.01	5.000	3.250	0.312	0.312	0.250	3.41	13.4	5.36	1.98	5.93	1.92	1.32	1.89	0.745	30.67
Z 5 1/16 × 3 5/16 × 4.84	5.062	3.312	0.375	0.312	0.250	4.12	16.2	6.41	1.99	7.40	2.37	1.34	2.33	0.752	31.13
Z 5 × 3 1/4 × 6.19	5.000	3.250	0.500	0.312	0.250	5.26	19.2	7.69	1.91	8.82	2.94	1.29	2.82	0.732	31.15

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in³.

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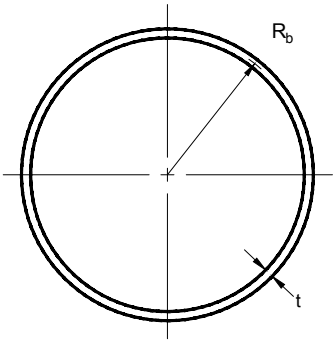
Table 16

ROUND TUBES



Designation							ID	Weight	A	I	S	Z	r	J	R_b/t
in.			in.				in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	-
1.500	OD	x	0.062	WALL			1.376	0.329	0.280	0.0725	0.097	0.128	0.509	0.145	11.6
1.500	OD	x	0.094	WALL			1.312	0.488	0.415	0.103	0.137	0.186	0.498	0.205	7.5
1.500	OD	x	0.125	WALL			1.250	0.635	0.540	0.129	0.172	0.237	0.488	0.255	5.5
1.500	OD	x	0.156	WALL			1.188	0.775	0.659	0.151	0.201	0.283	0.478	0.297	4.3
1.500	OD	x	0.188	WALL			1.124	0.911	0.775	0.170	0.227	0.326	0.469	0.333	3.5
1.500	OD	x	0.250	WALL			1.000	1.15	0.982	0.199	0.266	0.396	0.451	0.383	2.5
1.500	OD	x	0.375	WALL			0.750	1.56	1.33	0.233	0.311	0.492	0.419	0.419	1.5
1.625	OD	x	0.125	WALL			1.375	0.693	0.589	0.167	0.205	0.282	0.532	0.331	6.0
1.625	OD	x	0.188	WALL			1.249	0.998	0.849	0.223	0.274	0.390	0.512	0.438	3.8
1.625	OD	x	0.250	WALL			1.125	1.27	1.08	0.264	0.324	0.478	0.494	0.510	2.8
1.750	OD	x	0.125	WALL			1.500	0.750	0.638	0.212	0.242	0.331	0.576	0.421	6.5
1.750	OD	x	0.188	WALL			1.374	1.08	0.923	0.285	0.326	0.461	0.556	0.563	4.2
1.750	OD	x	0.250	WALL			1.250	1.39	1.18	0.341	0.389	0.568	0.538	0.663	3.0
1.750	OD	x	0.375	WALL			1.000	1.90	1.62	0.411	0.470	0.727	0.504	0.766	1.8
1.875	OD	x	0.125	WALL			1.625	0.808	0.687	0.264	0.282	0.383	0.620	0.526	7.0
1.875	OD	x	0.188	WALL			1.499	1.17	0.996	0.359	0.383	0.537	0.600	0.709	4.5
1.875	OD	x	0.250	WALL			1.375	1.50	1.28	0.431	0.460	0.665	0.581	0.843	3.3
1.875	OD	x	0.375	WALL			1.125	2.08	1.77	0.528	0.563	0.861	0.547	0.994	2.0
2.000	OD	x	0.125	WALL			1.750	0.866	0.736	0.325	0.325	0.440	0.664	0.647	7.5
2.000	OD	x	0.188	WALL			1.624	1.26	1.07	0.444	0.444	0.619	0.644	0.878	4.8
2.000	OD	x	0.250	WALL			1.500	1.62	1.37	0.537	0.537	0.771	0.625	1.05	3.5
2.000	OD	x	0.312	WALL			1.376	1.95	1.65	0.609	0.609	0.899	0.607	1.18	2.7
2.000	OD	x	0.375	WALL			1.250	2.25	1.91	0.666	0.666	1.01	0.590	1.26	2.2
2.000	OD	x	0.500	WALL			1.000	2.77	2.36	0.736	0.736	1.17	0.559	1.33	1.5
2.250	OD	x	0.125	WALL			2.000	0.981	0.834	0.473	0.420	0.565	0.753	0.942	8.5
2.250	OD	x	0.188	WALL			1.874	1.43	1.22	0.653	0.580	0.802	0.732	1.29	5.5
2.250	OD	x	0.250	WALL			1.750	1.85	1.57	0.798	0.709	1.01	0.713	1.57	4.0
2.250	OD	x	0.312	WALL			1.626	2.23	1.90	0.915	0.813	1.18	0.694	1.78	3.1
2.250	OD	x	0.375	WALL			1.500	2.60	2.21	1.01	0.897	1.34	0.676	1.94	2.5
2.250	OD	x	0.500	WALL			1.250	3.23	2.75	1.14	1.01	1.57	0.643	2.10	1.8

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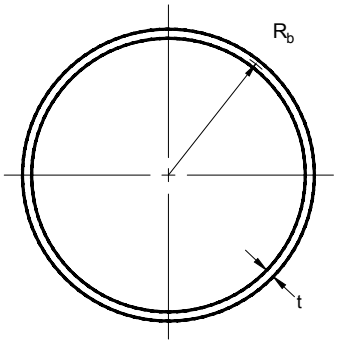
Table 16

ROUND TUBES (Continued)



Designation							ID	Weight	A	I	S	Z	r	J	R_b/t
in.			in.				in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	-
2.375	OD	x	0.188	WALL			1.999	1.52	1.29	0.778	0.655	0.901	0.776	1.54	5.8
2.375	OD	x	0.250	WALL			1.875	1.96	1.67	0.955	0.804	1.13	0.756	1.88	4.3
2.375	OD	x	0.375	WALL			1.625	2.77	2.36	1.22	1.03	1.52	0.719	2.36	2.7
2.375	OD	x	0.500	WALL			1.375	3.46	2.95	1.39	1.17	1.80	0.686	2.59	1.9
2.500	OD	x	0.125	WALL			2.250	1.10	0.933	0.659	0.528	0.706	0.841	1.32	9.5
2.500	OD	x	0.188	WALL			2.124	1.61	1.37	0.918	0.735	1.01	0.820	1.82	6.1
2.500	OD	x	0.250	WALL			2.000	2.08	1.77	1.13	0.906	1.27	0.800	2.24	4.5
2.500	OD	x	0.312	WALL			1.876	2.52	2.14	1.31	1.05	1.50	0.781	2.57	3.5
2.500	OD	x	0.375	WALL			1.750	2.94	2.50	1.46	1.17	1.71	0.763	2.83	2.8
2.500	OD	x	0.500	WALL			1.500	3.69	3.14	1.67	1.34	2.04	0.729	3.14	2.0
2.500	OD	x	0.625	WALL			1.250	4.33	3.68	1.80	1.44	2.28	0.699	3.24	1.5
2.500	OD	x	0.750	WALL			1.000	4.85	4.12	1.87	1.49	2.44	0.673	3.16	1.2
2.625	OD	x	0.250	WALL			2.125	2.19	1.87	1.33	1.01	1.42	0.844	2.63	4.8
2.750	OD	x	0.125	WALL			2.500	1.21	1.03	0.890	0.647	0.862	0.929	1.78	10.5
2.750	OD	x	0.188	WALL			2.374	1.78	1.51	1.25	0.908	1.24	0.908	2.48	6.8
2.750	OD	x	0.250	WALL			2.250	2.31	1.96	1.55	1.13	1.57	0.888	3.07	5.0
2.750	OD	x	0.312	WALL			2.126	2.81	2.39	1.80	1.31	1.86	0.869	3.55	3.9
2.750	OD	x	0.375	WALL			2.000	3.29	2.80	2.02	1.47	2.13	0.850	3.95	3.2
2.750	OD	x	0.500	WALL			1.750	4.16	3.53	2.35	1.71	2.57	0.815	4.47	2.3
2.750	OD	x	0.625	WALL			1.500	4.91	4.17	2.56	1.86	2.90	0.783	4.71	1.7
2.750	OD	x	0.750	WALL			1.250	5.54	4.71	2.69	1.95	3.14	0.755	4.71	1.3
2.875	OD	x	0.250	WALL			2.375	2.42	2.06	1.79	1.25	1.73	0.932	3.55	5.3
2.875	OD	x	0.500	WALL			1.875	4.39	3.73	2.75	1.91	2.86	0.858	5.26	2.4
3.000	OD	x	0.125	WALL			2.750	1.33	1.13	1.17	0.779	1.03	1.02	2.33	11.5
3.000	OD	x	0.188	WALL			2.624	1.95	1.66	1.65	1.10	1.49	0.996	3.28	7.5
3.000	OD	x	0.250	WALL			2.500	2.54	2.16	2.06	1.37	1.90	0.976	4.08	5.5
3.000	OD	x	0.375	WALL			2.250	3.64	3.09	2.72	1.81	2.60	0.938	5.33	3.5
3.000	OD	x	0.500	WALL			2.000	4.62	3.93	3.19	2.13	3.17	0.901	6.14	2.5
3.000	OD	x	0.625	WALL			1.750	5.48	4.66	3.52	2.34	3.61	0.868	6.58	1.9
3.000	OD	x	0.750	WALL			1.500	6.23	5.30	3.73	2.49	3.94	0.839	6.71	1.5
3.000	OD	x	1.000	WALL			1.000	7.39	6.28	3.93	2.62	4.33	0.791	6.28	1.0
3.250	OD	x	0.250	WALL			2.750	2.77	2.36	2.67	1.64	2.26	1.06	5.30	6.0
3.250	OD	x	0.375	WALL			2.500	3.98	3.39	3.56	2.19	3.12	1.03	7.00	3.8
3.250	OD	x	0.500	WALL			2.250	5.08	4.32	4.22	2.60	3.82	0.988	8.17	2.8

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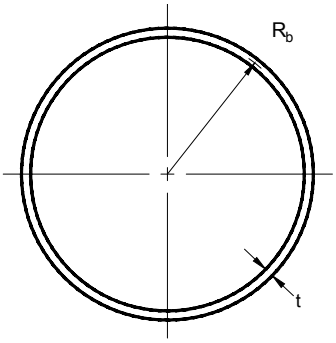
Table 16

ROUND TUBES (Continued)



Designation							ID	Weight	*A*	*I*	*S*	*Z*	*r*	*J*	R_b/t
in.			in.				in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	-
3.500	OD	x	0.125	WALL			3.250	1.56	1.33	1.89	1.08	1.42	1.19	3.77	13.5
3.500	OD	x	0.188	WALL			3.124	2.30	1.96	2.69	1.54	2.06	1.17	5.36	8.8
3.500	OD	x	0.250	WALL			3.000	3.00	2.55	3.39	1.94	2.65	1.15	6.74	6.5
3.500	OD	x	0.312	WALL			2.876	3.67	3.12	4.01	2.29	3.18	1.13	7.94	5.1
3.500	OD	x	0.375	WALL			2.750	4.33	3.68	4.56	2.61	3.68	1.11	8.99	4.2
3.500	OD	x	0.500	WALL			2.500	5.54	4.71	5.45	3.11	4.54	1.08	10.6	3.0
3.500	OD	x	0.750	WALL			2.000	7.62	6.48	6.58	3.76	5.81	1.01	12.3	1.8
3.750	OD	x	0.125	WALL			3.500	1.67	1.42	2.34	1.25	1.64	1.28	4.68	14.5
3.750	OD	x	0.188	WALL			3.374	2.47	2.10	3.35	1.78	2.39	1.26	6.67	9.5
3.750	OD	x	0.250	WALL			3.250	3.23	2.75	4.23	2.26	3.07	1.24	8.42	7.0
3.750	OD	x	0.375	WALL			3.000	4.68	3.98	5.73	3.06	4.29	1.20	11.3	4.5
3.750	OD	x	0.500	WALL			2.750	6.00	5.11	6.90	3.68	5.32	1.16	13.5	3.3
4.000	OD	x	0.125	WALL			3.750	1.79	1.52	2.86	1.43	1.88	1.37	5.71	15.5
4.000	OD	x	0.188	WALL			3.624	2.65	2.25	4.10	2.05	2.73	1.35	8.18	10.1
4.000	OD	x	0.250	WALL			3.500	3.46	2.95	5.20	2.60	3.52	1.33	10.4	7.5
4.000	OD	x	0.312	WALL			3.376	4.25	3.61	6.19	3.09	4.25	1.31	12.3	5.9
4.000	OD	x	0.375	WALL			3.250	5.02	4.27	7.09	3.54	4.95	1.29	14.0	4.8
4.000	OD	x	0.500	WALL			3.000	6.47	5.50	8.59	4.30	6.17	1.25	16.8	3.5
4.000	OD	x	0.625	WALL			2.750	7.79	6.63	9.76	4.88	7.20	1.21	18.9	2.7
4.000	OD	x	0.750	WALL			2.500	9.01	7.66	10.6	5.32	8.06	1.18	20.2	2.2
4.250	OD	x	0.125	WALL			4.000	1.90	1.62	3.45	1.62	2.13	1.46	6.89	16.5
4.250	OD	x	0.250	WALL			3.750	3.69	3.14	6.31	2.97	4.01	1.42	12.6	8.0
4.250	OD	x	0.375	WALL			3.500	5.37	4.57	8.65	4.07	5.65	1.38	17.1	5.2
4.250	OD	x	0.500	WALL			3.250	6.93	5.89	10.5	4.96	7.07	1.34	20.7	3.8
4.500	OD	x	0.125	WALL			4.250	2.02	1.72	4.11	1.83	2.39	1.55	8.22	17.5
4.500	OD	x	0.188	WALL			4.124	2.99	2.55	5.93	2.64	3.50	1.53	11.8	11.5
4.500	OD	x	0.250	WALL			4.000	3.93	3.34	7.56	3.36	4.52	1.51	15.1	8.5
4.500	OD	x	0.312	WALL			3.876	4.83	4.10	9.05	4.02	5.48	1.48	18.0	6.7
4.500	OD	x	0.375	WALL			3.750	5.71	4.86	10.4	4.63	6.40	1.46	20.7	5.5
4.500	OD	x	0.500	WALL			3.500	7.39	6.28	12.8	5.67	8.04	1.43	25.1	4.0
4.500	OD	x	0.625	WALL			3.250	8.95	7.61	14.7	6.51	9.47	1.39	28.6	3.1
4.500	OD	x	0.750	WALL			3.000	10.4	8.84	16.2	7.18	10.7	1.35	31.1	2.5
4.500	OD	x	1.000	WALL			2.500	12.9	11.0	18.2	8.09	12.6	1.29	33.7	1.8

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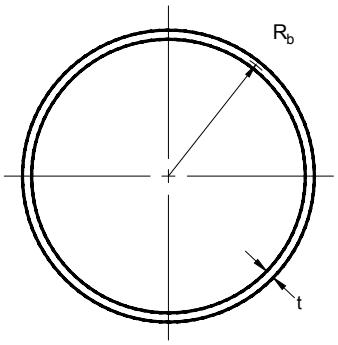
Table 16

ROUND TUBES (Continued)



Designation														ID	Weight	A	I	S	Z	r	J	R_b/t
in.			in.											in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	-
4.750	OD	x	0.125	WALL										4.500	2.14	1.82	4.86	2.05	2.67	1.64	9.71	18.5
4.750	OD	x	0.188	WALL										4.374	3.17	2.69	7.02	2.96	3.91	1.61	14.0	12.1
4.750	OD	x	0.250	WALL										4.250	4.16	3.53	8.97	3.78	5.07	1.59	17.9	9.0
4.750	OD	x	0.375	WALL										4.000	6.06	5.15	12.4	5.23	7.20	1.55	24.7	5.8
4.750	OD	x	0.500	WALL										3.750	7.85	6.68	15.3	6.43	9.07	1.51	30.1	4.3
5.000	OD	x	0.125	WALL										4.750	2.25	1.91	5.69	2.28	2.97	1.72	11.4	19.5
5.000	OD	x	0.188	WALL										4.624	3.34	2.84	8.24	3.30	4.36	1.70	16.5	12.8
5.000	OD	x	0.250	WALL										4.500	4.39	3.73	10.6	4.22	5.65	1.68	21.0	9.5
5.000	OD	x	0.312	WALL										4.376	5.40	4.60	12.7	5.07	6.87	1.66	25.2	7.5
5.000	OD	x	0.375	WALL										4.250	6.41	5.45	14.7	5.87	8.04	1.64	29.1	6.2
5.000	OD	x	0.500	WALL										4.000	8.31	7.07	18.1	7.25	10.2	1.60	35.8	4.5
5.000	OD	x	0.625	WALL										3.750	10.1	8.59	21.0	8.39	12.0	1.56	41.1	3.5
5.000	OD	x	0.750	WALL										3.500	11.8	10.0	23.3	9.33	13.7	1.53	45.2	2.8
5.000	OD	x	1.000	WALL										3.000	14.8	12.6	26.7	10.7	16.3	1.46	50.3	2.0
5.500	OD	x	0.125	WALL										5.250	2.48	2.11	7.63	2.77	3.61	1.90	15.2	21.5
5.500	OD	x	0.188	WALL										5.124	3.69	3.14	11.1	4.03	5.31	1.88	22.1	14.1
5.500	OD	x	0.250	WALL										5.000	4.85	4.12	14.2	5.18	6.90	1.86	28.4	10.5
5.500	OD	x	0.375	WALL										4.750	7.10	6.04	19.9	7.25	9.87	1.82	39.6	6.8
5.500	OD	x	0.500	WALL										4.500	9.24	7.85	24.8	9.01	12.5	1.78	49.1	5.0
5.500	OD	x	0.750	WALL										4.000	13.2	11.2	32.4	11.8	17.1	1.70	63.1	3.2
5.500	OD	x	1.000	WALL										3.500	16.6	14.1	37.6	13.7	20.6	1.63	71.6	2.3
6.000	OD	x	0.125	WALL										5.750	2.71	2.31	9.96	3.32	4.32	2.08	19.9	23.5
6.000	OD	x	0.188	WALL										5.624	4.04	3.43	14.5	4.84	6.35	2.06	29.0	15.5
6.000	OD	x	0.250	WALL										5.500	5.31	4.52	18.7	6.23	8.27	2.03	37.3	11.5
6.000	OD	x	0.312	WALL										5.376	6.56	5.58	22.6	7.54	10.1	2.01	45.1	9.1
6.000	OD	x	0.375	WALL										5.250	7.79	6.63	26.3	8.78	11.9	1.99	52.4	7.5
6.000	OD	x	0.500	WALL										5.000	10.2	8.64	32.9	11.0	15.2	1.95	65.3	5.5
6.000	OD	x	0.625	WALL										4.750	12.4	10.6	38.6	12.9	18.1	1.91	76.2	4.3
6.000	OD	x	0.750	WALL										4.500	14.5	12.4	43.5	14.5	20.8	1.88	85.2	3.5
6.000	OD	x	1.000	WALL										4.000	18.5	15.7	51.1	17.0	25.3	1.80	98.2	2.5
6.500	OD	x	0.250	WALL										6.000	5.77	4.91	24.0	7.39	9.77	2.21	47.9	12.5
6.500	OD	x	0.375	WALL										5.750	8.49	7.22	34.0	10.5	14.1	2.17	67.7	8.2
6.500	OD	x	0.500	WALL										5.500	11.1	9.42	42.7	13.1	18.0	2.13	84.8	6.0
6.500	OD	x	0.750	WALL										5.000	15.9	13.5	56.9	17.5	24.9	2.05	112	3.8

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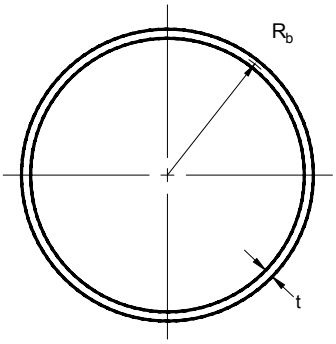
Table 16

ROUND TUBES (Continued)



Designation					ID	Weight	*A*	*I*	*S*	*Z*	*r*	*J*	R_b/t
in.			in.		in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	-
6.750	OD	x	0.500	WALL	5.750	11.5	9.82	48.2	14.3	19.6	2.22	95.9	6.3
6.750	OD	x	0.750	WALL	5.250	16.6	14.1	64.6	19.1	27.1	2.14	127	4.0
7.000	OD	x	0.250	WALL	6.500	6.23	5.30	30.2	8.64	11.4	2.39	60.4	13.5
7.000	OD	x	0.375	WALL	6.250	9.18	7.80	43.0	12.3	16.5	2.35	85.6	8.8
7.000	OD	x	0.500	WALL	6.000	12.0	10.2	54.2	15.5	21.2	2.30	108	6.5
7.000	OD	x	0.750	WALL	5.500	17.3	14.7	72.9	20.8	29.4	2.23	144	4.2
7.000	OD	x	1.000	WALL	5.000	22.2	18.8	87.2	24.9	36.3	2.15	170	3.0
7.500	OD	x	0.250	WALL	7.000	6.70	5.69	37.5	9.99	13.1	2.56	74.8	14.5
7.500	OD	x	0.375	WALL	6.750	9.87	8.39	53.4	14.2	19.1	2.52	107	9.5
7.500	OD	x	0.500	WALL	6.500	12.9	11.0	67.7	18.1	24.5	2.48	135	7.0
8.000	OD	x	0.125	WALL	7.750	3.64	3.09	24.0	5.99	7.75	2.78	47.9	31.5
8.000	OD	x	0.250	WALL	7.500	7.16	6.09	45.7	11.4	15.0	2.74	91.4	15.5
8.000	OD	x	0.375	WALL	7.250	10.6	8.98	65.4	16.4	21.8	2.70	131	10.2
8.000	OD	x	0.500	WALL	7.000	13.9	11.8	83.2	20.8	28.2	2.66	166	7.5
8.000	OD	x	0.625	WALL	6.750	17.0	14.5	99.2	24.8	34.1	2.62	197	5.9
8.000	OD	x	0.750	WALL	6.500	20.1	17.1	113	28.4	39.6	2.58	224	4.8
8.000	OD	x	1.000	WALL	6.000	25.9	22.0	137	34.4	49.3	2.50	269	3.5
8.500	OD	x	0.250	WALL	8.000	7.62	6.48	55.2	13.0	17.0	2.92	110	16.5
9.000	OD	x	0.250	WALL	8.500	8.08	6.87	65.8	14.6	19.1	3.09	132	17.5
9.000	OD	x	0.375	WALL	8.250	11.9	10.2	94.7	21.0	27.9	3.05	189	11.5
9.000	OD	x	0.500	WALL	8.000	15.7	13.4	121	26.9	36.2	3.01	241	8.5
10.000	OD	x	0.250	WALL	9.500	9.01	7.66	91.1	18.2	23.8	3.45	182	19.5
10.000	OD	x	0.375	WALL	9.250	13.3	11.3	132	26.3	34.8	3.41	263	12.8
10.000	OD	x	0.500	WALL	9.000	17.5	14.9	169	33.8	45.2	3.36	337	9.5
10.000	OD	x	0.625	WALL	8.750	21.6	18.4	203	40.6	55.0	3.32	404	7.5
10.000	OD	x	0.750	WALL	8.500	25.6	21.8	235	46.9	64.3	3.28	466	6.2
10.000	OD	x	1.000	WALL	8.000	33.3	28.3	290	58.0	81.3	3.20	573	4.5
10.500	OD	x	0.250	WALL	10.000	9.47	8.05	106	20.1	26.3	3.63	211	20.5
10.500	OD	x	0.375	WALL	9.750	14.0	11.9	153	29.2	38.5	3.58	306	13.5
10.500	OD	x	0.500	WALL	9.500	18.5	15.7	197	37.5	50.0	3.54	393	10.0
10.500	OD	x	0.750	WALL	9.000	27.0	23.0	275	52.3	71.4	3.46	546	6.5

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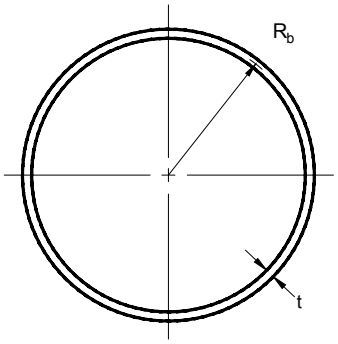
Table 16

ROUND TUBES (Continued)



Designation in.					ID in.	Weight lb/ft	*A* in^2	*I* in^4	*S* in^3	*Z* in^3	*r* in.	*J* in^4	R_b/t -
11.000	OD	x	0.375	WALL	10.250	14.7	12.5	177	32.2	42.4	3.76	353	14.2
11.000	OD	x	0.500	WALL	10.000	19.4	16.5	228	41.4	55.2	3.72	455	10.5
11.000	OD	x	0.750	WALL	9.500	28.4	24.2	319	58.0	78.9	3.63	634	6.8
11.000	OD	x	1.000	WALL	9.000	36.9	31.4	397	72.1	100	3.55	785	5.0
12.000	OD	x	0.250	WALL	11.500	10.9	9.23	159	26.6	34.5	4.16	319	23.5
12.000	OD	x	0.375	WALL	11.250	16.1	13.7	232	38.6	50.7	4.11	463	15.5
12.000	OD	x	0.500	WALL	11.000	21.2	18.1	299	49.9	66.2	4.07	597	11.5
12.000	OD	x	0.750	WALL	10.500	31.2	26.5	421	70.2	95.1	3.99	839	7.5
12.000	OD	x	1.000	WALL	10.000	40.6	34.6	527	87.8	121	3.91	1045	5.5

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.
4. Tube is produced by several methods. Seamless tube is usually required for applications with internal pressure.

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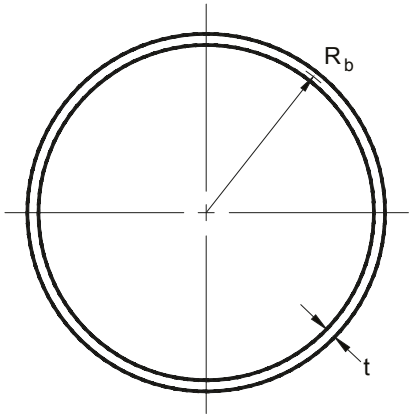
Table 17

PIPES



Nominal Pipe Size	Sched. No.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Area A in^2	Weight lb/ft	I in^4	S in^3	Z in^3	r in.	J in^4	R_b/t -
1/8	40	0.405	0.269	0.068	0.0720	0.085	0.0011	0.0053	0.00783	0.122	0.00204	2.48
	80	0.405	0.215	0.095	0.0925	0.109	0.0012	0.0060	0.00942	0.115	0.00222	1.63
1/4	40	0.540	0.364	0.088	0.125	0.147	0.0033	0.012	0.0182	0.163	0.00638	2.57
	80	0.540	0.302	0.119	0.157	0.185	0.0038	0.014	0.0217	0.155	0.00697	1.77
3/8	40	0.675	0.493	0.091	0.167	0.196	0.0073	0.022	0.0313	0.209	0.0142	3.21
	80	0.675	0.423	0.126	0.217	0.256	0.0086	0.026	0.0386	0.199	0.0164	2.18
1/2	5	0.840	0.710	0.065	0.158	0.186	0.012	0.028	0.0391	0.275	0.0238	5.96
	10	0.840	0.674	0.083	0.197	0.232	0.014	0.034	0.0478	0.269	0.0283	4.56
	40	0.840	0.622	0.109	0.250	0.294	0.017	0.041	0.0587	0.261	0.0334	3.35
	80	0.840	0.546	0.147	0.320	0.376	0.020	0.048	0.0717	0.250	0.0384	2.36
	160	0.840	0.464	0.188	0.385	0.453	0.022	0.053	0.0821	0.240	0.0409	1.73
3/4	5	1.050	0.920	0.065	0.201	0.237	0.025	0.047	0.0632	0.349	0.0488	7.58
	10	1.050	0.884	0.083	0.252	0.297	0.030	0.057	0.0778	0.343	0.0589	5.83
	40	1.050	0.824	0.113	0.333	0.391	0.037	0.071	0.0997	0.334	0.0730	4.15
	80	1.050	0.742	0.154	0.433	0.51 0	0.045	0.085	0.125	0.321	0.0870	2.91
	160	1.050	0.612	0.219	0.572	0.672	0.053	0.101	0.155	0.304	0.0987	1.90
1	5	1.315	1.185	0.065	0.255	0.300	0.050	0.076	0.102	0.443	0.100	9.62
	10	1.315	1.097	0.109	0.413	0.486	0.076	0.115	0.159	0.428	0.150	5.53
	40	1.315	1.049	0.133	0.494	0.581	0.087	0.133	0.187	0.421	0.173	4.44
	80	1.315	0.957	0.179	0.639	0.751	0.106	0.161	0.233	0.407	0.206	3.17
	160	1.315	0.815	0.250	0.836	0.984	0.125	0.190	0.289	0.387	0.237	2.13
1 1/4	5	1.660	1.530	0.065	0.326	0.383	0.104	0.125	0.165	0.564	0.207	12.3
	10	1.660	1.442	0.109	0.531	0.625	0.160	0.193	0.263	0.550	0.319	7.11
	40	1.660	1.380	0.140	0.669	0.786	0.195	0.235	0.324	0.540	0.386	5.43
	80	1.660	1.278	0.191	0.881	1.04	0.242	0.291	0.414	0.524	0.476	3.85
	160	1.660	1.160	0.250	1.11	1.30	0.284	0.342	0.502	0.506	0.550	2.82
1 1/2	5	1.900	1.770	0.065	0.375	0.441	0.158	0.166	0.219	0.649	0.315	14.1
	10	1.900	1.682	0.109	0.613	0.721	0.247	0.260	0.350	0.634	0.492	8.2
	40	1.900	1.610	0.145	0.799	0.940	0.310	0.326	0.448	0.623	0.616	6.1
	80	1.900	1.500	0.200	1.07	1.26	0.391	0.412	0.581	0.605	0.772	4.3
	160	1.900	1.338	0.281	1.43	1.68	0.482	0.508	0.744	0.581	0.937	2.9

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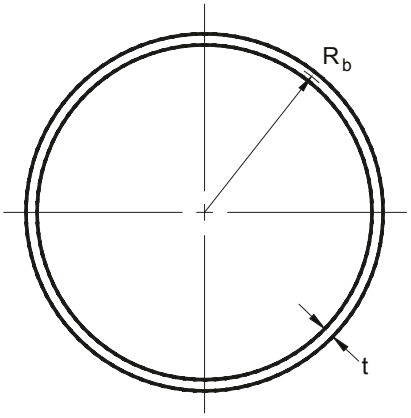
Table 17

PIPES (Continued)



Nominal Pipe Size	Sched. No.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Area A in^2	Weight lb/ft	I in^4	S in^3	Z in^3	r in.	J in^4	R_b/t -
2	5	2.375	2.245	0.065	0.472	0.555	0.315	0.265	0.347	0.817	0.629	17.8
	10	2.375	2.157	0.109	0.776	0.913	0.499	0.420	0.560	0.802	1.00	10.4
	40	2.375	2.067	0.154	1.07	1.26	0.666	0.561	0.761	0.787	1.33	7.2
	80	2.375	1.939	0.218	1.48	1.74	0.868	0.731	1.02	0.766	1.72	4.9
	160	2.375	1.687	0.344	2.19	2.58	1.16	0.980	1.43	0.728	2.26	3.0
2 1/2	5	2.875	2.709	0.083	0.728	0.856	0.710	0.494	0.647	0.988	1.42	16.8
	10	2.875	2.635	0.120	1.04	1.22	0.987	0.687	0.911	0.975	1.97	11.5
	40	2.875	2.469	0.203	1.70	2.00	1.53	1.06	1.45	0.947	3.04	6.6
	80	2.875	2.323	0.276	2.25	2.65	1.92	1.34	1.87	0.924	3.81	4.7
	160	2.875	2.125	0.375	2.95	3.46	2.35	1.64	2.36	0.894	4.60	3.3
3	5	3.500	3.334	0.083	0.891	1.05	1.30	0.744	0.969	1.21	2.60	20.6
	10	3.500	3.260	0.120	1.27	1.50	1.82	1.04	1.37	1.20	3.64	14.1
	40	3.500	3.068	0.216	2.23	2.62	3.02	1.72	2.33	1.16	6.01	7.6
	80	3.500	2.900	0.300	3.02	3.55	3.89	2.23	3.08	1.14	7.72	5.3
	160	3.500	2.624	0.438	4.21	4.95	5.04	2.88	4.13	1.09	9.88	3.5
3 1/2	5	4.000	3.834	0.083	1.02	1.20	1.96	0.98	1.27	1.39	3.92	23.6
	10	4.000	3.760	0.120	1.46	1.72	2.76	1.38	1.81	1.37	5.51	16.2
	40	4.000	3.548	0.226	2.68	3.15	4.79	2.39	3.22	1.34	9.54	8.3
	80	4.000	3.364	0.318	3.68	4.33	6.28	3.14	4.32	1.31	12.5	5.8
4	5	4.500	4.334	0.083	1.15	1.35	2.81	1.25	1.62	1.56	5.62	26.6
	10	4.500	4.260	0.120	1.65	1.94	3.96	1.76	2.30	1.55	7.92	18.3
	40	4.500	4.026	0.237	3.17	3.73	7.23	3.21	4.31	1.51	14.4	9.0
	80	4.500	3.826	0.337	4.41	5.18	9.61	4.27	5.85	1.48	19.1	6.2
	120	4.500	3.624	0.438	5.59	6.57	11.7	5.18	7.25	1.44	23.1	4.6
	160	4.500	3.438	0.531	6.62	7.79	13.3	5.90	8.41	1.42	26.1	3.7
5	5	5.563	5.345	0.109	1.87	2.20	6.95	2.50	3.24	1.93	13.9	25.0
	10	5.563	5.295	0.134	2.29	2.69	8.43	3.03	3.95	1.92	16.8	20.3
	40	5.563	5.047	0.258	4.30	5.06	15.2	5.45	7.27	1.88	30.3	10.3
	80	5.563	4.813	0.375	6.11	7.19	20.7	7.43	10.1	1.84	41.1	6.9
	120	5.563	4.563	0.500	7.95	9.35	25.7	9.25	12.9	1.80	51.0	5.1
	160	5.563	4.313	0.625	9.70	11.4	30.0	10.8	15.3	1.76	59.1	4.0

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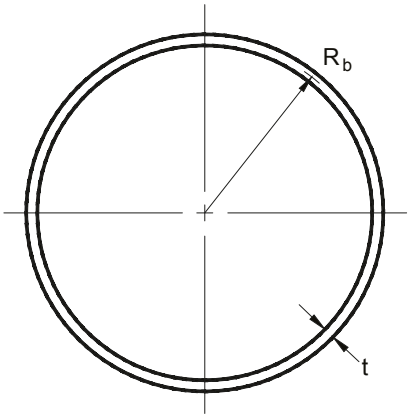
Table 17

PIPES (Continued)



Nominal Pipe Size	Sched. No.	Outside Diameter in.	Inside Diameter in.	Wall Thickness in.	Area A in^2	Weight lb/ft	I in^4	S in^3	Z in^3	r in.	J in^4	R_b/t -
6	5	6.625	6.407	0.109	2.23	2.62	11.8	3.58	4.63	2.30	23.7	29.9
	10	6.625	6.357	0.134	2.73	3.21	14.4	4.35	5.65	2.30	28.8	24.2
	40	6.625	6.065	0.280	5.58	6.56	28.1	8.50	11.3	2.25	56.2	11.3
	80	6.625	5.761	0.432	8.40	9.88	40.5	12.2	16.6	2.19	80.6	7.2
	120	6.625	5.501	0.562	10.7	12.6	49.6	15.0	20.7	2.15	98.4	5.4
	160	6.625	5.187	0.719	13.3	15.7	59.0	17.8	25.2	2.10	116	4.1
8	5	8.625	8.407	0.109	2.92	3.43	26.4	6.13	7.91	3.01	52.9	39.1
	10	8.625	8.329	0.148	3.94	4.64	35.4	8.21	10.6	3.00	70.8	28.6
	20	8.625	8.125	0.250	6.58	7.74	57.7	13.4	17.5	2.96	115	16.8
	30	8.625	8.071	0.277	7.26	8.54	63.4	14.7	19.3	2.95	127	15.1
	40	8.625	7.981	0.322	8.40	9.88	72.5	16.8	22.2	2.94	145	12.9
	60	8.625	7.813	0.406	10.5	12.3	88.7	20.6	27.4	2.91	177	10.1
	80	8.625	7.625	0.500	12.8	15.0	106	24.5	33.0	2.88	211	8.1
	100	8.625	7.437	0.594	15.0	17.6	121	28.2	38.4	2.85	242	6.8
	120	8.625	7.187	0.719	17.9	21.0	141	32.6	45.1	2.81	279	5.5
	140	8.625	7.001	0.812	19.9	23.4	154	35.6	49.7	2.78	304	4.8
	160	8.625	6.813	0.906	22.0	25.8	166	38.5	54.2	2.75	327	4.3
10	5	10.750	10.482	0.134	4.47	5.26	63.0	11.7	15.1	3.75	126	39.6
	10	10.750	10.420	0.165	5.49	6.45	76.9	14.3	18.5	3.74	154	32.1
	20	10.750	10.250	0.250	8.25	9.70	114	21.2	27.6	3.71	227	21.0
	30	10.750	10.136	0.307	10.1	11.8	137	25.6	33.5	3.69	275	17.0
	40	10.750	10.020	0.365	11.9	14.0	161	29.9	39.4	3.67	321	14.2
	60	10.750	9.750	0.500	16.1	18.9	212	39.4	52.6	3.63	423	10.3
	80	10.750	9.562	0.594	19.0	22.3	245	45.6	61.3	3.60	489	8.5
	100	10.750	9.312	0.719	22.7	26.6	286	53.3	72.5	3.56	570	7.0
12	5	12.750	12.438	0.156	6.17	7.26	122	19.2	24.7	4.45	245	40.4
	10	12.750	12.390	0.180	7.11	8.36	140	22.0	28.4	4.44	281	34.9
	20	12.750	12.250	0.250	9.82	11.5	192	30.1	39.1	4.42	383	25.0
	30	12.750	12.090	0.330	12.9	15.1	248	39.0	50.9	4.39	497	18.8
	40	12.750	11.938	0.406	15.7	18.5	300	47.1	61.9	4.37	600	15.2
	60	12.750	11.626	0.562	21.5	25.3	400	62.8	83.5	4.31	799	10.8
	80	12.750	11.374	0.688	26.1	30.7	476	74.6	100	4.27	948	8.8

1. Users are encouraged to check availability with suppliers, especially for shaded sizes.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.
4. Sizes are in accordance with ASME B36.10M and B36.19M

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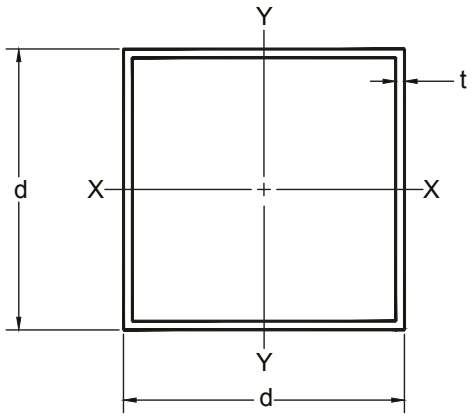
Table 18

SQUARE TUBES



Designation	*d*	*t*	Weight	*A*	I_x, I_y	S_x, S_y	r_x, r_y	*J*	Z_x, Z_y	*b*/*t*
	in.	in.	lb/ft	in^2	in^4	in^3	in.	in^4	in^3	-
RT 1 x 1 x 0.065	1.000	0.065	0.286	0.243	0.0356	0.0712	0.383	0.0531	0.0854	13.4
RT 1 x 1 x 0.095	1.000	0.095	0.404	0.344	0.0475	0.0949	0.371	0.0704	0.117	8.5
RT 1 x 1 x 0.125	1.000	0.125	0.515	0.438	0.0570	0.114	0.361	0.0837	0.145	6.0
RT 1.25 x 1.25 x 0.065	1.250	0.065	0.362	0.308	0.0723	0.116	0.485	0.108	0.137	17.2
RT 1.25 x 1.25 x 0.095	1.250	0.095	0.516	0.439	0.0982	0.157	0.473	0.146	0.191	11.2
RT 1.25 x 1.25 x 0.125	1.250	0.125	0.662	0.563	0.120	0.192	0.462	0.178	0.238	8.0
RT 1.375 x 1.375 x 0.125	1.375	0.125	0.735	0.625	0.164	0.239	0.513	0.244	0.294	9.0
RT 1.5 x 1.5 x 0.065	1.500	0.065	0.439	0.373	0.128	0.171	0.586	0.192	0.201	21.1
RT 1.5 x 1.5 x 0.078	1.500	0.078	0.522	0.444	0.150	0.200	0.581	0.224	0.237	17.2
RT 1.5 x 1.5 x 0.095	1.500	0.095	0.628	0.534	0.176	0.235	0.575	0.263	0.282	13.8
RT 1.5 x 1.5 x 0.125	1.500	0.125	0.809	0.688	0.218	0.291	0.564	0.325	0.355	10.0
RT 1.5 x 1.5 x 0.25	1.500	0.250	1.47	1.25	0.339	0.451	0.520	0.488	0.594	4.0
RT 1.75 x 1.75 x 0.125	1.750	0.125	0.956	0.813	0.360	0.411	0.665	0.536	0.496	12.0
RT 2 x 2 x 0.095	2.000	0.095	0.851	0.724	0.439	0.439	0.779	0.657	0.518	19.1
RT 2 x 2 x 0.125	2.000	0.125	1.10	0.938	0.552	0.552	0.767	0.824	0.660	14.0
RT 2 x 2 x 0.156	2.000	0.156	1.35	1.15	0.657	0.657	0.755	0.978	0.798	10.8
RT 2 x 2 x 0.188	2.000	0.188	1.60	1.36	0.754	0.754	0.744	1.12	0.929	8.6
RT 2 x 2 x 0.25	2.000	0.250	2.06	1.75	0.911	0.911	0.722	1.34	1.16	6.0
RT 2.25 x 2.25 x 0.125	2.250	0.125	1.25	1.06	0.802	0.713	0.869	1.20	0.848	16.0
RT 2.5 x 2.5 x 0.125	2.500	0.125	1.40	1.19	1.12	0.896	0.971	1.67	1.06	18.0
RT 2.5 x 2.5 x 0.188	2.500	0.188	2.04	1.74	1.56	1.25	0.947	2.32	1.51	11.3
RT 2.5 x 2.5 x 0.25	2.500	0.250	2.65	2.25	1.92	1.54	0.924	2.85	1.91	8.0

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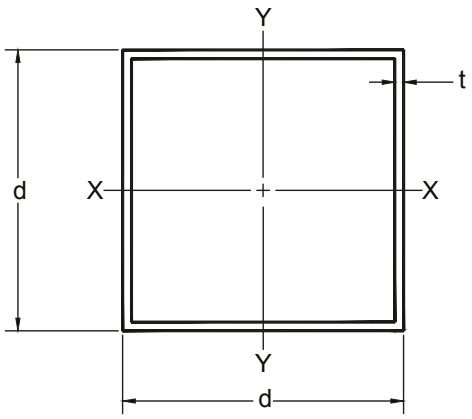
Table 18

SQUARE TUBES (Continued)



Designation	d	t	Weight	A	I_x, I_y	S_x, S_y	r_x, r_y	J	Z_x, Z_y	b/t
	in.	in.	lb/ft	in^2	in^4	in^3	in.	in^4	in^3	-
RT 2.75 x 2.75 x 0.125	2.750	0.125	1.54	1.31	1.51	1.10	1.07	2.26	1.29	20.0
RT 2.75 x 2.75 x 0.188	2.750	0.188	2.27	1.93	2.12	1.54	1.05	3.16	1.85	12.6
RT 3 x 3 x 0.095	3.000	0.095	1.30	1.10	1.55	1.04	1.19	2.33	1.20	29.6
RT 3 x 3 x 0.125	3.000	0.125	1.69	1.44	1.98	1.32	1.17	2.97	1.55	22.0
RT 3 x 3 x 0.188	3.000	0.188	2.49	2.11	2.80	1.87	1.15	4.18	2.23	14.0
RT 3 x 3 x 0.25	3.000	0.250	3.23	2.75	3.49	2.33	1.13	5.20	2.84	10.0
RT 3 x 3 x 0.375	3.000	0.375	4.63	3.94	4.61	3.08	1.08	6.78	3.90	6.0
RT 3.5 x 3.5 x 0.125	3.500	0.125	1.98	1.69	3.21	1.83	1.38	4.81	2.14	26.0
RT 3.5 x 3.5 x 0.25	3.500	0.250	3.82	3.25	5.76	3.29	1.33	8.58	3.97	12.0
RT 3.5 x 3.5 x 0.375	3.500	0.375	5.51	4.69	7.74	4.42	1.28	11.4	5.52	7.3
RT 4 x 4 x 0.125	4.000	0.125	2.28	1.94	4.85	2.43	1.58	7.27	2.82	30.0
RT 4 x 4 x 0.188	4.000	0.188	3.37	2.87	6.96	3.48	1.56	10.4	4.10	19.3
RT 4 x 4 x 0.25	4.000	0.250	4.41	3.75	8.83	4.41	1.53	13.2	5.28	14.0
RT 4 x 4 x 0.375	4.000	0.375	6.39	5.44	12.0	6.02	1.49	17.9	7.42	8.7
RT 4 x 4 x 0.5	4.000	0.500	8.23	7.00	14.6	7.29	1.44	21.4	9.25	6.0
RT 5 x 5 x 0.125	5.000	0.125	2.87	2.44	9.66	3.86	1.99	14.5	4.46	38.0
RT 5 x 5 x 0.188	5.000	0.188	4.26	3.62	14.0	5.59	1.97	20.9	6.53	24.6
RT 5 x 5 x 0.25	5.000	0.250	5.59	4.75	17.9	7.16	1.94	26.8	8.47	18.0
RT 5 x 5 x 0.375	5.000	0.375	8.16	6.94	24.9	9.96	1.89	37.1	12.1	11.3
RT 6 x 6 x 0.125	6.000	0.125	3.45	2.94	16.9	5.64	2.40	25.3	6.47	46.0
RT 6 x 6 x 0.188	6.000	0.188	5.14	4.37	24.6	8.21	2.37	36.9	9.53	29.9
RT 6 x 6 x 0.25	6.000	0.250	6.76	5.75	31.7	10.6	2.35	47.5	12.4	22.0
RT 6 x 6 x 0.375	6.000	0.375	9.92	8.44	44.7	14.9	2.30	66.7	17.8	14.0
RT 6 x 6 x 0.5	6.000	0.500	12.9	11.0	55.9	18.6	2.25	83.2	22.8	10.0
RT 8 x 8 x 0.188	8.000	0.188	6.91	5.87	59.8	14.9	3.19	89.6	17.2	40.6
RT 8 x 8 x 0.25	8.000	0.250	9.11	7.75	77.7	19.4	3.17	116	22.5	30.0
RT 8 x 8 x 0.375	8.000	0.375	13.5	11.4	111	27.8	3.12	166	32.7	19.3
RT 8 x 8 x 0.5	8.000	0.500	17.6	15.0	141	35.3	3.07	211	42.3	14.0

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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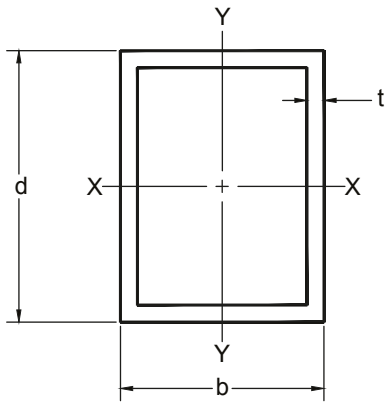
Table 19

RECTANGULAR TUBES



Designation	Depth	Width				Axis X-X				Axis Y-Y				
	d	b	t	Weight	A	I_x	S_x	Z_x	r_x	I_y	S_y	Z_y	r_y	J
RT d x b x t	in.	in.	in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	in^3	in^3	in.	in^4
RT 1 1/2 x 1 x 1/8	1.5	1	0.125	0.662	0.563	0.159	0.212	0.270	0.532	0.0811	0.162	0.199	0.380	0.161
RT 1 3/4 x 1 1/2 x 1/8	1.75	1.5	0.125	0.882	0.750	0.318	0.364	0.445	0.652	0.248	0.331	0.398	0.575	0.416
RT 2 x 1 x 1/8	2	1	0.125	0.809	0.688	0.332	0.332	0.426	0.695	0.105	0.210	0.254	0.391	0.245
RT 2 x 1 1/4 x 1/8	2	1.25	0.125	0.882	0.750	0.387	0.387	0.484	0.718	0.180	0.288	0.344	0.489	0.371
RT 2 x 1 1/2 x 1/8	2	1.5	0.125	0.956	0.813	0.442	0.442	0.543	0.737	0.278	0.370	0.441	0.585	0.511
RT 2 x 1 1/2 x 1/4	2	1.5	0.250	1.76	1.50	0.719	0.719	0.938	0.692	0.438	0.583	0.750	0.540	0.798
RT 2 x 1 3/4 x 1/8	2	1.75	0.125	1.03	0.875	0.497	0.497	0.602	0.753	0.401	0.458	0.547	0.677	0.663
RT 2 1/4 x 1 3/4 x 1/8	2.25	1.75	0.125	1.10	0.938	0.661	0.588	0.715	0.840	0.442	0.506	0.598	0.687	0.795
RT 2 1/2 x 1 x 1/8	2.5	1	0.125	0.956	0.813	0.590	0.472	0.613	0.852	0.129	0.258	0.309	0.399	0.332
RT 2 1/2 x 1 1/4 x 1/8	2.5	1.25	0.125	1.03	0.875	0.678	0.543	0.688	0.881	0.219	0.351	0.414	0.501	0.510
RT 2 1/2 x 1 1/2 x 1/8	2.5	1.5	0.125	1.10	0.938	0.767	0.613	0.762	0.904	0.337	0.449	0.527	0.599	0.711
RT 2 1/2 x 1 3/4 x 1/8	2.5	1.75	0.125	1.18	1.00	0.855	0.684	0.836	0.925	0.484	0.553	0.648	0.696	0.931
RT 2 3/4 x 1 3/4 x 1/8	2.75	1.75	0.125	1.25	1.06	1.08	0.785	0.965	1.01	0.525	0.6 00	0.699	0.703	1.07
RT 3 x 1 x 1/8	3	1	0.125	1.10	0.938	0.950	0.633	0.832	1.01	0.153	0.307	0.363	0.404	0.422
RT 3 x 1 1/4 x 1/8	3	1.25	0.125	1.18	1.00	1.08	0.720	0.922	1.04	0.259	0.415	0.484	0.509	0.654
RT 3 x 1 1/2 x 1/8	3	1.5	0.125	1.2 5	1.06	1.21	0.806	1.01	1.07	0.396	0.528	0.613	0.611	0.919
RT 3 x 1 1/2 x 3/16	3	1.5	0.188	1.82	1.55	1.68	1.12	1.44	1.04	0.533	0.711	0.859	0.586	1.24
RT 3 x 1 3/4 x 1/8	3	1.75	0.125	1.32	1.13	1.34	0.892	1.10	1.09	0.566	0.647	0.750	0.710	1.21
RT 3 x 2 x 1/8	3	2	0.125	1.40	1.19	1.47	0.978	1.19	1.11	0.772	0.77	0.895	0.806	1.53
RT 3 x 2 x 1/4	3	2	0.250	2.65	2.25	2.55	1.70	2.16	1.06	1.30	1.30	1.59	0.759	2.57
RT 3 1/2 x 1 3/4 x 1/8	3.5	1.75	0.125	1.47	1.25	1.96	1.12	1.40	1.25	0.649	0.742	0.8 52	0.721	1.50

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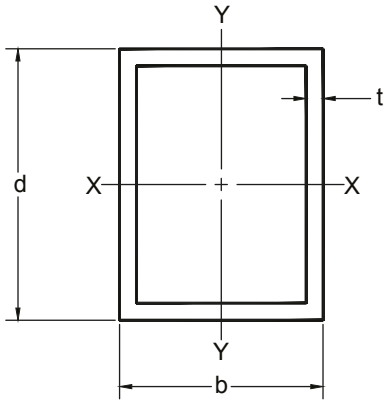
Table 19

RECTANGULAR TUBES (Continued)



Designation	Depth	Width				Axis X-X				Axis Y-Y				
	d	*b*	*t*	Weight	*A*	I_x	S_x	Z_x	r_x	I_y	S_y	Z_y	r_y	*J*
RT d x b x t	in.	in.	in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	in^3	in^3	in.	in^4
RT 4 x 1 x 1/8	4	1	0.125	1.40	1.19	2.04	1.02	1.36	1.31	0.201	0.403	0.473	0.412	0.605
RT 4 x 1 1/2 x 1/8	4	1.5	0.125	1.54	1.31	2.51	1.25	1.61	1.38	0.515	0.686	0.785	0.626	1.35
RT 4 x 1 3/4 x 1/8	4	1.75	0.125	1.62	1.38	2.74	1.37	1.73	1.41	0.732	0.836	0.953	0.730	1.80
RT 4 x 2 x 1/8	4	2	0.125	1.69	1.44	2.98	1.49	1.85	1.44	0.992	0.992	1.13	0.831	2.30
RT 4 x 2 x 3/16	4	2	0.188	2.49	2.11	4.23	2.11	2.67	1.41	1.37	1.37	1.61	0.806	3.19
RT 4 x 2 x 1/4	4	2	0.250	3.23	2.75	5.31	2.65	3.41	1.39	1.68	1.68	2.03	0.782	3.92
RT 4 x 2 1/2 x 1/8	4	2.5	0.125	1.84	1.56	3.45	1.72	2.09	1.48	1.65	1.32	1.50	1.03	3.39
RT 4 x 3 x 1/8	4	3	0.125	1.98	1.69	3.92	1.96	2.33	1.52	2.50	1.67	1.91	1.22	4.60
RT 4 x 3 x 3/16	4	3	0.188	2.93	2.49	5.59	2.80	3.38	1.50	3.54	2.36	2.76	1.19	6.52
RT 4 x 3 x 1/4	4	3	0.250	3.82	3.25	7.07	3.53	4.34	1.47	4.44	2.96	3.53	1.17	8.18
RT 4 x 3 x 3/8	4	3	0.375	5.51	4.69	9.56	4.78	6.06	1.43	5.92	3.94	4.89	1.12	10.9
RT 4 x 3 x 1/2	4	3	0.500	7.06	6.00	11.5	5.75	7.50	1.38	7.00	4.67	6.00	1.08	12.8
RT 4 1/2 x 1 3/4 x 1/8	4.5	1.75	0.125	1.76	1.50	3.69	1.64	2.09	1.57	0.814	0.931	1.05	0.737	2.11
RT 5 x 1 3/4 x 1/8	5	1.75	0.125	1.91	1.63	4.83	1.93	2.48	1.72	0.897	1.03	1.16	0.743	2.41
RT 5 x 1 3/4 x 3/16	5	1.75	0.188	2.82	2.40	6.91	2.76	3.59	1.70	1.23	1.41	1.65	0.717	3.33
RT 5 x 2 x 1/8	5	2	0.125	1.98	1.69	5.20	2.08	2.63	1.76	1.21	1.21	1.36	0.847	3.09
RT 5 x 2 x 3/16	5	2	0.188	2.93	2.49	7.45	2.98	3.82	1.73	1.68	1.68	1.95	0.822	4.32
RT 5 x 2 x 1/4	5	2	0.250	3.82	3.25	9.44	3.78	4.91	1.70	2.07	2.07	2.47	0.798	5.32
RT 5 x 2 1/2 x 1/8	5	2.5	0.125	2.13	1.81	5.95	2.38	2.93	1.81	2.00	1.60	1.80	1.05	4.62
RT 5 x 3 x 1/8	5	3	0.125	2.28	1.94	6.69	2.68	3.24	1.86	3.02	2.01	2.27	1.25	6.34
RT 5 x 3 x 3/16	5	3	0.188	3.37	2.87	9.63	3.85	4.72	1.83	4.29	2.86	3.29	1.22	9.03
RT 5 x 3 x 1/4	5	3	0.250	4.41	3.75	12.3	4.91	6.09	1.81	5.39	3.59	4.22	1.20	11.4
RT 5 x 4 x 1/4	5	4	0.250	5.00	4.25	15.1	6.04	7.28	1.88	10.6	5.29	6.22	1.58	18.7
RT 6 x 1 1/2 x 1/8	6	1.5	0.125	2.13	1.81	7.20	2.40	3.17	1.99	0.752	1.00	1.13	0.644	2.25
RT 6 x 1 3/4 x 1/8	6	1.75	0.125	2.21	1.88	7.74	2.58	3.35	2.03	1.06	1.21	1.36	0.753	3.04
RT 6 x 2 x 1/8	6	2	0.125	2.28	1.94	8.28	2.76	3.54	2.07	1.43	1.43	1.60	0.860	3.91
RT 6 x 2 x 3/16	6	2	0.188	3.37	2.87	11.9	3.98	5.16	2.04	1.99	1.99	2.29	0.834	5.47
RT 6 x 2 x 1/4	6	2	0.250	4.41	3.75	15.2	5.07	6.66	2.01	2.45	2.45	2.91	0.809	6.75
RT 6 x 3 x 1/8	6	3	0.125	2.57	2.19	10.4	3.48	4.27	2.18	3.53	2.36	2.63	1.27	8.15

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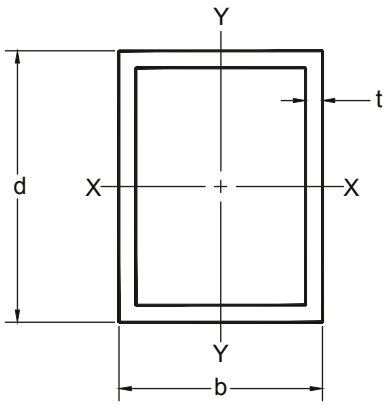
Table 19

RECTANGULAR TUBES (Continued)



Designation	Depth	Width				Axis X-X				Axis Y-Y				
	d	*b*	*t*	Weight	*A*	I_x	S_x	Z_x	r_x	I_y	S_y	Z_y	r_y	*J*
RT d x b x t	in.	in.	in.	lb/ft	in^2	in^4	in^3	in^3	in.	in^4	in^3	in^3	in.	in^4
RT 6 x 3 x 3/16	6	3	0.188	3.81	3.24	15.1	5.03	6.25	2.16	5.03	3.35	3.82	1.25	11.6
RT 6 x 4 x 1/8	6	4	0.125	2.87	2.44	12.6	4.20	5.00	2.27	6.73	3.37	3.79	1.66	13.3
RT 6 x 4 x 3/16	6	4	0.188	4.26	3.62	18.3	6.09	7.34	2.25	9.69	4.85	5.53	1.64	19.2
RT 6 x 4 x 1/4	6	4	0.250	5.59	4.75	23.5	7.82	9.53	2.22	12.3	6.17	7.16	1.61	24.5
RT 6 x 4 x 1/2	6	4	0.500	10.6	9.00	40.8	13.6	17.3	2.13	20.8	10.4	12.8	1.52	41.2
RT 8 x 2 x 1/8	8	2	0.125	2.87	2.44	17.5	4.36	5.72	2.68	1.87	1.87	2.07	0.876	5.59
RT 8 x 3 x 1/4	8	3	0.250	6.17	5.25	40.1	10.0	12.8	2.76	8.23	5.49	6.28	1.25	21.6
RT 8 x 4 x 3/16	8	4	0.188	5.14	4.37	36.8	9.21	11.3	2.90	12.4	6.21	6.97	1.69	28.7
RT 8 x 4 x 1/4	8	4	0.250	6.76	5.75	47.6	11.9	14.8	2.88	15.9	7.93	9.03	1.66	36.7
RT 8 x 4 x 3/8	8	4	0.375	9.92	8.44	67.5	16.9	21.3	2.83	21.9	11.0	12.9	1.61	50.9
RT 8 x 4 x 1/2	8	4	0.500	12.9	11.0	84.9	21.2	27.3	2.78	26.9	13.5	16.3	1.56	62.6
RT 8 x 5 x 3/8	8	5	0.375	10.8	9.19	78.4	19.6	24.2	2.92	37.0	14.8	17.3	2.01	76.1

1. Users are encouraged to check availability with suppliers.
2. Dimensional tolerances are given in *Aluminum Standards and Data*.
3. Weights are for a density of 0.098 lb/in^3.

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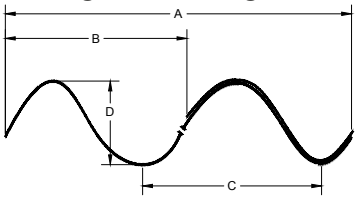
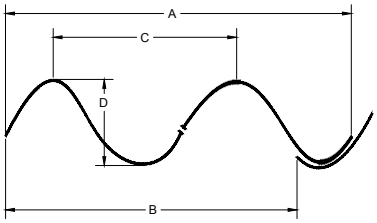
Table 20

ROOFING AND SIDING – DIMENSIONS AND WEIGHTS

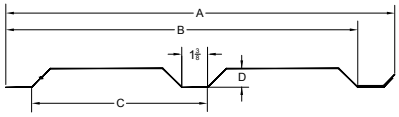
Corrugated Roofing



Corrugated Siding

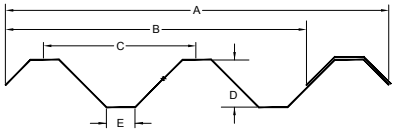


Ribbed Siding



Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[2] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Weight Per 100 Sq Ft[4] lb
	A	B	C	D	
0.024	35	32	2⅔	⅞	41
0.024	48⅓	45⅓	2⅔	⅞	41
0.032	35	32	2⅔	⅞	55
0.032	48⅓	45⅓	2⅔	⅞	55
0.032	48⅜	45⅜	2⅔	⅞	55
0.040	48⅓	45⅓	2⅔	⅞	69
0.024	33¾	32	2⅔	⅞	41
0.024	47	45⅓	2⅔	⅞	41
0.032	33¾	32	2⅔	⅞	55
0.032	47	45⅓	2⅔	⅞	55
0.032	47⅛	45⅜	2⅔	⅞	55
0.032	41⅝	40 (see note 6)	4	1	58
0.032	41⅝	40 (see note 6)	8	1	52
0.040	41⅝	40 (see note 6)	4	1	73
0.040	41⅝	40 (see note 6)	8	1	65

V-Beam Roofing and Siding



Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[5] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Width of Crown and Valley in.	Nominal Weight Per 100 Sq Ft[4] lb
	A	B	C	D	W	
0.032	41⅝	39	4⅞	1¾	¾	58
0.032	45	42⅔	5⅓	1¾	1⅛	58
0.040	41⅝	39	4⅞	1¾	¾	73
0.040	45	42⅔	5⅓	1¾	1⅛	73
0.050	41⅝	39	4⅞	1¾	¾	91
0.050	45	42⅔	5⅓	1¾	1⅛	91

[1] Applicable to flat sheet prior to corrugating or embossing.
[2] Based on 1½ corrugations side lap.
[3] As measured between the outside surfaces of adjacent corrugations.
[4] Based on over-all width of formed sheet.
[5] Based on one corrugation side lap.
[6] Based on side lap of 1⅝ in.

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Table 21

ROOFING AND SIDING – SECTION PROPERTIES

	Thickness, in.	Weight, lb/ft^2	Area, in.^{2} per ft of width	Moment of Inertia, in.^{4} per ft of width	Minimum Section Modulus, in.^{3} per ft of width	Maximum Section Modulus, in.^{3} per ft of width	Radius of Gyration, in.
Corrugated Roofing and Siding	0.024	0.414	0.352	0.0307	0.0708	0.0708	0.295
	0.032	0.552	0.469	0.0409	0.0936	0.0936	0.295
	0.040	0.689	0.586	0.0512	0.116	0.116	0.295
Ribbed Siding, 4” Pitch	0.032	0.585	0.497	0.0836	0.160	0.175	0.410
	0.040	0.730	0.621	0.104	0.198	0.217	0.410
Ribbed Siding, 8” Pitch	0.032	0.518	0.441	0.0648	0.0895	0.235	0.383
	0.040	0.648	0.551	0.0810	0.111	0.289	0.383
V-Beam Roofing and Siding, 4⅞” Pitch	0.032	0.584	0.497	0.179	0.205	0.205	0.600
	0.040	0.730	0.621	0.223	0.255	0.255	0.600
	0.050	0.913	0.776	0.279	0.317	0.317	0.600
V-Beam Roofing and Siding, 5⅓” Pitch	0.032	0.581	0.494	0.199	0.229	0.229	0.635
	0.040	0.726	0.617	0.249	0.285	0.285	0.635
	0.050	0.907	0.771	0.311	0.354	0.354	0.635

*Calculated on basis of nominal dimensions (See Table 20)

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Table 22

DECIMAL EQUIVALENTS IN INCHES OF SHEET METAL

Gage	Aluminum		Steel		Galvanized Steel		Stainless Steel	
	American Wire Gage (AWG) ASTM B258		US Standard Gage for Uncoated Hot- & Cold-Rolled Sheets		Galvanized Sheet Gage for Hot-Dipped Zinc Coated Sheets			
	thickness in.	weight lb/ft^2	thickness in.	weight lb/ft^2	thickness in.	weight lb/ft^2	thickness in.	weight lb/ft^2
30	0.0100	0.141	0.0120	0.500	0.0157	0.656	0.0125	
29	0.0113	0.160	0.0135	0.563	0.0172	0.719	0.0141	
28	0.0126	0.178	0.0149	0.625	0.0187	0.781	0.0156	
27	0.0142	0.200	0.0164	0.688	0.0202	0.844	0.0172	
26	0.0159	0.224	0.0179	0.750	0.0217	0.906	0.0187	0.756
25	0.0179	0.253	0.0209	0.875	0.0247	1.031	0.0219	
24	0.0201	0.284	0.0239	1.000	0.0276	1.156	0.0250	1.008
23	0.0226	0.319	0.0269	1.125	0.0306	1.281	0.0281	
22	0.0253	0.357	0.0299	1.250	0.0336	1.406	0.0312	1.26
21	0.0285	0.402	0.0329	1.375	0.0366	1.531	0.0344	
20	0.0320	0.452	0.0359	1.500	0.0396	1.656	0.0375	1.512
19	0.0359	0.507	0.0418	1.750	0.0456	1.906	0.0437	
18	0.0403	0.569	0.0478	2.000	0.0516	2.156	0.0500	2.016
17	0.0453	0.639	0.0538	2.250	0.0575	2.406	0.0562	
16	0.0508	0.717	0.0598	2.500	0.0635	2.656	0.0625	2.52
15	0.0571	0.806	0.0673	2.813	0.0710	2.969	0.0703	
14	0.0641	0.905	0.0747	3.125	0.0785	3.281	0.0781	3.15
13	0.0720	1.016	0.0897	3.750	0.0934	3.906	0.0937	
12	0.0808	1.140	0.1046	4.375	0.1084	4.531	0.1094	4.41
11	0.0907	1.280	0.1196	5.000	0.1233	5.156	0.1250	5.04
10	0.1019	1.438	0.1345	5.625	0.1382	5.781	0.1406	5.67
9	0.1144	1.614	0.1495	6.250	0.1532	6.406	0.1562	
8	0.1285	1.813	0.1644	6.875	0.1681	7.031	0.1719	6.93
7	0.1443	2.036	0.1793	7.500			0.1875	7.871
6	0.1620	2.286	0.1943	8.125			0.2031	
5			0.2092	8.750			0.2187	
4			0.2242	9.375			0.2187	
3			0.2391	10.00			0.2344	

Thicknesses are shown for information only. Sheet is specified by thickness rather than gage number.

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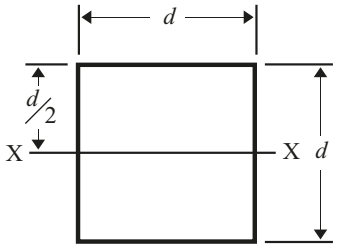
Table 23

GEOMETRIC SHAPES

SQUARE



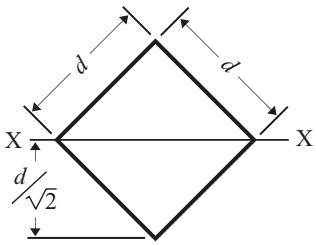
$$A = d^2$$

$$I = \frac{d^4}{12}$$

$$S = \frac{d^3}{6}$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

SQUARE



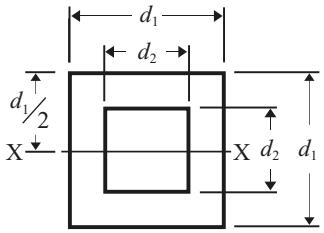
$$A = d^2$$

$$I = \frac{d^4}{12}$$

$$S = \frac{\sqrt{2}d^3}{12} = 0.1179d^3$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

HOLLOW SQUARE



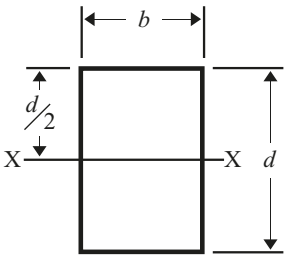
$$A = d_1^2 - d_2^2$$

$$I = \frac{d_1^4 - d_2^4}{12}$$

$$S = \frac{d_1^4 - d_2^4}{6d_1}$$

$$r = \sqrt{\frac{d_1^2 + d_2^2}{12}}$$

RECTANGLE



$$A = bd$$

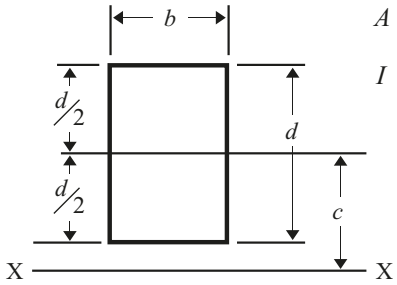
$$I = \frac{bd^3}{12}$$

$$S = \frac{bd^2}{6}$$

$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

$$Z = \frac{bd^2}{4}$$

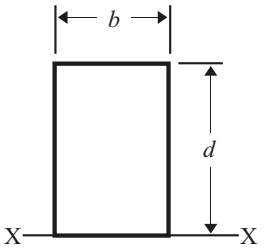
RECTANGLE



$$A = bd$$

$$I = A\left(\frac{d^2}{12} + c^2\right)$$

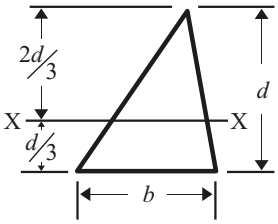
RECTANGLE



$$A = bd$$

$$I = \frac{bd^3}{3}$$

TRIANGLE

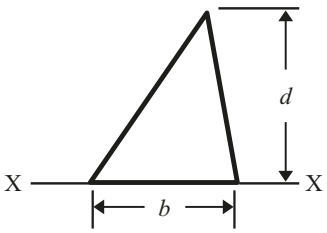


$$A = \frac{bd}{2}$$

$$I = \frac{bd^3}{36}$$

$$r = \frac{d}{\sqrt{18}} = 0.2357d$$

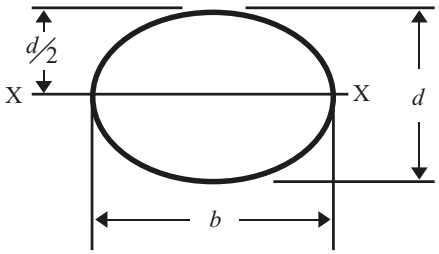
TRIANGLE



$$A = \frac{bd}{2}$$

$$I = \frac{bd^3}{12}$$

ELLIPSE



$$A = \frac{\pi bd}{4}$$

$$I = \frac{\pi bd^3}{64}$$

$$S = \frac{\pi bd^2}{32}$$

$$r = \frac{d}{4}$$

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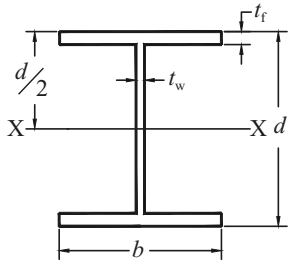
Table 23

GEOMETRIC SHAPES (CONTINUED)

I-BEAM



$$A = 2bt_f + (d - 2t_f)t_w$$

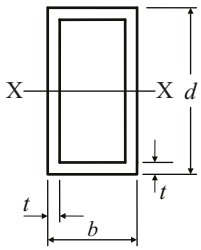
$$I_x = \frac{t_w}{12}(d - 2t_f)^3 + 2\left[\frac{bt_f^3}{12} + bt_f\left(\frac{d - t_f}{2}\right)^2\right]$$

$$J = [2bt_f^3 + (d - 2t_f)t_w^3]/3$$

$$C_w = \frac{t_f(d - t_f)^2b^3}{24} \approx \frac{I_y d^2}{4}$$

$$Z_x = bt_f(d - t_f) + (d/2 - t_f)^2 t_w$$

HOLLOW RECTANGLE



$$A = 2t(d + b - 2t)$$

$$I_x = \frac{(bd^3 - (b - 2t)(d - 2t)^3)}{12}$$

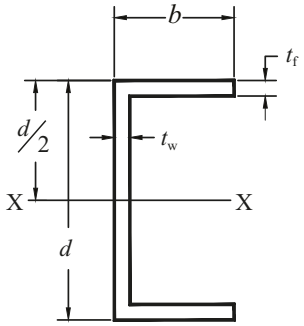
$$S_x = \frac{(bd^3 - (b - 2t)(d - 2t)^3)}{6d}$$

$$r_x = \sqrt{\frac{bd^3 - (b - 2t)(d - 2t)^3}{24t(d + b - 2t)}}$$

$$J = 2t(d - t)^2(b - t)^2/(d + b - 2t)$$

$$Z_x = bt(d - t) + 2t(d/2 - t)^2$$

CHANNEL



$$A = 2bt_f + (d - 2t_f)t_w$$

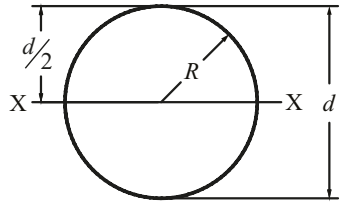
$$I_x = \frac{t_w}{12}(d - 2t_f)^3 + 2\left[\frac{bt_f^3}{12} + bt_f\left(\frac{d - t_f}{2}\right)^2\right]$$

$$J = \frac{2bt_f^3 + (d - 2t_f)t_w^3}{3}$$

$$C_w = \frac{t_f b^3(d - t_f)^2(3bt_f + 2t_w(d - t_f))}{12(6bt_f + (d - t_f)t_w)}$$

$$Z_x = bt_f(d - t_f) + (d/2 - t_f)^2 t_w$$

CIRCLE



$$A = \pi R^2 = \frac{\pi d^2}{4} \qquad r = \frac{R}{2} = \frac{d}{4}$$

$$I = \frac{\pi R^4}{4} = \frac{\pi d^4}{64} \qquad J = \frac{\pi R^4}{2} = \frac{\pi d^4}{32}$$

$$S = \frac{\pi R^3}{4} = \frac{\pi d^3}{32} \qquad Z = \frac{4R^3}{3} = \frac{d^3}{6}$$

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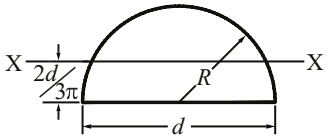
Table 23

GEOMETRIC SHAPES (CONTINUED)

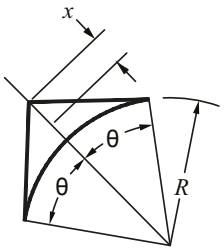
HALF CIRCLE



$$A = \frac{\pi R^2}{2} = \frac{\pi d^2}{8}$$

$$I = 0.1098R^4 = 0.0069d^4$$

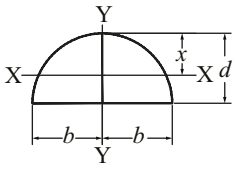
CIRCULAR FILLET



$$A = (\tan\theta - \theta)R^2$$

$$x = \left(\sec\theta - \frac{\tan^2\theta \sin\theta}{3(\tan\theta - \theta)}\right)R$$

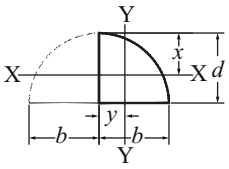
PARABOLA



$$A = \frac{4bd}{3}$$

$$x = \frac{6d}{10}$$

HALF PARABOLA

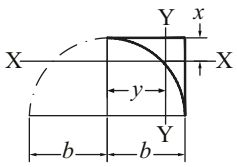


$$A = \frac{2bd}{3}$$

$$x = \frac{6d}{10}$$

$$y = \frac{3b}{8}$$

COMPLEMENT OF HALF PARABOLA

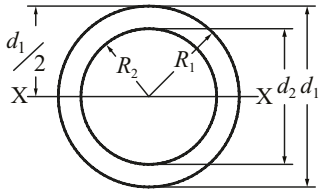


$$A = \frac{bd}{3}$$

$$x = \frac{3d}{10}$$

$$y = \frac{3b}{4}$$

HOLLOW CIRCLE



$$A = \pi(R_1^2 - R_2^2) = \frac{\pi(d_1^2 - d_2^2)}{4}$$

$$r = \sqrt{\frac{(R_1^2 + R_2^2)}{4}} = \sqrt{\frac{(d_1^2 + d_2^2)}{16}}$$

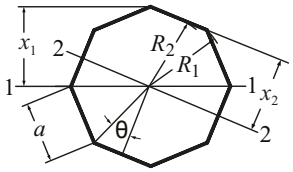
$$I = \frac{\pi(R_1^4 - R_2^4)}{4} = \frac{\pi(d_1^4 - d_2^4)}{64}$$

$$J = \frac{\pi t(R_1 + R_2)^3}{4}$$

$$S = \frac{\pi(R_1^4 - R_2^4)}{4R_1} = \frac{\pi(d_1^4 - d_2^4)}{32d_1}$$

$$Z = \frac{(d_1^3 - d_2^3)}{6}$$

REGULAR POLYGON



n = Number of Sides

$$a = 2\sqrt{R_1^2 - R_2^2}, \quad \theta = \frac{180^\circ}{n}$$

$$A = \frac{na^2\cot\theta}{4} = \frac{nR_1^2\sin 2\theta}{2} = nR_2^2\tan\theta$$

$$x_1 = R_1 = \frac{a}{2\sin\theta}, \qquad x_2 = R_2 = \frac{a}{2\tan\theta}$$

$$I_{1-1} = I_{2-2} = \frac{A(6R_1^2 - a^2)}{24} = \frac{A(12R_2^2 + a^2)}{48}$$

$$S_{1-1} = \frac{A(6R_1^2 - a^2)}{24R_1}, \quad S_{2-2} = \frac{A(12R_2^2 + a^2)}{48R_2}$$

$$r_{1-1} = \sqrt{\frac{6R_1^2 - a^2}{24}}, \qquad r_{2-2} = \sqrt{\frac{12R_2^2 + a^2}{48}}$$

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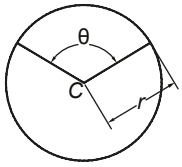
Table 23

GEOMETRIC SHAPES (CONTINUED)

CIRCULAR SECTOR



Area of sector = ½ (length of arc × r)

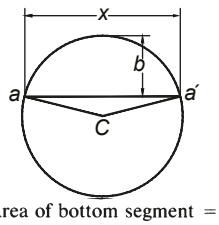
$= \text{Area of circle} \times \frac{\theta}{360}$

$= 0.0087266 \times r^2 \times \theta$

r = radius of circle

θ = sector angle in degrees

CIRCULAR SEGMENT



Area of top segment =

Area of top sector − Area of triangle $aa'c$ =

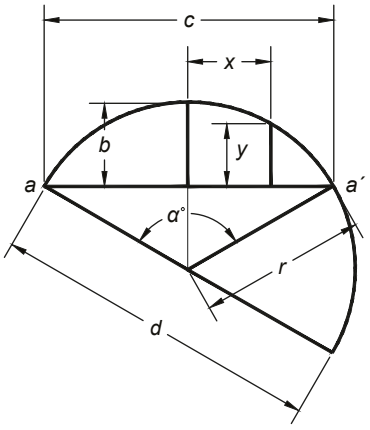
$$\frac{(\text{Length of top arc} \times r) - x(r - b)}{2}.$$

r = radius of circle

x = chord $\qquad$ b = rise

Area of bottom segment = Area of circle − Area of top segment

PROPERTIES OF THE CIRCLE



Circumference = $6.28318r = 3.14159d$

Diameter = 0.31834 circumference

Area = $3.14159r^2$

Arc $aa' = \frac{\pi r\alpha^\circ}{180^\circ} = 0.017453r\alpha^\circ$

Angle $\alpha^\circ = \frac{180^\circ}{\pi r} aa' = 57.29578 \frac{aa'}{r}$

Radius $r = \frac{4b^2 + c^2}{8b}$

Chord $c = 2\sqrt{2br - b^2} = 2r \sin \frac{\alpha}{2}$

Rise $b = r - \frac{1}{2}\sqrt{4r^2 - c^2} = \frac{c}{2} \tan \frac{\alpha}{4}$

$= 2r \sin^2 \frac{\alpha}{4} = r + y - \sqrt{r^2 - x^2}$

$y = b - r + \sqrt{r^2 - x^2}$

$x = \sqrt{r^2 - (r + y - b)^2}$

Diameter of circle of equal periphery as square = 1.27324 side of square

Side of square of equal periphery as circle = 0.78540 diameter of circle

Diameter of circle circumscribed about square = 1.41421 side of square

Side of square inscribed in circle = 0.70711 diameter of circle

FUNCTIONS OF π

$\pi = 3.14159265359$, log = 0.4971499

$\pi^2 = 9.8696044$, log = 0.9942997

$\pi^3 = 31.0062767$, log = 1.4914496

$\sqrt{\pi} = 1.7724539$, log = 0.2485749

$\frac{1}{\pi} = 0.3183099$, log = 1.5028501

$\frac{1}{\pi^2} = 0.1013212$, log = 1.0057003

$\frac{1}{\pi^3} = 0.0322515$, log = 2.5085500

$\sqrt{\frac{1}{\pi}} = 0.5641896$, log = 1.7514251

$\frac{\pi}{180} = 0.0174533$, log = 2.2418774

$\frac{180}{\pi} = 57.2957795$, log = 1.7581226

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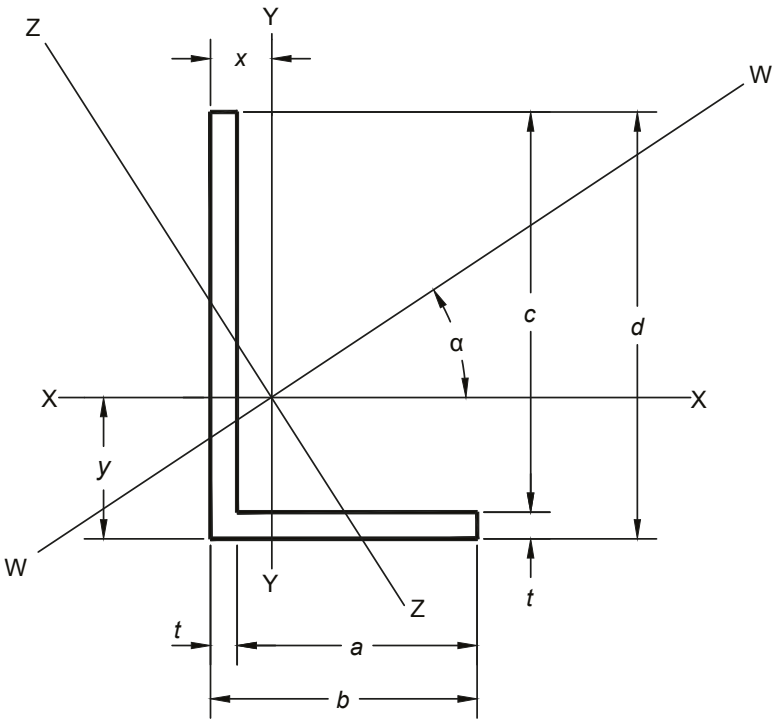
ANGLE



Z-Z axis is axis of minimum I

$$x = \frac{b^2 + ct}{2(b+c)} \qquad y = \frac{d^2 + at}{2(b+c)}$$

$$I_x = \frac{t(d-y)^3 + by^3 - a(y-t)^3}{3} \qquad I_y = \frac{t(b-x)^3 + dx^3 - c(x-t)^3}{3}$$

$$K = \frac{abcdt}{4(b+c)} \qquad \alpha = (1/2)\tan^{-1}\left(\frac{2K}{I_y - I_x}\right)$$

$$I_z = I_x \sin^2 \alpha + I_y \cos^2 \alpha + K \sin 2\alpha$$

$$I_x + I_y = I_w + I_z$$

$$I_w = I_x \cos^2 \alpha + I_y \sin^2 \alpha - K \sin 2\alpha$$

$$x_o = x - t/2 \qquad y_o = y - t/2$$

$$w_o = y_o \sin \alpha + x_o \cos \alpha \qquad z_o = y_o \cos \alpha - x_o \sin \alpha$$

$$b' = d - t/2 \qquad d' = b - t/2$$

$$C_1 = \frac{{x_o}^2}{2}\left[{y_o}^2 - (y_o - b')^2\right] + \frac{\left({y_o}^4 - (y_o - b')^4\right)}{4} + \frac{y_o}{3}\left[{x_o}^3 - (x_o - d')^3\right] + {y_o}^3 d'$$

$$C_2 = \frac{{y_o}^2}{2}\left[{x_o}^2 - (x_o - d')^2\right] + \frac{\left({x_o}^4 - (x_o - d')^4\right)}{4} + \frac{x_o}{3}\left[{y_o}^3 - (y_o - b')^3\right] + {x_o}^3 b'$$

$$\beta_w = \frac{t(C_1 \cos \alpha - C_2 \sin \alpha)}{I_w} - 2z_o$$

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PART VI
DESIGN AIDS

The Aluminum Association

ALUMINUM
DESIGN MANUAL
2020

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Aluminum Design Manual

PART VI

Design Aids

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Design Aids
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Table 1-1
BUCKLING CONSTANTS (UNWELDED)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
1060	H12	B209, sheet & plate	0.017	2.000	11	9	8.1	8.8	0.032	184.1	10.2	0.040	171.0	10.2	0.278	26.6	13.6	0.061	148.6	15.3	0.653	13.6	6.9	0.022	207.9
1060	H12	B210, drawn tube	0.010	0.500	10	4	3.6	3.8	0.009	280.0	4.3	0.011	263.0	4.4	0.090	36.4	5.7	0.017	229.0	6.6	0.212	18.0	2.9	0.006	320.3
1060	H14	B209, sheet & plate	0.009	1.000	12	10	9	9.9	0.038	174.3	11.5	0.047	161.6	11.4	0.321	25.2	15.2	0.072	140.4	17.1	0.756	13.1	7.8	0.026	196.4
1060	H14	B210, drawn tube	0.010	0.500	12	10	9	9.9	0.038	174.3	11.5	0.047	161.6	11.4	0.321	25.2	15.2	0.072	140.4	17.1	0.756	13.1	7.8	0.026	196.4
1100	H12	B209, sheet & plate	0.017	2.000	14	11	9.9	10.9	0.044	165.8	12.7	0.055	153.5	12.6	0.367	24.1	16.8	0.084	133.3	18.9	0.863	12.7	8.6	0.031	186.6
1100	H12	B210, drawn tube	0.014	0.500	14	11	9.9	10.9	0.044	165.8	12.7	0.055	153.5	12.6	0.367	24.1	16.8	0.084	133.3	18.9	0.863	12.7	8.6	0.031	186.6
1100	H14	B209, sheet & plate	0.009	1.000	16	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
1100	H14	B210, drawn tube	0.014	0.500	16	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
2014	T6	B209, sheet & plate	0.040	0.249	66	58	58	67.3	0.550	50.2	77.6	0.680	46.8	73.0	3.137	9.44	117.2	1.547	50.5	109.5	8.977	6.3	47.0	0.321	60.1
2014	T651	B209, sheet & plate	0.250	2.000	67	59	59	68.6	0.565	49.8	79.1	0.700	46.3	74.3	3.212	9.36	119.5	1.592	50.0	111.5	9.193	6.2	47.9	0.330	59.5
2014	T6, T6510, T6511	B221, extrusion	–	0.499	60	53	53	61.1	0.476	52.7	70.4	0.588	49.1	66.5	2.768	9.84	106.0	1.330	53.1	99.7	7.922	6.4	42.7	0.277	63.1
2014	T6, T651	B211, bar, rod, & wire	0.125	8.000	65	55	55	63.6	0.505	51.7	73.3	0.624	48.1	69.1	2.914	9.67	110.5	1.415	52.1	103.6	8.339	6.4	44.4	0.294	61.8
2014	T6	B210, drawn tube	0.018	0.500	65	55	55	63.6	0.505	51.7	73.3	0.624	48.1	69.1	2.914	9.67	110.5	1.415	52.1	103.6	8.339	6.4	44.4	0.294	61.8
Alclad 2014	T6	B209, sheet & plate	0.040	0.050	63	55	55	63.6	0.505	51.7	73.3	0.624	48.1	69.1	2.914	9.67	110.5	1.415	52.1	103.6	8.339	6.4	44.4	0.294	61.8
Alclad 2014	T6	B209, sheet & plate	0.051	0.124	64	57	57	66.1	0.534	50.7	76.2	0.661	47.2	71.7	3.062	9.51	115.0	1.502	51.0	107.5	8.763	6.3	46.2	0.312	60.6
Alclad 2014	T651	B209, sheet & plate	0.250	0.499	64	57	57	66.1	0.534	50.7	76.2	0.661	47.2	71.7	3.062	9.51	115.0	1.502	51.0	107.5	8.763	6.3	46.2	0.312	60.6
2219	T87	B209, sheet & plate	0.250	3.000	64	51	51	58.7	0.447	53.8	67.5	0.552	50.1	63.9	2.624	10.0	101.5	1.247	54.3	95.8	7.510	6.5	40.9	0.260	64.4
3003	H12	B209, sheet & plate	0.017	2.000	17	12	10.8	11.9	0.050	158.4	13.9	0.063	146.5	13.8	0.414	23.1	18.5	0.097	127.2	20.7	0.974	12.3	9.4	0.035	178.1
3003	H12	B210, drawn tube	0.010	0.500	17	12	10.8	11.9	0.050	158.4	13.9	0.063	146.5	13.8	0.414	23.1	18.5	0.097	127.2	20.7	0.974	12.3	9.4	0.035	178.1
3003	H14	B209, sheet & plate	0.009	1.000	20	17	15.3	17.2	0.087	131.9	20.3	0.111	121.4	19.9	0.672	19.5	27.0	0.171	105.3	29.8	1.582	10.9	13.8	0.062	147.5
3003	H14	B210, drawn tube	0.010	0.500	20	17	15.3	17.2	0.087	131.9	20.3	0.111	121.4	19.9	0.672	19.5	27.0	0.171	105.3	29.8	1.582	10.9	13.8	0.062	147.5
3003	H16	B209, sheet & plate	0.006	0.162	24	21	18.9	21.5	0.121	118.0	25.5	0.157	108.3	24.8	0.903	17.7	33.9	0.241	93.9	37.2	2.125	10.1	17.3	0.088	131.5
3003	H16	B210, drawn tube	0.010	0.500	24	21	18.9	21.5	0.121	118.0	25.5	0.157	108.3	24.8	0.903	17.7	33.9	0.241	93.9	37.2	2.125	10.1	17.3	0.088	131.5
3003	H18	B209, sheet & plate	0.006	0.128	27	24	21.6	24.8	0.150	109.9	29.5	0.195	100.7	28.5	1.088	16.6	39.3	0.300	87.3	42.7	2.561	9.7	20.0	0.109	122.2
3003	H18	B210, drawn tube	0.010	0.500	27	24	21.6	24.8	0.150	109.9	29.5	0.195	100.7	28.5	1.088	16.6	39.3	0.300	87.3	42.7	2.561	9.7	20.0	0.109	122.2
Alclad 3003	H12	B209, sheet & plate	0.017	2.000	16	11	9.9	10.9	0.044	165.8	12.7	0.055	153.5	12.6	0.367	24.1	16.8	0.084	133.3	18.9	0.863	12.7	8.6	0.031	186.6
Alclad 3003	H14	B209, sheet & plate	0.009	1.000	19	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4

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Table 1-1
BUCKLING CONSTANTS (UNWELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
Alclad 3003	H16	B209, sheet & plate	0.006	0.162	23	20	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	16.4	0.081	135.0
Alclad 3003	H14	B210, drawn tube	0.010	0.500	19	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4
Alclad 3003	H18	B210, drawn tube	0.010	0.500	26	23	20.7	23.7	0.140	112.4	28.2	0.182	103.1	27.3	1.026	16.9	37.5	0.280	89.3	40.9	2.413	9.8	19.1	0.102	125.1
3004	H32	B209, sheet & plate	0.017	2.000	28	21	18.9	21.5	0.121	118.0	25.5	0.157	108.3	24.8	0.903	17.7	33.9	0.241	93.9	37.2	2.125	10.1	17.3	0.088	131.5
3004	H34	B209, sheet & plate	0.009	1.000	32	25	22.5	25.9	0.160	107.5	30.9	0.209	98.5	29.7	1.152	16.2	41.1	0.321	85.3	44.6	2.711	9.5	21.0	0.117	119.5
3004	H36	B209, sheet & plate	0.006	0.162	35	28	25.2	29.2	0.192	101.2	34.9	0.251	92.6	33.5	1.350	15.4	46.5	0.387	80.2	50.3	3.177	9.2	23.7	0.141	112.3
3004	H38	B209, sheet & plate	0.006	0.128	38	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
Alclad 3004	H32	B209, sheet & plate	0.017	2.000	27	20	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	16.4	0.081	135.0
Alclad 3004	H34	B209, sheet & plate	0.009	1.000	31	24	21.6	24.8	0.150	109.9	29.5	0.195	100.7	28.5	1.088	16.6	39.3	0.300	87.3	42.7	2.561	9.7	20.0	0.109	122.2
Alclad 3004	H36	B209, sheet & plate	0.006	0.162	34	27	24.3	28.1	0.181	103.2	33.6	0.237	94.4	32.2	1.283	15.6	44.7	0.364	81.8	48.4	3.020	9.3	22.8	0.133	114.6
3005	H25	B209, sheet & plate	0.016	0.080	26	22	19.8	22.6	0.131	115.1	26.8	0.169	105.6	26.0	0.964	17.3	35.7	0.260	91.5	39.0	2.268	10.0	18.2	0.095	128.2
3005	H28	B209, sheet & plate	0.016	0.080	31	27	24.3	28.1	0.181	103.2	33.6	0.237	94.4	32.2	1.283	15.6	44.7	0.364	81.8	48.4	3.020	9.3	22.8	0.133	114.6
3105	H25	B209, sheet & plate	0.013	0.080	23	19	17.1	19.3	0.104	124.4	22.9	0.133	114.3	22.3	0.785	18.5	30.4	0.205	99.2	33.5	1.848	10.5	15.5	0.075	138.8
5005	H12	B209, sheet & plate	0.017	2.000	18	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
5005	H14	B209, sheet & plate	0.009	1.000	21	17	15.3	17.2	0.087	131.9	20.3	0.111	121.4	19.9	0.672	19.5	27.0	0.171	105.3	29.8	1.582	10.9	13.8	0.062	147.5
5005	H16	B209, sheet & plate	0.006	0.162	24	20	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	16.4	0.081	135.0
5005	H32	B209, sheet & plate	0.017	2.000	17	12	10.8	11.9	0.050	158.4	13.9	0.063	146.5	13.8	0.414	23.1	18.5	0.097	127.2	20.7	0.974	12.3	9.4	0.035	178.1
5005	H34	B209, sheet & plate	0.009	1.000	20	15	13.5	15.1	0.071	140.9	17.7	0.091	129.9	17.4	0.565	20.7	23.5	0.139	112.8	26.1	1.329	11.4	12.0	0.051	157.8
5005	H36	B209, sheet & plate	0.006	0.162	23	18	16.2	18.3	0.095	128.0	21.6	0.122	117.7	21.1	0.728	19.0	28.7	0.187	102.1	31.6	1.714	10.7	14.6	0.068	143.0
5050	H32	B209, sheet & plate	0.017	0.249	22	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4
5050	H32	B210, drawn tube	0.010	0.500	22	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4
5050	H34	B209, sheet & plate	0.009	0.249	25	20	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	16.4	0.081	135.0
5050	H34	B210, drawn tube	0.010	0.500	25	20	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	16.4	0.081	135.0
5050	H36	B209, sheet & plate	0.006	0.162	27	22	19.8	22.6	0.131	115.1	26.8	0.169	105.6	26.0	0.964	17.3	35.7	0.260	91.5	39.0	2.268	10.0	18.2	0.095	128.2
5052	O	B209, sheet & plate	0.006	3.000	25	9.5	9.5	10.4	0.041	169.4	12.1	0.052	157.0	12.1	0.346	24.5	16.1	0.079	136.3	18.1	0.815	12.9	7.3	0.024	201.9
5052	H32	B209, sheet & plate	0.017	2.000	31	23	20.7	23.7	0.140	112.4	28.2	0.182	103.1	27.3	1.026	16.9	37.5	0.280	89.3	40.9	2.413	9.8	19.1	0.102	125.1
5052	H32	B210, drawn tube	0.010	0.450	31	23	20.7	23.7	0.140	112.4	28.2	0.182	103.1	27.3	1.026	16.9	37.5	0.280	89.3	40.9	2.413	9.8	19.1	0.102	125.1
5052	H34	B209, sheet & plate	0.009	1.000	34	26	23.4	27.0	0.171	105.3	32.2	0.223	96.4	31.0	1.217	15.9	42.9	0.342	83.5	46.5	2.864	9.4	21.9	0.125	117.0
5052	H34	B210, drawn tube	0.010	0.450	34	26	23.4	27.0	0.171	105.3	32.2	0.223	96.4	31.0	1.217	15.9	42.9	0.342	83.5	46.5	2.864	9.4	21.9	0.125	117.0

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Table 1-1
BUCKLING CONSTANTS (UNWELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
5052	H36	B209, sheet & plate	0.006	0.162	37	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5083	O	B221, extrusion	–	2.999	39	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.1	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4
5083	H112	B221, extrusion	–	2.999	39	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4
5083	O	B209, sheet & plate	0.051	1.500	40	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5083	H111	B221, extrusion	–	2.999	40	24	21.6	24.8	0.150	109.9	29.5	0.195	100.7	28.5	1.088	16.6	39.3	0.300	87.3	42.7	2.561	9.7	20.0	0.109	122.2
5083	H111	B247, forging	–	4.000	42	22	19.8	22.6	0.131	115.1	26.8	0.169	105.6	26.0	0.964	17.3	35.7	0.260	91.5	39.0	2.268	10.0	18.2	0.095	128.2
5083	H116	B928, sheet & plate	0.125	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5083	H116	B928, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5083	H32	B209, sheet & plate	0.125	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5083	H32	B209, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5083	H321	B928, sheet & plate	0.125	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5083	H321	B928, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5086	O	B221, extrusion	–	2.999	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B221, extrusion	–	2.999	35	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
5086	O	B209, sheet & plate	0.020	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H111	B221, extrusion	–	2.999	36	21	18.9	21.5	0.121	118.0	25.5	0.157	108.3	24.8	0.903	17.7	33.9	0.241	93.9	37.2	2.125	10.1	17.3	0.088	131.5
5086	H112	B209, sheet & plate	0.188	0.499	36	18	16.2	18.3	0.095	128.0	21.6	0.122	117.7	21.1	0.728	19.0	28.7	0.187	102.1	31.6	1.714	10.7	14.6	0.068	143.0
5086	H112	B209, sheet & plate	0.500	1.000	35	16	14.4	16.1	0.079	136.2	19.0	0.101	125.5	18.6	0.618	20.1	25.2	0.155	108.9	28.0	1.454	11.1	12.9	0.056	152.4
5086	H112	B209, sheet & plate	1.001	2.000	35	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
5086	H112	B209, sheet & plate	2.001	3.000	34	14	12.6	14.0	0.064	146.1	16.5	0.081	134.9	16.2	0.513	21.5	21.8	0.124	117.1	24.3	1.207	11.7	11.1	0.045	163.8
5086	H116	B928, sheet & plate	0.063	2.000	40	28	25.2	29.2	0.192	101.2	34.9	0.251	92.6	33.5	1.350	15.4	46.5	0.387	80.2	50.3	3.177	9.2	23.7	0.141	112.3
5086	H32	B209, sheet & plate	0.020	2.000	40	28	25.2	29.2	0.192	101.2	34.9	0.251	92.6	33.5	1.350	15.4	46.5	0.387	80.2	50.3	3.177	9.2	23.7	0.141	112.3
5086	H32	B210, drawn tube	0.010	0.450	40	28	25.2	29.2	0.192	101.2	34.9	0.251	92.6	33.5	1.350	15.4	46.5	0.387	80.2	50.3	3.177	9.2	23.7	0.141	112.3
5086	H34	B209, sheet & plate	0.009	1.000	44	34	30.6	36.0	0.263	91.2	43.2	0.346	83.2	41.1	1.772	14.0	57.6	0.533	72.1	61.6	4.170	8.6	29.4	0.194	100.9
5086	H34	B210, drawn tube	0.010	0.450	44	34	30.6	36.0	0.263	91.2	43.2	0.346	83.2	41.1	1.772	14.0	57.6	0.533	72.1	61.6	4.170	8.6	29.4	0.194	100.9
5086	H321	B928, sheet & plate	0.063	2.000	40	28	25.2	29.2	0.192	101.2	34.9	0.251	92.6	33.5	1.350	15.4	46.5	0.387	80.2	50.3	3.177	9.2	23.7	0.141	112.3
5154	H38	B209, sheet & plate	0.006	0.128	45	35	31.5	37.1	0.275	89.8	44.6	0.363	81.9	42.3	1.846	13.8	59.5	0.559	70.9	63.5	4.343	8.5	30.3	0.203	99.3
5454	O	B221, extrusion	–	2.999	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	H112	B221, extrusion	–	2.999	31	12	10.8	11.9	0.050	158.4	13.9	0.063	146.5	13.8	0.414	23.1	18.5	0.097	127.2	20.7	0.974	12.3	9.4	0.035	178.1

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Table 1-1
BUCKLING CONSTANTS (UNWELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	Thickness Inches To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
5454	O	B209, sheet & plate	0.020	3.000	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	H111	B221, extrusion	–	2.999	33	19	17.1	19.3	0.104	124.4	22.9	0.133	114.3	22.3	0.785	18.5	30.4	0.205	99.2	33.5	1.848	10.5	15.5	0.075	138.8
5454	H32	B209, sheet & plate	0.020	2.000	36	26	23.4	27.0	0.171	105.3	32.2	0.223	96.4	31.0	1.217	15.9	42.9	0.342	83.5	46.5	2.864	9.4	21.9	0.125	117.0
5454	H34	B209, sheet & plate	0.020	1.000	39	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5456	O	B209, sheet & plate	0.051	1.500	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H116	B928, sheet & plate	0.063	1.250	46	33	29.7	34.8	0.250	92.7	41.8	0.329	84.6	39.8	1.700	14.2	55.7	0.507	73.3	59.7	3.999	8.7	28.4	0.185	102.6
5456	H116	B928, sheet & plate	1.251	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5456	H116	B928, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5456	H32	B209, sheet & plate	0.188	0.499	46	33	29.7	34.8	0.250	92.7	41.8	0.329	84.6	39.8	1.700	14.2	55.7	0.507	73.3	59.7	3.999	8.7	28.4	0.185	102.6
5456	H32	B209, sheet & plate	0.500	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5456	H32	B209, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
5456	H321	B928, sheet & plate	0.188	0.499	46	33	29.7	34.8	0.250	92.7	41.8	0.329	84.6	39.8	1.700	14.2	55.7	0.507	73.3	59.7	3.999	8.7	28.4	0.185	102.6
5456	H321	B928, sheet & plate	0.500	1.500	44	31	27.9	32.6	0.226	95.9	39.0	0.297	87.6	37.3	1.557	14.6	52.0	0.457	75.8	55.9	3.664	8.8	26.5	0.167	106.2
5456	H321	B928, sheet & plate	1.501	3.000	41	29	26.1	30.3	0.203	99.4	36.3	0.266	90.8	34.8	1.418	15.1	48.4	0.410	78.7	52.1	3.337	9.1	24.7	0.149	110.2
6005	T5	B221, extrusion	–	1.000	38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6005A	T5	B221, extrusion	–	0.999	38	31	31	34.6	0.203	70.0	39.5	0.247	65.6	38.1	1.317	12.5	58.4	0.544	71.6	57.1	3.769	7.8	23.9	0.116	84.3
6005A	T61	B221, extrusion	–	1.000	38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6, T651	B209, sheet & plate	0.010	4.000	42	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B632, tread plate	0.100	0.625	42	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6, T6510, T6511	B221, extrusion	All		38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6, T651	B211, bar, rod, & wire	0.125	8.000	42	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B210, drawn tube	0.025	0.500	42	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B241, pipe & tube	All		38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B429, pipe & tube	All		38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B247, forging	–	4.000	38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6061	T6	B308, std struct. profile	0.062		38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6063	T5	B221, extrusion	–	0.500	22	16	16	17.3	0.072	98.9	19.5	0.086	93.3	19.2	0.529	16.6	28.3	0.184	102.8	28.8	1.513	9.8	11.8	0.040	120.0
6063	T5	B221, extrusion	0.501	1.000	21	15	15	16.2	0.065	102.3	18.2	0.077	96.5	18.0	0.484	17.0	26.4	0.165	106.5	26.9	1.384	10.0	11.0	0.036	124.1
6063	T52	B221, extrusion	–	1.000	22	16	16	17.3	0.072	98.9	19.5	0.086	93.3	19.2	0.529	16.6	28.3	0.184	102.8	28.8	1.513	9.8	11.8	0.040	120.0

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Table 1-1
BUCKLING CONSTANTS (UNWELDED)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
6063	T6	B221, extrusion	–	1.000	30	25	25	27.6	0.145	78.4	31.4	0.175	73.5	30.5	0.978	13.7	46.1	0.382	80.6	45.7	2.800	8.4	19.0	0.082	94.6
6063	T6	B241, pipe & tube	–	1.000	30	25	25	27.6	0.145	78.4	31.4	0.175	73.5	30.5	0.978	13.7	46.1	0.382	80.6	45.7	2.800	8.4	19.0	0.082	94.6
6063	T6	B429, pipe & tube	–	1.000	30	25	25	27.6	0.145	78.4	31.4	0.175	73.5	30.5	0.978	13.7	46.1	0.382	80.6	45.7	2.800	8.4	19.0	0.082	94.6
6063	T832	B210, drawn tube	0.05	0.259	40	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6066	T6, T6510, T6511	B221, extrusion	All		50	45	45	51.4	0.366	57.5	59.0	0.451	53.7	56.1	2.206	10.6	88.3	1.011	58.2	84.1	6.313	6.8	35.7	0.212	68.9
6070	T6	B221, extrusion	–	2.999	48	45	45	51.4	0.366	57.5	59.0	0.451	53.7	56.1	2.206	10.6	88.3	1.011	58.2	84.1	6.313	6.8	35.7	0.212	68.9
6082	T6, T6511	B221, extrusion	0.200	6.000	45	38	38	42.9	0.280	62.9	49.2	0.343	58.8	47.0	1.745	11.4	73.2	0.763	63.9	70.6	4.995	7.2	29.8	0.162	75.5
6105	T5	B221, extrusion	–	1.000	38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6351	T5	B221, extrusion	–	1.000	38	35	35	39.4	0.246	65.7	45.0	0.300	61.4	43.2	1.558	11.9	66.8	0.666	66.9	64.8	4.458	7.4	27.2	0.141	78.9
6351	T6	B221, extrusion	–	0.749	42	37	37	41.7	0.268	63.8	47.8	0.329	59.6	45.8	1.682	11.6	71.1	0.730	64.9	68.6	4.814	7.3	28.9	0.155	76.6
6360	T5	B221, extrusion	–	0.25	22	16	16	17.3	0.072	98.9	19.5	0.086	93.3	19.2	0.529	16.6	28.3	0.184	102.8	28.8	1.513	9.8	11.8	0.040	120.0
6360	T6	B221, extrusion	–	0.25	30	25	25	27.6	0.145	78.4	31.4	0.175	73.6	30.5	0.978	13.7	46.1	0.382	80.6	45.7	2.799	8.4	19.0	0.082	94.6
6463	T6	B221, extrusion	–	0.500	30	25	25	27.6	0.145	78.4	31.4	0.175	73.5	30.5	0.978	13.7	46.1	0.382	80.6	45.7	2.800	8.4	19.0	0.082	94.6
7005	T53	B221, extrusion	–	0.750	50	44	44	50.2	0.353	58.2	57.6	0.435	54.3	54.8	2.138	10.7	86.1	0.974	58.9	82.2	6.120	6.9	34.9	0.205	69.8

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Table 1-2
BUCKLING CONSTANTS (WELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
1060	H12	B209, sheet & plate	0.017	2.000	8	2.5	2.5	2.6	0.005	337.6	2.9	0.006	318.7	3.0	0.055	42.2	3.9	0.009	277.6	4.5	0.128	20.5	1.8	0.003	410.5
1060	H12	B210, drawn tube	0.010	0.500	8.5	2.5	2.5	2.6	0.005	337.6	2.9	0.006	318.7	3.0	0.055	42.2	3.9	0.009	277.6	4.5	0.128	20.5	1.8	0.003	410.5
1060	H14	B209, sheet & plate	0.009	1.000	8	2.5	2.5	2.6	0.005	337.6	2.9	0.006	318.7	3.0	0.055	42.2	3.9	0.009	277.6	4.5	0.128	20.5	1.8	0.003	410.5
1060	H14	B210, drawn tube	0.010	0.500	8.5	2.5	2.5	2.6	0.005	337.6	2.9	0.006	318.7	3.0	0.055	42.2	3.9	0.009	277.6	4.5	0.128	20.5	1.8	0.003	410.5
1100	H12	B209, sheet & plate	0.017	2.000	11	3.5	3.5	3.7	0.009	284.1	4.2	0.010	267.0	4.3	0.087	36.9	5.5	0.016	232.4	6.4	0.204	18.2	2.5	0.005	343.7
1100	H12	B210, drawn tube	0.014	0.500	11	3.5	3.5	3.7	0.009	284.1	4.2	0.010	267.0	4.3	0.087	36.9	5.5	0.016	232.4	6.4	0.204	18.2	2.5	0.005	343.7
1100	H14	B209, sheet & plate	0.009	1.000	11	3.5	3.5	3.7	0.009	284.1	4.2	0.010	267.0	4.3	0.087	36.9	5.5	0.016	232.4	6.4	0.204	18.2	2.5	0.005	343.7
1100	H14	B210, drawn tube	0.014	0.500	11	3.5	3.5	3.7	0.009	284.1	4.2	0.010	267.0	4.3	0.087	36.9	5.5	0.016	232.4	6.4	0.204	18.2	2.5	0.005	343.7
2014	T6	B209, sheet & plate	0.040	0.249	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2014	T651	B209, sheet & plate	0.250	2.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2014	T6, T6510, T6511	B221, extrusion	–	0.499	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2014	T6, T651	B211, bar, rod, & wire	0.125	8.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2014	T6	B210, drawn tube	0.018	0.500	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alclad 2014	T6	B209, sheet & plate	0.040	0.050	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alclad 2014	T6	B209, sheet & plate	0.051	0.124	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alclad 2014	T651	B209, sheet & plate	0.250	0.499	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2219	T87	B209, sheet & plate	0.250	3.000	35	26	26	30.2	0.202	99.6	36.1	0.265	91.0	34.6	1.411	15.1	48.1	0.407	78.8	51.9	3.319	9.1	21.9	0.125	117.0
3003	H12	B209, sheet & plate	0.017	2.000	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H12	B210, drawn tube	0.010	0.500	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H14	B209, sheet & plate	0.009	1.000	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H14	B210, drawn tube	0.010	0.500	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H16	B209, sheet & plate	0.006	0.162	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H16	B210, drawn tube	0.010	0.500	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H18	B209, sheet & plate	0.006	0.128	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
3003	H18	B210, drawn tube	0.010	0.500	14	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
Alclad 3003	H12	B209, sheet & plate	0.017	2.000	13	4.5	4.5	4.8	0.013	249.6	5.5	0.016	233.8	5.6	0.123	33.9	7.2	0.024	203.4	8.3	0.289	16.7	3.3	0.007	300.9
Alclad 3003	H14	B209, sheet & plate	0.009	1.000	13	4.5	4.5	4.8	0.013	249.6	5.5	0.016	233.8	5.6	0.123	33.9	7.2	0.024	203.4	8.3	0.289	16.7	3.3	0.007	300.9
Alclad 3003	H16	B209, sheet & plate	0.006	0.162	13	4.5	4.5	4.8	0.013	249.6	5.5	0.016	233.8	5.6	0.123	33.9	7.2	0.024	203.4	8.3	0.289	16.7	3.3	0.007	300.9
Alclad 3003	H14	B210, drawn tube	0.010	0.500	13	4.5	4.5	4.8	0.013	249.6	5.5	0.016	233.8	5.6	0.123	33.9	7.2	0.024	203.4	8.3	0.289	16.7	3.3	0.007	300.9

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Table 1-2
BUCKLING CONSTANTS (WELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
Alclad 3003	H18	B210, drawn tube	0.010	0.500	13	4.5	4.5	4.8	0.013	249.6	5.5	0.016	233.8	5.6	0.123	33.9	7.2	0.024	203.4	8.3	0.289	16.7	3.3	0.007	300.9
3004	H32	B209, sheet & plate	0.017	2.000	22	8.5	8.5	9.3	0.034	179.5	10.8	0.043	166.6	10.8	0.297	25.9	14.3	0.066	144.8	16.1	0.698	13.4	6.5	0.020	214.4
3004	H34	B209, sheet & plate	0.009	1.000	22	8.5	8.5	9.3	0.034	179.5	10.8	0.043	166.6	10.8	0.297	25.9	14.3	0.066	144.8	16.1	0.698	13.4	6.5	0.020	214.4
3004	H36	B209, sheet & plate	0.006	0.162	22	8.5	8.5	9.3	0.034	179.5	10.8	0.043	166.6	10.8	0.297	25.9	14.3	0.066	144.8	16.1	0.698	13.4	6.5	0.020	214.4
3004	H38	B209, sheet & plate	0.006	0.128	22	8.5	8.5	9.3	0.034	179.5	10.8	0.043	166.6	10.8	0.297	25.9	14.3	0.066	144.8	16.1	0.698	13.4	6.5	0.020	214.4
Alclad 3004	H32	B209, sheet & plate	0.017	2.000	21	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
Alclad 3004	H34	B209, sheet & plate	0.009	1.000	21	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
Alclad 3004	H36	B209, sheet & plate	0.006	0.162	21	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
3005	H25	B209, sheet & plate	0.016	0.080	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3005	H28	B209, sheet & plate	0.016	0.080	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3105	H25	B209, sheet & plate	0.013	0.080	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
5005	H12	B209, sheet & plate	0.017	2.000	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5005	H14	B209, sheet & plate	0.009	1.000	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5005	H16	B209, sheet & plate	0.006	0.162	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5005	H32	B209, sheet & plate	0.017	2.000	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5005	H34	B209, sheet & plate	0.009	1.000	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5005	H36	B209, sheet & plate	0.006	0.162	15	5	5	5.4	0.015	236.4	6.1	0.018	221.1	6.2	0.142	32.5	8.1	0.028	192.3	9.3	0.335	16.1	3.7	0.009	284.5
5050	H32	B209, sheet & plate	0.017	0.249	18	6	6	6.5	0.020	215.2	7.4	0.025	200.6	7.5	0.183	30.6	9.8	0.038	174.5	11.2	0.431	15.1	4.5	0.012	258.2
5050	H32	B210, drawn tube	0.010	0.500	18	6	6	6.5	0.020	215.2	7.4	0.025	200.6	7.5	0.183	30.6	9.8	0.038	174.5	11.2	0.431	15.1	4.5	0.012	258.2
5050	H34	B209, sheet & plate	0.009	0.249	18	6	6	6.5	0.020	215.2	7.4	0.025	200.6	7.5	0.183	30.6	9.8	0.038	174.5	11.2	0.431	15.1	4.5	0.012	258.2
5050	H34	B210, drawn tube	0.010	0.500	18	6	6	6.5	0.020	215.2	7.4	0.025	200.6	7.5	0.183	30.6	9.8	0.038	174.5	11.2	0.431	15.1	4.5	0.012	258.2
5050	H36	B209, sheet & plate	0.006	0.162	18	6	6	6.5	0.020	215.2	7.4	0.025	200.6	7.5	0.183	30.6	9.8	0.038	174.5	11.2	0.431	15.1	4.5	0.012	258.2
5052	O	B209, sheet & plate	0.006	3.000	25	9.5	9.5	10.4	0.041	169.4	12.1	0.052	157.0	12.1	0.346	24.5	16.1	0.079	136.3	18.1	0.815	12.9	7.3	0.024	201.9
5052	H32	B209, sheet & plate	0.017	2.000	25	9.5	9.5	10.4	0.041	169.4	12.1	0.052	157.0	12.1	0.346	24.5	16.1	0.079	136.3	18.1	0.815	12.9	7.3	0.024	201.9
5052	H32	B210, drawn tube	0.010	0.450	25	10	10	11.0	0.044	164.9	12.8	0.056	152.7	12.7	0.372	23.9	17.0	0.086	132.6	19.1	0.875	12.7	7.8	0.026	196.4
5052	H34	B209, sheet & plate	0.009	1.000	25	9.5	9.5	10.4	0.041	169.4	12.1	0.052	157.0	12.1	0.346	24.5	16.1	0.079	136.3	18.1	0.815	12.9	7.3	0.024	201.9
5052	H34	B210, drawn tube	0.010	0.450	25	10	10	11.0	0.044	164.9	12.8	0.056	152.7	12.7	0.372	23.9	17.0	0.086	132.6	19.1	0.875	12.7	7.8	0.026	196.4
5052	H36	B209, sheet & plate	0.006	0.162	25	9.5	9.5	10.4	0.041	169.4	12.1	0.052	157.0	12.1	0.346	24.5	16.1	0.079	136.3	18.1	0.815	12.9	7.3	0.024	201.9
5083	O	B221, extrusion	–	2.999	39	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.2	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4

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Table 1-2
BUCKLING CONSTANTS (WELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
5083	H112	B221, extrusion	–	2.999	39	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.2	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4
5083	O	B209, sheet & plate	0.051	1.500	40	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5083	H111	B221, extrusion	–	2.999	39	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.2	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4
5083	H111	B247, forging	–	4.000	38	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.2	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4
5083	H116	B928, sheet & plate	0.125	1.500	40	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5083	H116	B928, sheet & plate	1.501	3.000	39	17	17	19.2	0.103	124.8	22.7	0.132	114.7	22.2	0.779	18.6	30.2	0.203	99.5	33.3	1.833	10.5	13.8	0.062	147.5
5083	H32	B209, sheet & plate	0.125	1.500	40	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5083	H32	B209, sheet & plate	1.501	3.000	39	17	17	19.2	0.103	124.8	22.7	0.132	114.7	22.2	0.779	18.6	30.2	0.203	99.5	33.3	1.833	10.5	13.8	0.062	147.5
5083	H321	B928, sheet & plate	0.125	1.500	40	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5083	H321	B928, sheet & plate	1.501	3.000	39	17	17	19.2	0.103	124.8	22.7	0.132	114.7	22.2	0.779	18.6	30.2	0.203	99.5	33.3	1.833	10.5	13.8	0.062	147.5
5086	O	B221, extrusion	–	2.999	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B221, extrusion	–	2.999	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	O	B209, sheet & plate	0.020	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H111	B221, extrusion	–	2.999	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B209, sheet & plate	0.188	0.499	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B209, sheet & plate	0.500	1.000	34	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B209, sheet & plate	1.001	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H112	B209, sheet & plate	2.001	3.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H116	B928, sheet & plate	0.063	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H32	B209, sheet & plate	0.020	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H32	B210, drawn tube	0.010	0.450	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H34	B209, sheet & plate	0.009	1.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H34	B210, drawn tube	0.010	0.450	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5086	H321	B928, sheet & plate	0.063	2.000	35	14	14	15.7	0.075	138.3	18.4	0.096	127.4	18.1	0.594	20.4	24.5	0.148	110.6	27.1	1.398	11.3	11.1	0.045	163.8
5154	H38	B209, sheet & plate	0.006	0.128	30	11	11	12.2	0.052	156.9	14.2	0.065	145.1	14.1	0.425	22.9	18.9	0.100	126.0	21.1	0.999	12.2	8.6	0.031	186.6
5454	O	B221, extrusion	–	2.999	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	H112	B221, extrusion	–	2.999	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	O	B209, sheet & plate	0.020	3.000	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	H111	B221, extrusion	–	2.999	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1

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Table 1-2
BUCKLING CONSTANTS (WELDED) (continued)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
5454	H32	B209, sheet & plate	0.020	2.000	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5454	H34	B209, sheet & plate	0.020	1.000	31	12	12	13.3	0.059	149.9	15.6	0.075	138.5	15.4	0.479	21.9	20.7	0.115	120.2	23.1	1.128	11.9	9.4	0.035	178.1
5456	O	B209, sheet & plate	0.051	1.500	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H116	B928, sheet & plate	0.063	1.250	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H116	B928, sheet & plate	1.251	1.500	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H116	B928, sheet & plate	1.501	3.000	41	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5456	H32	B209, sheet & plate	0.188	0.499	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H32	B209, sheet & plate	0.500	1.500	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H32	B209, sheet & plate	1.501	3.000	41	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
5456	H321	B928, sheet & plate	0.188	0.499	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H321	B928, sheet & plate	0.500	1.500	42	19	19	21.6	0.123	117.7	25.7	0.158	108.0	24.9	0.910	17.6	34.1	0.243	93.6	37.4	2.141	10.1	15.5	0.075	138.8
5456	H321	B928, sheet & plate	1.501	3.000	41	18	18	20.4	0.112	121.1	24.2	0.145	111.2	23.5	0.844	18.1	32.2	0.223	96.4	35.3	1.985	10.3	14.6	0.068	143.0
6005	T5	B221, extrusion	–	1.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6005A	T5	B221, extrusion	–	0.999	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6005A	T61	B221, extrusion	–	1.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6, T651	B209, sheet & plate	0.010	4.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B632, tread plate	0.100	0.625	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6, T6510, T6511	B221, extrusion	All		24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6, T651	B211, bar, rod, & wire	0.125	8.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B210, drawn tube	0.025	0.500	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B241, pipe & tube	All		24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B429, pipe & tube	All		24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B247, forging	–	4.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6061	T6	B308, std struct. profile	0.062		24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6063	T5	B221, extrusion	–	0.500	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6063	T5	B221, extrusion	0.501	1.000	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6063	T52	B221, extrusion	–	1.000	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6063	T6	B221, extrusion	–	1.000	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6063	T6	B241, pipe & tube	–	1.000	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4

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Table 1-2
BUCKLING CONSTANTS (WELDED)

Alloy	Temper	ASTM Specification Product*	Thickness Inches From	To	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
6063	T6	B429, pipe & tube	–	1.000	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6063	T832	B210, drawn tube	0.05	0.259	17	8	8	8.7	0.031	185.3	10.1	0.039	172.1	10.1	0.273	26.7	13.4	0.060	149.6	15.1	0.642	13.7	6.1	0.018	221.4
6066	T6, T6510, T6511	B221, extrusion	All		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6070	T6	B221, extrusion	–	2.999	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6082	T6, T6511	B221, extrusion	0.200	6.000	28	16	16	18.0	0.093	128.9	21.3	0.120	118.5	20.8	0.716	19.2	28.3	0.184	102.8	31.2	1.684	10.7	12.9	0.056	152.4
6105	T5	B221, extrusion	–	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6351	T5	B221, extrusion	–	1.000	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6351	T6	B221, extrusion	–	0.749	24	15	15	16.8	0.084	133.3	19.9	0.108	122.7	19.5	0.654	19.7	26.4	0.165	106.5	29.2	1.539	11.0	12.0	0.051	157.8
6360	T5	B221, extrusion	–	0.25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6360	T6	B221, extrusion	–	0.25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6463	T6	B221, extrusion	–	0.500	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7005	T53	B221, extrusion	–	0.750	40	24	24	27.7	0.178	103.9	33.1	0.232	95.1	31.8	1.261	15.7	44.1	0.357	82.4	47.7	2.968	9.3	20.0	0.109	122.2

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Table 1-3
RESISTANCE AND SAFETY FACTORS IN THE *SPECIFICATION FOR ALUMINUM STRUCTURES*

Limit State	ϕ building	Ω building	Specification Section
Members:			
axial tension: rupture	0.75	1.95	D.1
axial tension: yield	0.90	1.65	D.1
axial compression	0.90	1.65	E.1
flexure: rupture	0.75	1.95	F.1
flexure: other limit states	0.90	1.65	F.1
shear: rupture	0.75	1.95	G.1
shear: other limit states	0.90	1.65	G.1
torsion: rupture	0.75	1.95	H.2
torsion: other limit states	0.90	1.65	H.2
Connections:			
welds	0.75	1.95	J.2
bolt tension	0.65	2.34	J.3.4
bolt bearing; rivet bearing	0.75	1.95	J.3.6, J.4.6
slip-critical bolt shear and tension	0.75	2.00	J.3.7.4
slip-critical bolt slip (standard size and short-slotted holes perpendicular to the direction of the load)	1.00	1.50	J.3.7.5
slip-critical bolt slip (oversized and short-slotted holes parallel to the direction of the load)	0.85	1.76	J.3.7.5
slip-critical bolt slip (long-slotted holes)	0.70	2.14	J.3.7.5
bolt shear; rivet shear	0.65	2.34	J.3.5, J.4.5
screwed connection tension	0.50	3.00	J.5.4
screwed connection shear	0.50	3.00	J.5.5
pin bearing	0.75	1.95	J.6.5
pin rupture from shear or flexure	0.65	2.34	J.6.4
pin yielding from shear or flexure	0.90	1.65	J.6.4
shear yielding of connectors	1.00	1.50	J.7.2a
shear rupture of connectors	0.75	1.95	J.7.2b
block shear rupture	0.75	1.95	J.7.3
bearing on flat surfaces	0.75	1.95	J.8
flange local bending	0.90	1.65	J.9.1
web local yielding	1.00	1.50	J.9.2
web crippling	0.75	1.95	J.9.3
braces	0.75	2.00*	6.1

*3.0 for torsional point bracing of beams

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Table 1-4

MEMBER NOMINAL STRENGTHS IN THE *SPECIFICATION FOR ALUMINUM STRUCTURES*

Type of Stress	Spec Section	Limit State	No Weld	Transverse Weld		Longitudinal Weld
Axial Tension	D.2a	yielding $P_{nt}=$	$F_{ty}A_g$	$F_{ty}A_g$		$F_{ty}(A_g - A_{wz}) + F_{tyw}A_{wz}$
	D.2b	rupture $P_{nt}=$	$\frac{F_{ty}A_e}{k_t}$	$\frac{F_{tu}(A_e - A_{ewz})}{k_t} + F_{tuw}A_{ewz}$		$\frac{F_{tu}(A_e - A_{ewz})}{k_t} + F_{tyw}A_{ewz}$
Axial Compression	E.2 buckling	member $P_{nc}=$	$P_{nco} = F_{co}A_g$	welds at ends P_{nco}	welds not at ends $P_{ncw} = F_{cw}A_g$	$P_{nco}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{P_{ncw}A_{wz}}{A_g}$
	B.5.4	local buckling $F_c=$	F_{co}	$F_{co}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{cw}A_{wz}}{A_g}$ if $b/t \le \lambda_1$, $F_c = F_{co}$		$F_{co}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{cw}A_{wz}}{A_g}$
Flexure	F.2	yielding $M_{np}=$	$ZF_{cy} \le 1.5S_tF_{ty}$ and $1.5S_cF_{cy}$			
	F.2	rupture $M_{nu}=$	$\frac{ZF_{tu}}{k_t}$			
	B.5.4	local buckling $F_c=$	F_{co}	$F_{co}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{cw}A_{wz}}{A_g}$		$F_{co}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{cw}A_{wz}}{A_g}$
	B.5.5	local buckling $F_b=$	F_{bo}	$F_{bo}\left(1 - \frac{A_{wzc}}{A_{gc}}\right) + \frac{F_{bw}A_{wzc}}{A_{gc}}$		$F_{bo}\left(1 - \frac{A_{wzc}}{A_{gc}}\right) + \frac{F_{bw}A_{wzc}}{A_{gc}}$
	F.4	lateral-torsional buckling $M_{nmb}=$	M_{nmbo}	welds at ends M_{nmbo}	welds not at ends M_{nmbw}	$M_{nmbo}\left(1 - \frac{A_{wz}}{A_f}\right) + \frac{M_{nmbw}A_{wz}}{A_f}$
Shear	G.1	yielding and buckling $V_n=$	$F_{so}A_v$	$F_{so}(A_v - A_{wz}) + F_{sw}A_{wz}$		$F_{so}(A_v - A_{wz}) + F_{sw}A_{wz}$
	G,2, G.3	rupture $V_n=$	$\frac{F_{su}A_n}{k_t}$	$\frac{F_{su}(A_n - A_{wz})}{k_t} + F_{suw}A_{wz}$		$\frac{F_{su}(A_n - A_{wz})}{k_t} + F_{suw}A_{wz}$
Torsion	H.2	rupture $F_s=$	$\frac{F_{su}}{k_t}$	$\frac{F_{su}}{k_t}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{suw}A_{wz}}{A_g}$		$\frac{F_{su}}{k_t}\left(1 - \frac{A_{wz}}{A_{gc}}\right) + \frac{F_{suw}A_{wz}}{A_g}$
	H.2	yielding buckling $F_s=$	F_{so}	$F_{so}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{suw}A_{wz}}{A_g}$		$F_{so}\left(1 - \frac{A_{wz}}{A_g}\right) + \frac{F_{sw}A_{wz}}{A_g}$

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Table 1-5
STRESSES CORRESPONDING TO NOMINAL STRENGTHS *F* IN THE *SPECIFICATION FOR ALUMINUM STRUCTURES*

Type of Stress	Section	λ	$\lambda \leq \lambda_1$	λ_1	$\lambda_1 < \lambda < \lambda_2$	λ_2	$\lambda \geq \lambda_2$
Axial Compression member buckling	E.2	kL/r	F_{cy}	$(B_c - F_{cy})/D_c$	$(B_c - D_c\lambda)(0.85 + 0.15(C_c - \lambda)/(C_c - \lambda_1))$	C_c	$0.85\pi^2E/\lambda^2$
Flexure lateral-torsional buckling	F.4	see F.4.2		-	$M_{np}(1 - \lambda/C_c)/S_{xc} + \pi^2E\lambda/C_c^3$	C_c	π^2E/λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns	B.5.4.1	b/t	F_{cy}	$(B_p - F_{cy})/(5D_p)$	$B_p - 5.0\ D_p\lambda$	$C_p/5$	$\pi^2E/(5.0\lambda)^2$
whose buckling axis is not an axis of symmetry							
flat elements supported on one edge	B.5.4.1	b/t	F_{cy}	$(B_p - F_{cy})/(5D_p)$	$B_p - 5.0\ D_p\lambda$	$k_1B_p/5D_p$	$k_2(B_pE)^{1/2}/(5\lambda)$
in all other columns and all beams							
flat elements supported on both edges	B.5.4.2	b/t	F_{cy}	$(B_p - F_{cy})/(1.6D_p)$	$B_p - 1.6\ D_p\lambda$	$k_1B_p/1.6D_p$	$k_2(B_pE)^{1/2}/(1.6\lambda)$
flat elements supported on both edges	B.5.4.4	λ_s	F_{cy}	$(B_c - F_{cy})/D_c$	$B_c - D_c\lambda$	C_c	π^2E/λ^2
and with an intermediate stiffener							
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	F_{cy}	$(B_t - F_{cy})/D_t$	$B_t - D_t\lambda$	C_t	$\pi^2E/[16\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.4.6	λ_{eq}	F_{cy}	$(B_p - F_{cy})/D_p$	$B_p - D_p\lambda$	k_1B_p/D_p	$k_2(B_pE)^{1/2}/\lambda$
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	$1.5F_{cy}$	$(B_{br} - 1.5F_{cy})/(mD_{br})$	$B_{br} - mD_{br}\lambda$	k_1B_{br}/mD_{br}	$k_2(B_{br}E)^{1/2}/(m\lambda)$
flat elements supported on tension edge,	B.5.5.2	b/t	$1.5F_{cy}$	$(B_{br} - 1.5F_{cy})/(3.5D_{br})$	$B_{br} - 3.5D_{br}\lambda$	$C_{br}/3.5$	$\pi^2E/(3.5\lambda)^2$
compression edge free							
flat elements supported on both edges	B.5.5.3	b/t	$1.5F_{cy}$	$(B_{br} - 1.5F_{cy})/(0.29D_{br})$	$B_{br} - 0.29D_{br}\lambda$	$k_1B_{br}/0.29D_{br}$	$k_2(B_{br}E)^{1/2}/(0.29\lambda)$
and with a longitudinal stiffener							
pipes and round tubes	B.5.5.4	$(R_b/t)^{1/2}$	$B_{tb} - D_{tb}\lambda$	C_{tb}	$B_t - D_t\lambda$	C_t	$\pi^2E/[16\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.5.5	λ_{eq}	$1.5F_{cy}$	$(B_{br} - 1.5F_{cy})/D_{br}$	$B_{br} - D_{br}\lambda$	k_1B_{br}/D_{br}	$k_2(B_{br}E)^{1/2}/\lambda$
Elements - Shear							
flat elements supported on both edges	G.2	b/t	F_{sy}	$(B_s - F_{sy})/1.25D_s$	$B_s - 1.25D_s\lambda$	$C_s/1.25$	$\pi^2E/(1.25\lambda)^2$
flat elements supported on one edge	G.3	b/t	F_{sy}	$(B_s - F_{sy})/3.0D_s$	$B_s - 3.0D_s\lambda$	$C_s/3.0$	$\pi^2E/(3.0\lambda)^2$
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(Lv/R_b)^{1/4}$	F_{sy}	$(1.3B_s - F_{sy})/1.63D_s$	$1.3B_s - 1.25D_s\lambda$	$C_s/1.25$	$1.3\pi^2E/(1.25\lambda)^2$
Torsion pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(Lv/R_b)^{1/4}$	F_{sy}	$(B_s - F_{sy})/1.25D_s$	$B_s - 1.25D_s\lambda$	$C_s/1.25$	$\pi^2E/(1.25\lambda)^2$

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Table 1-5 (continued)

STRESSES CORRESPONDING TO NOMINAL STRENGTHS *F* IN THE *SPECIFICATION FOR ALUMINUM STRUCTURES*

Type of Stress	Section	*F*
Axial Tension		
axial tension stress on effective net area	D.2a	F_{tu}/k_t
axial tension stress on gross area	D.2b	F_{ty}
Shear or Torsion		
rupture	G.1, H.2	$0.6F_{tu}/k_t$
Bearing		
bolts, rivets, or screws on holes	J.3.6a, J.4.6, J.5.5.1	$2F_{tu}$
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	$1.33F_{tu}$

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Table 1-6
ELEMENTS IN UNIFORM COMPRESSION

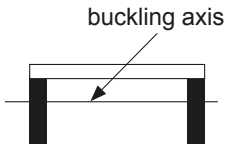
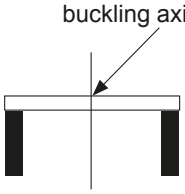
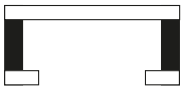
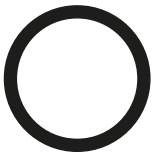
Section	flat or curved?	one edge	intermediate stiffener?	other edge	Example
B.5.4.1 elastic buckling	flat	supported	no	free	
B.5.4.1 post buckling	flat	supported	no	free	
B.5.4.2	flat	supported	no	supported	
B.5.4.3	flat	supported	no	stiffened	
B.5.4.4	flat	supported	yes	supported	
B.5.4.5	curved	supported	no	supported	
B.5.4.6	flat	whole shape			

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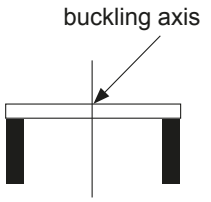
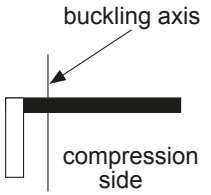
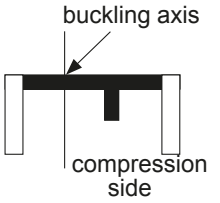
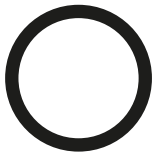
Table 1-7
ELEMENTS IN FLEXURAL COMPRESSION

Section	flat or curved?	one edge	intermediate stiffener?	other edge	Example
B.5.5.1	flat	supported	no	supported	
B.5.5.2	flat	tension edge supported	no	compression edge free	
B.5.5.3	flat	supported	yes	supported	
B.5.5.4	pipes and round tubbes				
B.5.5.5	flat	whole shape			

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Tables 2-1 through 2-24 and 2-1W through 2-24W

1. These tables provide allowable stresses F/Ω for building-type structures determined in accordance with the *Specification for Aluminum Structures.*
2. For tubes with circumferential welds, these tables apply for $R_b/t < 20$.

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Table 2-1

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

1100 - H14 **ASTM B209 0.009 to 1.000 in. thick**
1100 - H14 **ASTM B210 0.014 to 0.500 thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	8.2
axial tension stress on gross area	D.2a	8.5
Shear or torsion		
Shear or torsion rupture	G, H.2	4.9
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	16.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	10.9
screws in holes	J.5.5.1	10.7

			F_{ty} =	14	k/in^2
			F_{cy} =	12.6	k/in^2
			F_{tu} =	16	k/in^2
			E =	10,100	k/in^2
			k_t =	1	

		λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	7.6	22.1	$0.00005\,\lambda^2 - 0.050\,\lambda + 8.7$	146	$51{,}352\ /\lambda^2$
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	146	$60{,}414\ /\lambda^2$
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.6	9.5	$10.0 - 0.246\,\lambda$	27	$2{,}417\ /\lambda^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.6	9.5	$10.0 - 0.246\,\lambda$	20.2	$101\ /\lambda$
flat elements supported on both edges	B.5.4.2	b/t	7.6	29.6	$10.0 - 0.079\,\lambda$	63	$315\ /\lambda$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.6	22.1	$8.5 - 0.039\,\lambda$	146	$60{,}414\ /\lambda^2$
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	7.6	7.0	$9.8 - 0.311\,\lambda$	22	$3{,}776\ /[\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.4.6	λ_{eq}	7.6	47.4	$10.0 - 0.049\,\lambda$	101	$504\ /\lambda$
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.5	36.4	$13.2 - 0.049\,\lambda$	135	$893\ /\lambda$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.5	6.8	$13.2 - 0.264\,\lambda$	33	$4{,}932\ /\lambda^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.5	81.5	$13.2 - 0.022\,\lambda$	303	$2{,}002\ /\lambda$
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	$14.7 - 0.732\,\lambda$	11.7	$9.8 - 0.311\,\lambda$	22	$3{,}776\ /[\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.5.5	λ_{eq}	11	23.6	$13.2 - 0.075\,\lambda$	88	$581\ /\lambda$
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.1	48.5	$6.8 - 0.034\,\lambda$	131	$38{,}665\ /\lambda^2$
flat elements supported on one edge	G.3	b/t	5.1	20.2	$6.8 - 0.082\,\lambda$	55	$6{,}713\ /\lambda^2$
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.1	82.4	$8.8 - 0.045\,\lambda$	131	$50{,}264\ /\lambda^2$
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.1	48.5	$6.8 - 0.034\,\lambda$	131	$38{,}665\ /\lambda^2$

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Table 2-2
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

3003 - H14 **ASTM B209 0.009 to 1.000 in. thick**
3003 - H14 **ASTM B210 0.010 to 0.500 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	10.3
axial tension stress on gross area	D.2a	10.3
Shear or torsion		
Shear or torsion rupture	G, H.2	6.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	20.5
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	13.6
screws in holes	J.5.5.1	13.3

F_{ty} = 17 k/in^2 E = 10,100 k/in^2
F_{cy} = 15.3 k/in^2 k_t = 1
F_{tu} = 20 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	9.3	21.8	0.00007 λ^2 - 0.068 λ + 10.7	132	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	132	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.3	9.0	12.3 - 0.338 λ	24	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.3	9.0	12.3 - 0.338 λ	18.2	112 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.3	28.0	12.3 - 0.108 λ	57	350 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.3	21.8	10.4 - 0.053 λ	132	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.3	6.8	12.0 - 0.408 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.3	44.8	12.3 - 0.068 λ	91	560 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.9	36.2	16.3 - 0.067 λ	122	993 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.9	6.7	16.3 - 0.362 λ	30	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.9	81.1	16.3 - 0.030 λ	272	2,225 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	18.1 - 0.959 λ	10.9	12.0 - 0.408 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	13.9	23.5	16.3 - 0.103 λ	79	645 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	6.2	45.8	8.3 - 0.047 λ	118	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	6.2	19.1	8.3 - 0.113 λ	49	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	6.2	75.8	10.8 - 0.061 λ	118	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	6.2	45.8	8.3 - 0.047 λ	118	38,665 /λ^2

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Table 2-3

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

3003 - H16 ASTM B209 0.006 to 0.162 in. thick
3003 - H16 ASTM B210 0.010 to 0.500 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	12.7
Shear or torsion		
Shear or torsion rupture	G, H.2	7.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	24.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	16.4
screws in holes	J.5.5.1	16.0

F_{ty} = 21 k/in^2 F_{cy} = 18.9 k/in^2 F_{tu} = 24 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	11.5	21.4	0.00011 λ^2 - 0.096 λ + 13.5	118	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	118	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	11.5	8.4	15.5 - 0.476 λ	22	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	11.5	8.4	15.5 - 0.476 λ	16.2	126 /λ
flat elements supported on both edges	B.5.4.2	b/t	11.5	26.3	15.5 - 0.152 λ	51	392 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	11.5	21.4	13.0 - 0.074 λ	118	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	11.5	6.5	15.0 - 0.547 λ	18	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	11.5	42.1	15.5 - 0.095 λ	81	628 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	17.2	35.7	20.6 - 0.095 λ	108	1,114 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	17.2	6.6	20.6 - 0.511 λ	27	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	17.2	80.1	20.6 - 0.042 λ	243	2,496 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	22.5 - 1.29 λ	10.1	15.0 - 0.547 λ	18	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	17.2	23.2	20.6 - 0.146 λ	70	724 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	7.6	43.0	10.5 - 0.067 λ	105	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	7.6	17.9	10.5 - 0.160 λ	44	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	7.6	69.2	13.6 - 0.087 λ	105	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	7.6	43.0	10.5 - 0.067 λ	105	38,665 /λ^2

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Table 2-4

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

Alclad 3004 - H34 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	14.5
Shear or torsion		
Shear or torsion rupture	G, H.2	9.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	31.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	21.1
screws in holes	J.5.5.1	20.7

F_{ty} = 24 k/in^2 E = 10,100 k/in^2
F_{cy} = 21.6 k/in^2 k_t = 1
F_{tu} = 31 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	13.1	21.1	0.00015 λ^2 - 0.120 λ + 15.6	110	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	110	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	13.1	8.1	17.9 - 0.592 λ	20	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	13.1	8.1	17.9 - 0.592 λ	15.1	135 /λ
flat elements supported on both edges	B.5.4.2	b/t	13.1	25.3	17.9 - 0.189 λ	47	422 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	13.1	21.1	15.0 - 0.091 λ	110	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	13.1	6.3	17.3 - 0.660 λ	17	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	13.1	40.5	17.9 - 0.118 λ	76	675 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	19.6	35.3	23.8 - 0.118 λ	101	1,198 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	19.6	6.6	23.8 - 0.637 λ	25	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	19.6	79.1	23.8 - 0.053 λ	226	2,685 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	25.9 - 1.55 λ	9.7	17.3 - 0.660 λ	17	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	19.6	22.9	23.8 - 0.182 λ	65	779 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	8.7	41.3	12.1 - 0.083 λ	98	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	8.7	17.2	12.1 - 0.199 λ	41	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	8.7	65.4	15.8 - 0.108 λ	98	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	8.7	41.3	12.1 - 0.083 λ	98	38,665 /λ^2

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Table 2-5
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 - H14 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	10.8
axial tension stress on gross area	D.2a	10.3
Shear or torsion		
Shear or torsion rupture	G, H.2	6.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	21.5
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	14.3
screws in holes	J.5.5.1	14.0

F_{ty} = 17 k/in^2 F_{cy} = 15.3 k/in^2 F_{tu} = 21 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	9.3	21.8	0.00007 λ^2 - 0.068 λ + 10.7	132	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	132	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.3	9.0	12.3 - 0.338 λ	24	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.3	9.0	12.3 - 0.338 λ	18.2	112 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.3	28.0	12.3 - 0.108 λ	57	350 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.3	21.8	10.4 - 0.053 λ	132	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.3	6.8	12.0 - 0.408 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.3	44.8	12.3 - 0.068 λ	91	560 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.9	36.2	16.3 - 0.067 λ	122	993 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.9	6.7	16.3 - 0.362 λ	30	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.9	81.1	16.3 - 0.030 λ	272	2,225 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	18.1 - 0.959 λ	10.9	12.0 - 0.408 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	23.5	44.8	16.3 - 0.103 λ	79	645 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	6.2	45.8	8.3 - 0.047 λ	118	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	6.2	19.1	8.3 - 0.113 λ	49	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	6.2	75.8	10.8 - 0.061 λ	118	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	6.2	45.8	8.3 - 0.047 λ	118	38,665 /λ^2

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Table 2-6
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 - H32 ASTM B209 0.017 to 2.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	8.7
axial tension stress on gross area	D.2a	7.3
Shear or torsion		
Shear or torsion rupture	G, H.2	5.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	17.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	11.6
screws in holes	J.5.5.1	11.3

F_{ty} = 12 k/in^2 F_{cy} = 10.8 k/in^2 F_{tu} = 17 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	6.5	22.4	0.00003 λ^2 - 0.039 λ + 7.4	158	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	158	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	6.5	9.9	8.4 - 0.192 λ	29	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	6.5	9.9	8.4 - 0.192 λ	22.0	93 /λ
flat elements supported on both edges	B.5.4.2	b/t	6.5	30.9	8.4 - 0.061 λ	69	290 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	6.5	22.4	7.2 - 0.030 λ	158	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	6.5	7.3	8.4 - 0.251 λ	23	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	6.5	49.5	8.4 - 0.038 λ	110	464 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	9.8	36.3	11.2 - 0.038 λ	147	822 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	9.8	6.7	11.2 - 0.205 λ	36	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	9.8	81.4	11.2 - 0.017 λ	329	1,842 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	12.5 - 0.590 λ	12.3	8.4 - 0.251 λ	23	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	23.6	49.5	11.2 - 0.059 λ	95	534 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	4.4	21.1	5.7 - 0.064 λ	59	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	4.4	88.0	7.4 - 0.035 λ	142	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2

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Table 2-7
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 - H34 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	10.3
axial tension stress on gross area	D.2a	9.1
Shear or torsion		
Shear or torsion rupture	G, H.2	6.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	20.5
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	13.6
screws in holes	J.5.5.1	13.3

F_{ty} = 15 k/in^2 E = 10,100 k/in^2
F_{cy} = 13.5 k/in^2 k_t = 1
F_{tu} = 20 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	8.2	22.0	0.00005 λ^2 - 0.056 λ + 9.4	141	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	141	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.2	9.3	10.7 - 0.276 λ	26	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.2	9.3	10.7 - 0.276 λ	19.5	105 /λ
flat elements supported on both edges	B.5.4.2	b/t	8.2	29.0	10.7 - 0.088 λ	61	327 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.2	22.0	9.1 - 0.043 λ	141	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	8.2	6.9	10.6 - 0.342 λ	21	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	8.2	46.5	10.7 - 0.055 λ	97	523 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	12.3	36.3	14.3 - 0.055 λ	130	927 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	12.3	6.7	14.3 - 0.295 λ	32	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	12.3	81.5	14.3 - 0.024 λ	292	2,079 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	15.8 - 0.805 λ	11.4	10.6 - 0.342 λ	21	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	12.3	23.6	14.3 - 0.084 λ	85	603 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.5	19.8	7.3 - 0.092 λ	53	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.5	80.0	9.5 - 0.050 λ	126	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2

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Table 2-8
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5050 - H34 ASTM B209 0.009 to 0.249 in. thick
5050 - H34 ASTM B210 0.010 to 0.500 in. thick

F_{ty} = 20 k/in^2 E = 10,100 k/in^2
F_{cy} = 18 k/in^2 k_t = 1
F_{tu} = 25 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	12.1
Shear or torsion		
Shear or torsion rupture	G, H.2	7.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	25.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	17.1
screws in holes	J.5.5.1	16.7

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	10.9	21.5	0.00010 λ^2 - 0.089 λ + 12.8	121	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	121	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	10.9	8.5	14.7 - 0.440 λ	22	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	10.9	8.5	14.7 - 0.440 λ	16.7	122 /λ
flat elements supported on both edges	B.5.4.2	b/t	10.9	26.7	14.7 - 0.141 λ	52	382 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ$_s$	10.9	21.5	12.4 - 0.068 λ	121	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	10.9	6.6	14.3 - 0.511 λ	18.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ$_{eq}$	10.9	42.7	14.7 - 0.088 λ	83	611 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	16.4	35.9	19.5 - 0.088 λ	111	1,085 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	16.4	6.7	19.5 - 0.472 λ	28	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	16.4	80.4	19.5 - 0.039 λ	249	2,431 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	21.4 - 1.20 λ	10.3	14.3 - 0.511 λ	18.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ$_{eq}$	16.4	23.3	19.5 - 0.135 λ	72	705 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	7.3	43.6	10.0 - 0.061 λ	108	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	7.3	18.2	10.0 - 0.147 λ	45	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	7.3	70.7	12.9 - 0.080 λ	108	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	7.3	43.6	10.0 - 0.061 λ	108	38,665 /λ^2

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Table 2-9
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 - H32 ASTM B209 0.017 to 2.000 in. thick
5052 - H32 ASTM B210 0.010 to 0.450 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	13.9
Shear or torsion		
Shear or torsion rupture	G, H.2	9.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	31.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	21.1
screws in holes	J.5.5.1	20.7

F_{ty} = 23 k/in^2 E = 10,100 k/in^2
F_{cy} = 20.7 k/in^2 k_t = 1
F_{tu} = 31 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	12.5	21.2	0.00014 λ^2 - 0.112 λ + 14.9	112	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	112	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	12.5	8.2	17.1 - 0.552 λ	21	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	12.5	8.2	17.1 - 0.552 λ	15.5	132 /λ
flat elements supported on both edges	B.5.4.2	b/t	12.5	25.6	17.1 - 0.177 λ	48	412 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	12.5	21.2	14.4 - 0.085 λ	112	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	12.5	6.4	16.5 - 0.622 λ	16.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	12.5	41.0	17.1 - 0.110 λ	77	660 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	18.8	35.4	22.7 - 0.110 λ	103	1,171 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	18.8	6.6	22.7 - 0.594 λ	26	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	18.8	79.4	22.7 - 0.049 λ	231	2,624 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	24.8 - 1.46 λ	9.8	16.5 - 0.622 λ	16.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	18.8	23.0	22.7 - 0.170 λ	67	761 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	8.4	41.8	11.6 - 0.077 λ	100	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	8.4	17.4	11.6 - 0.185 λ	42	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	8.4	66.6	15.1 - 0.101 λ	100	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	8.4	41.8	11.6 - 0.077 λ	100	38,665 /λ^2

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Table 2-10
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 - H34 **ASTM B209 0.009 to 1.000 in. thick**
5052 - H34 **ASTM B210 0.010 to 0.450 in. thick**

F_{ty} = 26 k/in^2 E = 10,100 k/in^2
F_{cy} = 23.4 k/in^2 k_t = 1
F_{tu} = 34 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	17.4
axial tension stress on gross area	D.2a	15.8
Shear or torsion		
Shear or torsion rupture	G, H.2	10.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	34.9
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	23.2
screws in holes	J.5.5.1	22.7

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	14.2	21.0	0.00018 λ^2 - 0.136 λ + 17.0	105	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	105	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.2	7.9	19.5 - 0.675 λ	19	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.2	7.9	19.5 - 0.675 λ	14.5	141 /λ
flat elements supported on both edges	B.5.4.2	b/t	14.2	24.7	19.5 - 0.216 λ	45	441 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.2	21.0	16.4 - 0.104 λ	105	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	14.2	6.2	18.8 - 0.738 λ	15.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eg}	14.2	39.5	19.5 - 0.135 λ	72	705 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	21.3	35.0	26.0 - 0.135 λ	96	1,252 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	21.3	6.5	26.0 - 0.726 λ	24	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	21.3	78.4	26.0 - 0.060 λ	216	2,806 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	28.2 - 1.74 λ	9.4	18.8 - 0.738 λ	15.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eg}	21.3	22.7	26.0 - 0.207 λ	63	814 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	9.5	40.3	13.3 - 0.094 λ	94	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	9.5	16.8	13.3 - 0.227 λ	39	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	9.5	63.2	17.2 - 0.123 λ	94	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	9.5	40.3	13.3 - 0.094 λ	94	38,665 /λ^2

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Table 2-11
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 - H36 ASTM B209 0.006 to 0.162 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	19.0
axial tension stress on gross area	D.2a	17.6
Shear or torsion		
Shear or torsion rupture	G, H.2	11.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	37.9
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	25.2
screws in holes	J.5.5.1	24.7

F_{ty} = 29 k/in^2 E = 10,100 k/in^2
F_{cy} = 26.1 k/in^2 k_t = 1
F_{tu} = 37 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	15.8	20.7	0.00024 λ^2 - 0.163 λ + 19.1	99	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	99	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.8	7.6	22.0 - 0.807 λ	18	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.8	7.6	22.0 - 0.807 λ	13.6	150 /λ
flat elements supported on both edges	B.5.4.2	b/t	15.8	23.9	22.0 - 0.258 λ	43	468 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.8	20.7	18.4 - 0.123 λ	99	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	15.8	6.1	21.1 - 0.860 λ	15.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	15.8	38.2	22.0 - 0.161 λ	68	748 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	23.7	34.5	29.3 - 0.161 λ	91	1,329 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	23.7	6.4	29.3 - 0.869 λ	22	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	23.7	77.4	29.3 - 0.072 λ	203	2,979 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	31.6 - 2.02 λ	9.1	21.1 - 0.860 λ	15.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	23.7	22.5	29.3 - 0.248 λ	59	864 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	10.5	38.9	14.9 - 0.113 λ	88	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	10.5	16.2	14.9 - 0.271 λ	37	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	10.5	60.2	19.4 - 0.147 λ	88	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	10.5	38.9	14.9 - 0.113 λ	88	38,665 /λ^2

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Table 2-12
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5083 - H116 ASTM B928 0.125 to 1.500 in. thick
5083 - H32 ASTM B209 0.125 to 1.500 in. thick
5083 - H321 ASTM B928 0.125 to 1.500 in. thick

F_{ty} = 31 k/in^2 E = 10,100 k/in^2
F_{cy} = 27.9 k/in^2 k_t = 1
F_{tu} = 44 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	22.6
axial tension stress on gross area	D.2a	18.8
Shear or torsion		
Shear or torsion rupture	G, H.2	13.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	45.1
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	30.0
screws in holes	J.5.5.1	29.3

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	16.9	20.6	0.00027 λ^2 - 0.182 λ + 20.5	96	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	96	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	16.9	7.5	23.7 - 0.900 λ	18	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	16.9	7.5	23.7 - 0.900 λ	13.1	155 /λ
flat elements supported on both edges	B.5.4.2	b/t	16.9	23.4	23.7 - 0.288 λ	41	485 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	16.9	20.6	19.7 - 0.137 λ	96	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	16.9	6.0	22.6 - 0.944 λ	14.6	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	16.9	37.4	23.7 - 0.180 λ	66	776 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	25.4	34.2	31.5 - 0.180 λ	88	1,379 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	25.4	6.4	31.5 - 0.970 λ	22	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	25.4	76.8	31.5 - 0.080 λ	196	3,091 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	33.9 - 2.22 λ	8.8	22.6 - 0.944 λ	14.6	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	25.4	22.3	31.5 - 0.277 λ	57	896 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	11.3	38.1	16.1 - 0.126 λ	85	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	11.3	15.9	16.1 - 0.303 λ	35	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	11.3	58.5	20.9 - 0.165 λ	85	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	11.3	38.1	16.1 - 0.126 λ	85	38,665 /λ^2

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Table 2-13
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5086 - H34 ASTM B209 0.009 to 1.000 in. thick
5086 - H34 ASTM B210 0.010 to 0.450 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	22.6
axial tension stress on gross area	D.2a	20.6
Shear or torsion		
Shear or torsion rupture	G, H.2	13.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	45.1
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	30.0
screws in holes	J.5.5.1	29.3

F_{ty} = 34 k/in^2 F_{cy} = 30.6 k/in^2 F_{tu} = 44 k/in^2

E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	18.5	20.4	0.00034 λ^2 - 0.212 λ + 22.7	91	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	91	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	18.5	7.3	26.2 - 1.048 λ	17	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	18.5	7.3	26.2 - 1.048 λ	12.5	163 /λ
flat elements supported on both edges	B.5.4.2	b/t	18.5	22.7	26.2 - 0.335 λ	39	510 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	18.5	20.4	21.8 - 0.159 λ	91	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	18.5	5.9	24.9 - 1.074 λ	14.0	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	18.5	36.4	26.2 - 0.210 λ	62	817 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	27.8	33.8	34.9 - 0.210 λ	83	1,451 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	27.8	6.3	34.9 - 1.130 λ	21	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	27.8	75.8	34.9 - 0.094 λ	186	3,252 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	37.3 - 2.53 λ	8.6	24.9 - 1.074 λ	14.0	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	27.8	22.0	34.9 - 0.323 λ	54	943 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	12.4	37.0	17.8 - 0.147 λ	81	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	12.4	15.4	17.8 - 0.353 λ	34	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	12.4	56.2	23.1 - 0.192 λ	81	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	12.4	37.0	17.8 - 0.147 λ	81	38,665 /λ^2

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Table 2-14
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5086 - H116 ASTM B928 0.063 to 2.000 in. thick
5086 - H32 ASTM B209 0.020 to 2.000 in. thick
5086 - H32 ASTM B210 0.010 to 0.450 in. thick

F_{ty} = 28 k/in^2 E = 10,100 k/in^2
F_{cy} = 25.2 k/in^2 k_t = 1
F_{tu} = 40 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	20.5
axial tension stress on gross area	D.2a	17.0
Shear or torsion		
Shear or torsion rupture	G, H.2	12.3
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	41.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	27.3
screws in holes	J.5.5.1	26.7

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	15.3	20.8	0.00022 λ^2 - 0.154 λ + 18.4	101	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	101	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.3	7.7	21.2 - 0.762 λ	19	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.3	7.7	21.2 - 0.762 λ	13.9	147 /λ
flat elements supported on both edges	B.5.4.2	b/t	15.3	24.1	21.2 - 0.244 λ	43	459 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.3	20.8	17.7 - 0.117 λ	101	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	15.3	6.1	20.3 - 0.818 λ	15.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	15.3	38.6	21.2 - 0.152 λ	69	734 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	22.9	34.7	28.2 - 0.152 λ	93	1,304 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	22.9	6.4	28.2 - 0.820 λ	23	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	22.9	77.8	28.2 - 0.068 λ	207	2,922 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	30.5 - 1.93 λ	9.2	20.3 - 0.818 λ	15.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	22.9	22.6	28.2 - 0.234 λ	60	847 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	10.2	39.3	14.4 - 0.107 λ	90	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	10.2	16.4	14.4 - 0.256 λ	37	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	10.2	61.2	18.7 - 0.139 λ	90	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	10.2	39.3	14.4 - 0.107 λ	90	38,665 /λ^2

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Table 2-15
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5454 - H32 ASTM B209 0.020 to 2.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	18.5
axial tension stress on gross area	D.2a	15.8
Shear or torsion		
Shear or torsion rupture	G, H.2	11.1
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	36.9
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	24.6
screws in holes	J.5.5.1	24.0

F_{ty} = 26 k/in^2 E = 10,100 k/in^2
F_{cy} = 23.4 k/in^2 k_t = 1
F_{tu} = 36 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	14.2	21.0	0.00018 λ^2 - 0.136 λ + 17.0	105	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	105	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.2	7.9	19.5 - 0.675 λ	19	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.2	7.9	19.5 - 0.675 λ	14.5	141 /λ
flat elements supported on both edges	B.5.4.2	b/t	14.2	24.7	19.5 - 0.216 λ	45	441 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.2	21.0	16.4 - 0.104 λ	105	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	14.2	6.2	18.8 - 0.738 λ	15.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	14.2	39.5	19.5 - 0.135 λ	72	705 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	21.3	35.0	26.0 - 0.135 λ	96	1,252 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	21.3	6.5	26.0 - 0.726 λ	24	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	21.3	78.4	26.0 - 0.060 λ	216	2,806 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	28.2 - 1.74 λ	9.4	18.8 - 0.738 λ	15.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	21.3	22.7	26.0 - 0.207 λ	63	814 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	9.5	40.3	13.3 - 0.094 λ	94	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	9.5	16.8	13.3 - 0.227 λ	39	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	9.5	63.2	17.2 - 0.123 λ	94	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	9.5	40.3	13.3 - 0.094 λ	94	38,665 /λ^2

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Table 2-16
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5454 - H34 ASTM B209 0.020 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	20.0
axial tension stress on gross area	D.2a	17.6
Shear or torsion		
Shear or torsion rupture	G, H.2	12.0
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	40.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	26.6
screws in holes	J.5.5.1	26.0

F_{ty} = 29 k/in^2 F_{cy} = 26.1 k/in^2 F_{tu} = 39 k/in^2

E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	15.8	20.7	0.00024 λ^2 - 0.163 λ + 19.1	99	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	99	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.8	7.6	22.0 - 0.807 λ	18	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.8	7.6	22.0 - 0.807 λ	13.6	150 /λ
flat elements supported on both edges	B.5.4.2	b/t	15.8	23.9	22.0 - 0.258 λ	43	468 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.8	20.7	18.4 - 0.123 λ	99	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	15.8	6.1	21.1 - 0.860 λ	15.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	15.8	38.2	22.0 - 0.161 λ	68	748 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	23.7	34.5	29.3 - 0.161 λ	91	1,329 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	23.7	6.4	29.3 - 0.869 λ	22	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	23.7	77.4	29.3 - 0.072 λ	203	2,979 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	31.6 - 2.02 λ	9.1	21.1 - 0.860 λ	15.1	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	23.7	22.5	29.3 - 0.248 λ	59	864 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	10.5	38.9	14.9 - 0.113 λ	88	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	10.5	16.2	14.9 - 0.271 λ	37	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	10.5	60.2	19.4 - 0.147 λ	88	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	10.5	38.9	14.9 - 0.113 λ	88	38,665 /λ^2

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Table 2-17
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6005A - T61 ASTM B221 0.000 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	19.5
axial tension stress on gross area	D.2a	21.2
Shear or torsion		
Shear or torsion rupture	G, H.2	11.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	39.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	25.9
screws in holes	J.5.5.1	25.3

F_{ty} = 35 k/in^2 E = 10,100 k/in^2
F_{cy} = 35 k/in^2 k_t = 1
F_{tu} = 38 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	21.2	17.8	0.00047 λ^2 - 0.232 λ + 25.2	66	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	66	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	12	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	10.5	186 /λ
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	27.3 - 0.291 λ	33	580 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	23.9 - 0.149 λ	66	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	21.2	5.3	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	21.2	33.3	27.3 - 0.182 λ	52	928 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	31.8	33.1	40.5 - 0.262 λ	77	1,563 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	31.8	6.1	40.5 - 1.412 λ	19	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	31.8	74.2	40.5 - 0.117 λ	173	3,502 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	39.3 - 2.70 λ	7.4	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	31.8	21.5	40.5 - 0.403 λ	50	1,016 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	12.7	14.7	16.5 - 0.257 λ	26	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	12.7	62.5	21.5 - 0.140 λ	63	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2

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Table 2-18
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6061 - T6 **ASTM B209 0.010 to 4.000 in. thick**
6061 - T651 **ASTM B209 0.010 to 4.000 in. thick**
6061 - T6 **ASTM B210 0.025 to 0.500 in. thick**
6061 - T6 **ASTM B211 0.125 to 8.000 in. thick**
6061 - T651 **ASTM B211 0.125 to 8.000 in. thick**
6061 - T6 **ASTM B632 0.010 to 0.625 in. thick**

F_{ty} = 35 k/in^2 E = 10,100 k/in^2
F_{cy} = 35 k/in^2 k_t = 1
F_{tu} = 42 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	21.5
axial tension stress on gross area	D.2a	21.2
Shear or torsion		
Shear or torsion rupture	G, H.2	12.9
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	43.1
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	28.6
screws in holes	J.5.5.1	28.0

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	21.2	17.8	0.00047 λ^2 - 0.232 λ + 25.2	66	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	66	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	12	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	10.5	186 /λ
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	27.3 - 0.291 λ	33	580 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	23.9 - 0.149 λ	66	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	21.2	5.3	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	21.2	33.3	27.3 - 0.182 λ	52	928 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	31.8	33.1	40.5 - 0.262 λ	77	1,563 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	31.8	6.1	40.5 - 1.412 λ	19	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	31.8	74.2	40.5 - 0.117 λ	173	3,502 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	39.3 - 2.70 λ	7.4	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	31.8	21.5	40.5 - 0.403 λ	50	1,016 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	12.7	14.7	16.5 - 0.257 λ	26	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	12.7	62.5	21.5 - 0.140 λ	63	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2

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Table 2-19
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	19.5
axial tension stress on gross area	D.2a	21.2
Shear or torsion		
Shear or torsion rupture	G, H.2	11.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	39.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	25.9
screws in holes	J.5.5.1	25.3

6061 - T6 ASTM B221, B241, B429
6061 - T6510 ASTM B221
6061 - T6511 ASTM B221
6061 - T6 ASTM B247 0.000 to 4.000 in. thick
6061 - T6 ASTM B308 0.062 in. thick and greater
6351 - T5 ASTM B221 0.000 to 1.000 in. thick

F_{ty} = 35 k/in^2 E = 10,100 k/in^2
F_{cy} = 35 k/in^2 k_t = 1
F_{tu} = 38 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	21.2	17.8	0.00047 λ^2 - 0.232 λ + 25.2	66	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	66	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	12	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	27.3 - 0.910 λ	10.5	186 /λ
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	27.3 - 0.291 λ	33	580 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	23.9 - 0.149 λ	66	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	21.2	5.3	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	21.2	33.3	27.3 - 0.182 λ	52	928 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	31.8	33.1	40.5 - 0.262 λ	77	1,563 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	31.8	6.1	40.5 - 1.412 λ	19	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	31.8	74.2	40.5 - 0.117 λ	173	3,502 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	39.3 - 2.70 λ	7.4	26.2 - 0.944 λ	11.9	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	31.8	21.5	40.5 - 0.403 λ	50	1,016 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	12.7	14.7	16.5 - 0.257 λ	26	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	12.7	62.5	21.5 - 0.140 λ	63	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	12.7	35.3	16.5 - 0.107 λ	63	38,665 /λ^2

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Table 2-20
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6063 - T5 **ASTM B221 0.000 to 0.500 in. thick**
6063 - T52 **ASTM B221 0.000 to 1.000 in. thick**

F_{ty} = 16 k/in^2 E = 10,100 k/in^2
F_{cy} = 16 k/in^2 k_t = 1
F_{tu} = 22 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	11.3
axial tension stress on gross area	D.2a	9.7
Shear or torsion		
Shear or torsion rupture	G, H.2	6.8
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	22.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	15.0
screws in holes	J.5.5.1	14.7

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	9.7	18.8	0.00008 λ^2 - 0.065 λ + 10.9	99	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	99	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.7	8.2	11.8 - 0.260 λ	19	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.7	8.2	11.8 - 0.260 λ	15.9	122 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.7	25.6	11.8 - 0.083 λ	50	382 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.7	18.8	10.5 - 0.044 λ	99	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.7	6.1	11.6 - 0.320 λ	16.6	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.7	41.0	11.8 - 0.052 λ	80	611 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	14.5	36.1	17.2 - 0.072 λ	119	1,017 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	14.5	6.7	17.2 - 0.389 λ	29	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	14.5	81.0	17.2 - 0.032 λ	266	2,280 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	17.5 - 0.917 λ	9.8	11.6 - 0.320 λ	16.6	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	14.5	23.5	17.2 - 0.111 λ	77	661 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.8	43.6	7.2 - 0.031 λ	96	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.8	18.2	7.2 - 0.073 λ	40	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.8	87.3	9.3 - 0.040 λ	96	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.8	43.6	7.2 - 0.031 λ	96	38,665 /λ^2

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Table 2-21
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6063 - T6 **ASTM B221, B241, B429 0.000 to 1.000 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.4
axial tension stress on gross area	D.2a	15.2
Shear or torsion		
Shear or torsion rupture	G, H.2	9.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	30.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	20.5
screws in holes	J.5.5.1	20.0

F_{ty} = 25 k/in^2 E = 10,100 k/in^2
F_{cy} = 25 k/in^2 k_t = 1
F_{tu} = 30 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	15.2	18.2	0.00022 λ^2 - 0.133 λ + 17.5	78	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	78	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.2	7.3	19.0 - 0.530 λ	15	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.2	7.3	19.0 - 0.530 λ	12.6	155 /λ
flat elements supported on both edges	B.5.4.2	b/t	15.2	22.8	19.0 - 0.170 λ	39	484 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.2	18.2	16.7 - 0.088 λ	78	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	15.2	5.6	18.5 - 0.593 λ	13.7	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	15.2	36.5	19.0 - 0.106 λ	63	775 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	22.7	34.7	27.9 - 0.150 λ	93	1,298 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	22.7	6.5	27.9 - 0.810 λ	23	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	22.7	77.8	27.9 - 0.067 λ	208	2,910 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	27.7 - 1.70 λ	8.4	18.5 - 0.593 λ	13.7	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	22.7	22.6	27.9 - 0.231 λ	60	844 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	9.1	38.7	11.5 - 0.062 λ	76	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	9.1	16.1	11.5 - 0.150 λ	32	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	9.1	72.2	15.0 - 0.081 λ	76	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	9.1	38.7	11.5 - 0.062 λ	76	38,665 /λ^2

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Table 2-22
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6082 - T6 **ASTM B221 0.200 to 6.000 in. thick**
6082 - T6511 **ASTM B221 0.200 to 6.000 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	23.1
axial tension stress on gross area	D.2a	23.0
Shear or torsion		
Shear or torsion rupture	G, H.2	13.8
Bearing		
bolts or rivets on holes	J.3.6a, J.4	46.2
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	30.7
screws in holes	J.5.5.1	30.0

F_{ty} = 38 k/in^2 E = 10,100 k/in^2
F_{cy} = 38 k/in^2 k_t = 1
F_{tu} = 45 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	23.0	17.6	0.00056 λ^2 - 0.266 λ + 27.5	63	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	63	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	23.0	6.5	29.8 - 1.039 λ	12	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	23.0	6.5	29.8 - 1.039 λ	10.0	194 /λ
flat elements supported on both edges	B.5.4.2	b/t	23.0	20.3	29.8 - 0.333 λ	31	606 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	23.0	17.6	26.0 - 0.170 λ	63	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	23.0	5.2	28.5 - 1.058 λ	11.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	23.0	32.5	29.8 - 0.208 λ	50	969 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	34.5	32.6	44.4 - 0.301 λ	74	1,635 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	34.5	6.1	44.4 - 1.619 λ	18	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	34.5	73.2	44.4 - 0.134 λ	165	3,666 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	42.8 - 3.03 λ	7.2	28.5 - 1.058 λ	11.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	34.5	21.2	44.4 - 0.463 λ	48	1,063 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	13.8	34.5	18.0 - 0.122 λ	60	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	13.8	14.4	18.0 - 0.294 λ	25	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	13.8	60.3	23.5 - 0.160 λ	60	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	13.8	34.5	18.0 - 0.122 λ	60	38,665 /λ^2

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Table 2-23
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6063 - T6 **ASTM B221, B241, B429 0.000 to 1.000 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.4
axial tension stress on gross area	D.2a	15.2
Shear or torsion		
Shear or torsion rupture	G, H.2	9.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	30.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	20.5
screws in holes	J.5.5.1	20.0

F_{ty} = 25 k/in^2 F_{cy} = 25 k/in^2 F_{tu} = 30 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	15.2	18.2	0.00022 λ^2 - 0.133 λ + 17.5	78	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	78	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.2	7.3	19.0 - 0.530 λ	15	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.2	7.3	19.0 - 0.530 λ	12.6	155 /λ
flat elements supported on both edges	B.5.4.2	b/t	15.2	22.8	19.0 - 0.170 λ	39	484 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.2	18.2	16.7 - 0.088 λ	78	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	15.2	5.6	18.5 - 0.593 λ	13.7	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	15.2	36.5	19.0 - 0.106 λ	63	775 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	22.7	34.7	27.9 - 0.150 λ	93	1,298 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	22.7	6.5	27.9 - 0.810 λ	23	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	22.7	77.8	27.9 - 0.067 λ	208	2,910 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	27.7 - 1.70 λ	8.4	18.5 - 0.593 λ	13.7	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	22.7	22.6	27.9 - 0.231 λ	60	844 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	9.1	38.7	11.5 - 0.062 λ	76	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	9.1	16.1	11.5 - 0.150 λ	32	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	9.1	72.2	15.0 - 0.081 λ	76	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	9.1	38.7	11.5 - 0.062 λ	76	38,665 /λ^2

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Table 2-24
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6082 - T6 **ASTM B221 0.200 to 6.000 in. thick**
6082 - T6511 **ASTM B221 0.200 to 6.000 in. thick**

F_{ty} = 38 k/in^2 E = 10,100 k/in^2
F_{cy} = 38 k/in^2 k_t = 1
F_{tu} = 45 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	23.1
axial tension stress on gross area	D.2a	23.0
Shear or torsion		
Shear or torsion rupture	G, H.2	13.8
Bearing		
bolts or rivets on holes	J.3.6a, J.4	46.2
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	30.7
screws in holes	J.5.5.1	30.0

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	23.0	17.6	0.00056 λ^2 - 0.266 λ + 27.5	63	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	63	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	23.0	6.5	29.8 - 1.039 λ	12	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	23.0	6.5	29.8 - 1.039 λ	10.0	194 /λ
flat elements supported on both edges	B.5.4.2	b/t	23.0	20.3	29.8 - 0.333 λ	31	606 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	23.0	17.6	26.0 - 0.170 λ	63	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	23.0	5.2	28.5 - 1.058 λ	11.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	23.0	32.5	29.8 - 0.208 λ	50	969 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	34.5	32.6	44.4 - 0.301 λ	74	1,635 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	34.5	6.1	44.4 - 1.619 λ	18	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	34.5	73.2	44.4 - 0.134 λ	165	3,666 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	42.8 - 3.03 λ	7.2	28.5 - 1.058 λ	11.4	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	34.5	21.2	44.4 - 0.463 λ	48	1,063 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	13.8	34.5	18.0 - 0.122 λ	60	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	13.8	14.4	18.0 - 0.294 λ	25	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	13.8	60.3	23.5 - 0.160 λ	60	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	13.8	34.5	18.0 - 0.122 λ	60	38,665 /λ^2

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Table 2-1W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

1100 - H14 **ASTM B209 0.009 to 1.000 in. thick**
1100 - H14 **ASTM B210 0.014 to 0.500 thick**

F_{tyw} = 3.5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 3.5 k/in^2 k_t = 1
F_{tuw} = 11 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	5.6
axial tension stress on gross area	D.2a	2.1
Shear or torsion		
Shear or torsion rupture	G, H.2	3.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	11.3
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	7.5
screws in holes	J.5.5.1	7.3

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	2.1	23.8	0.000003 λ^2 - 0.007 λ + 2.3	284	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	284	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	2.1	13.3	2.5 - 0.032 λ	53	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	2.1	13.3	2.5 - 0.032 λ	40.0	51 /λ
flat elements supported on both edges	B.5.4.2	b/t	2.1	41.6	2.5 - 0.010 λ	125	159 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	2.1	23.8	2.2 - 0.005 λ	284	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	2.1	8.9	2.6 - 0.053 λ	37	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	2.1	66.6	2.5 - 0.006 λ	200	255 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.2	28.1	3.4 - 0.006 λ	268	450 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.2	5.2	3.4 - 0.034 λ	66	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.2	62.9	3.4 - 0.003 λ	601	1,008 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	3.9 - 0.124 λ	18.2	2.6 - 0.053 λ	37	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	3.2	18.2	3.4 - 0.010 λ	174	292 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.3	70.5	1.5 - 0.004 λ	275	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.3	29.4	1.5 - 0.009 λ	115	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.3	148.9	2.0 - 0.005 λ	275	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.3	70.5	1.5 - 0.004 λ	275	38,665 /λ^2

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Table 2-2W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

3003 - H14 **ASTM B209 0.009 to 1.000 in. thick**
3003 - H14 **ASTM B210 0.010 to 0.500 in. thick**

F_{tyw} = 5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 5 k/in^2 k_t = 1
F_{tuw} = 14 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	7.2
axial tension stress on gross area	D.2a	3.0
Shear or torsion		
Shear or torsion rupture	G, H.2	4.3
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	14.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	9.5
screws in holes	J.5.5.1	9.3

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	3.0	23.4	0.00001 λ^2 - 0.012 λ + 3.3	236	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	236	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	44	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	33.2	61 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	3.7 - 0.018 λ	104	192 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	3.2 - 0.009 λ	236	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.0	8.4	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.0	60.9	3.7 - 0.011 λ	166	307 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.5	32.5	4.9 - 0.011 λ	222	544 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.5	6.0	4.9 - 0.060 λ	55	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.5	72.8	4.9 - 0.005 λ	497	1,219 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	5.6 - 0.203 λ	16.1	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	4.5	21.1	4.9 - 0.017 λ	144	353 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.8	26.8	2.2 - 0.016 λ	95	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.8	127.9	2.9 - 0.009 λ	228	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2

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Table 2-3W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

3003 - H16 **ASTM B209 0.006 to 0.162 in. thick**
3003 - H16 **ASTM B210 0.010 to 0.500 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	7.2
axial tension stress on gross area	D.2a	3.0
Shear or torsion		
Shear or torsion rupture	G, H.2	4.3
Bearing		
bolts or rivets on holes	J.3.6a, J.4.(	14.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	9.5
screws in holes	J.5.5.1	9.3

F_{tyw} = 5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 5 k/in^2 k_t = 1
F_{tuw} = 14 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	3.0	23.4	0.00001 λ^2 - 0.012 λ + 3.3	236	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	236	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	44	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	33.2	61 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	3.7 - 0.018 λ	104	192 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	3.2 - 0.009 λ	236	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.0	8.4	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.0	60.9	3.7 - 0.011 λ	166	307 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.5	32.5	4.9 - 0.011 λ	222	544 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.5	6.0	4.9 - 0.060 λ	55	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.5	72.8	4.9 - 0.005 λ	497	1,219 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	5.6 - 0.203 λ	16.1	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	4.5	21.1	4.9 - 0.017 λ	144	353 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.8	26.8	2.2 - 0.016 λ	95	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.8	127.9	2.9 - 0.009 λ	228	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2

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Table 2-4W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

Alclad 3004 - H34 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	10.8
axial tension stress on gross area	D.2a	4.8
Shear or torsion		
Shear or torsion rupture	G, H.2	6.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	21.5
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	14.3
screws in holes	J.5.5.1	14.0

F_{tyw} = 8 k/in^2 E = 10,100 k/in^2
F_{cyw} = 8 k/in^2 k_t = 1
F_{tuw} = 21 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	4.8	22.8	0.00002 λ^2 - 0.024 λ + 5.4	185	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	185	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	34	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	25.8	79 /λ
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	6.1 - 0.038 λ	81	247 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	4.8	22.8	5.3 - 0.019 λ	185	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	4.8	7.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	4.8	53.7	6.1 - 0.024 λ	129	395 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	7.3	35.6	8.1 - 0.023 λ	173	699 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.3	6.6	8.1 - 0.127 λ	43	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.3	79.8	8.1 - 0.010 λ	387	1,567 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	9.2 - 0.389 λ	13.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	7.3	23.1	8.1 - 0.036 λ	112	455 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	2.9	23.6	3.7 - 0.033 λ	74	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	2.9	104.6	4.8 - 0.018 λ	177	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2

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Table 2-5W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 - H14 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0
Shear or torsion		
Shear or torsion rupture	G, H.2	4.6
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	15.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	10.2
screws in holes	J.5.5.1	10.0

F_{tyw} = 5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 5 k/in^2 k_t = 1
F_{tuw} = 15 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	3.0	23.4	0.00001 λ^2 - 0.012 λ + 3.3	236	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	236	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	44	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	33.2	61 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	3.7 - 0.018 λ	104	192 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	3.2 - 0.009 λ	236	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.0	8.4	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.0	60.9	3.7 - 0.011 λ	166	307 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.5	32.5	4.9 - 0.011 λ	222	544 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.5	6.0	4.9 - 0.060 λ	55	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.5	72.8	4.9 - 0.005 λ	497	1,219 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	5.6 - 0.203 λ	16.1	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	4.5	21.1	4.9 - 0.017 λ	144	353 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.8	26.8	2.2 - 0.016 λ	95	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.8	127.9	2.9 - 0.009 λ	228	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2

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Table 2-6W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 - H32 ASTM B209 0.017 to 2.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0
Shear or torsion		
Shear or torsion rupture	G, H.2	4.6
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	15.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	10.2
screws in holes	J.5.5.1	10.0

F_{tyw} = 5 k/in^2 F_{cyw} = 5 k/in^2 F_{tuw} = 15 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	3.0	23.4	0.00001 λ^2 - 0.012 λ + 3.3	236	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	236	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	44	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	33.2	61 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	3.7 - 0.018 λ	104	192 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	3.2 - 0.009 λ	236	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.0	8.4	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.0	60.9	3.7 - 0.011 λ	166	307 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.5	32.5	4.9 - 0.011 λ	222	544 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.5	6.0	4.9 - 0.060 λ	55	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.5	72.8	4.9 - 0.005 λ	497	1,219 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	5.6 - 0.203 λ	16.1	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	4.5	21.1	4.9 - 0.017 λ	144	353 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.8	26.8	2.2 - 0.016 λ	95	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.8	127.9	2.9 - 0.009 λ	228	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2

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Table 2-7W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 - H34 ASTM B209 0.009 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0
Shear or torsion		
Shear or torsion rupture	G, H.2	4.6
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	15.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	10.2
screws in holes	J.5.5.1	10.0

F_{tyw} = 5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 5 k/in^2 k_t = 1
F_{tuw} = 15 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	3.0	23.4	0.00001 λ^2 - 0.012 λ + 3.3	236	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	236	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	44	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	3.7 - 0.056 λ	33.2	61 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	3.7 - 0.018 λ	104	192 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	3.2 - 0.009 λ	236	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.0	8.4	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.0	60.9	3.7 - 0.011 λ	166	307 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.5	32.5	4.9 - 0.011 λ	222	544 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.5	6.0	4.9 - 0.060 λ	55	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.5	72.8	4.9 - 0.005 λ	497	1,219 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	5.6 - 0.203 λ	16.1	3.8 - 0.086 λ	33	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	4.5	21.1	4.9 - 0.017 λ	144	353 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	1.8	26.8	2.2 - 0.016 λ	95	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	1.8	127.9	2.9 - 0.009 λ	228	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	1.8	64.3	2.2 - 0.007 λ	228	38,665 /λ^2

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Table 2-8W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5050 - H34 ASTM B209 0.009 to 0.249 in. thick
5050 - H34 ASTM B210 0.010 to 0.500 in. thick

F_{tyw} = 6 k/in^2 E = 10,100 k/in^2
F_{cyw} = 6 k/in^2 k_t = 1
F_{tuw} = 18 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	9.2
axial tension stress on gross area	D.2a	3.6
Shear or torsion		
Shear or torsion rupture	G, H.2	5.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	18.5
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	12.3
screws in holes	J.5.5.1	12.0

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	3.6	23.2	0.00001 λ^2 - 0.015 λ + 4.0	215	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	215	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.6	11.6	4.5 - 0.075 λ	40	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.6	11.6	4.5 - 0.075 λ	30.1	68 /λ
flat elements supported on both edges	B.5.4.2	b/t	3.6	36.3	4.5 - 0.024 λ	94	212 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.6	23.2	3.9 - 0.012 λ	215	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	3.6	8.1	4.5 - 0.111 λ	31	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	3.6	58.0	4.5 - 0.015 λ	150	339 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	5.5	34.0	6.0 - 0.015 λ	201	599 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	5.5	6.3	6.0 - 0.080 λ	50	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	5.5	76.3	6.0 - 0.007 λ	451	1,343 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	6.8 - 0.261 λ	15.1	4.5 - 0.111 λ	31	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	5.5	22.1	6.0 - 0.023 λ	131	390 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	2.2	61.3	2.7 - 0.009 λ	207	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	2.2	25.5	2.7 - 0.021 λ	86	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	2.2	118.3	3.5 - 0.011 λ	207	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	2.2	61.3	2.7 - 0.009 λ	207	38,665 /λ^2

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Table 2-9W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 - H32 ASTM B209 0.017 to 2.000 in. thick
5052 - H32 ASTM B210 0.010 to 0.450 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	5.8
Shear or torsion		
Shear or torsion rupture	G, H.2	7.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	25.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	17.1
screws in holes	J.5.5.1	16.7

F_{tyw} = 9.5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 9.5 k/in^2 k_t = 1
F_{tuw} = 25 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	5.8	22.6	0.00003 λ^2 - 0.032 λ + 6.5	169	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	169	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	31	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	23.5	87 /λ
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.1	7.4 - 0.050 λ	74	271 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.6	6.3 - 0.025 λ	169	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	5.8	7.4	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	5.8	51.3	7.4 - 0.031 λ	118	433 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.6	36.1	9.8 - 0.031 λ	157	767 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.6	6.7	9.8 - 0.167 λ	39	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.6	80.9	9.8 - 0.014 λ	353	1,719 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	11.0 - 0.494 λ	12.9	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	8.6	23.5	9.8 - 0.048 λ	102	499 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	3.5	22.5	4.4 - 0.044 λ	67	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	3.5	97.2	5.8 - 0.024 λ	162	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2

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Table 2-10W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 - H34 **ASTM B209 0.009 to 1.000 in. thick**
5052 - H34 **ASTM B210 0.010 to 0.450 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	5.8
Shear or torsion		
Shear or torsion rupture	G, H.2	7.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	25.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	17.1
screws in holes	J.5.5.1	16.7

F_{tyw} = 9.5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 9.5 k/in^2 k_t = 1
F_{tuw} = 25 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	5.8	22.6	0.00003 λ^2 - 0.032 λ + 6.5	169	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	169	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	31	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	23.5	87 /λ
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.1	7.4 - 0.050 λ	74	271 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.6	6.3 - 0.025 λ	169	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	5.8	7.4	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	5.8	51.3	7.4 - 0.031 λ	118	433 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.6	36.1	9.8 - 0.031 λ	157	767 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.6	6.7	9.8 - 0.167 λ	39	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.6	80.9	9.8 - 0.014 λ	353	1,719 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	11.0 - 0.494 λ	12.9	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	8.6	23.5	9.8 - 0.048 λ	102	499 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	3.5	22.5	4.4 - 0.044 λ	67	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	3.5	97.2	5.8 - 0.024 λ	162	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2

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Table 2-11W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 - H36 ASTM B209 0.006 to 0.162 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	5.8
Shear or torsion		
Shear or torsion rupture	G, H.2	7.7
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	25.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	17.1
screws in holes	J.5.5.1	16.7

F_{tyw} = 9.5 k/in^2 E = 10,100 k/in^2
F_{cyw} = 9.5 k/in^2 k_t = 1
F_{tuw} = 25 k/in^2

	Section	Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	5.8	22.6	0.00003 λ^2 - 0.032 λ + 6.5	169	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	169	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	31	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	7.4 - 0.156 λ	23.5	87 /λ
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.1	7.4 - 0.050 λ	74	271 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.6	6.3 - 0.025 λ	169	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	5.8	7.4	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	5.8	51.3	7.4 - 0.031 λ	118	433 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.6	36.1	9.8 - 0.031 λ	157	767 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.6	6.7	9.8 - 0.167 λ	39	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.6	80.9	9.8 - 0.014 λ	353	1,719 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	11.0 - 0.494 λ	12.9	7.3 - 0.210 λ	25	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	8.6	23.5	9.8 - 0.048 λ	102	499 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	3.5	22.5	4.4 - 0.044 λ	67	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	3.5	97.2	5.8 - 0.024 λ	162	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	3.5	54.1	4.4 - 0.018 λ	162	38,665 /λ^2

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Table 2-12W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5083 - H116 ASTM B928 0.125 to 1.500 in. thick
5083 - H32 ASTM B209 0.125 to 1.500 in. thick
5083 - H321 ASTM B928 0.125 to 1.500 in. thick

F_{tyw} = 18 k/in^2 E = 10,100 k/in^2
F_{cyw} = 18 k/in^2 k_t = 1
F_{tuw} = 40 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	20.5
axial tension stress on gross area	D.2a	10.9
Shear or torsion		
Shear or torsion rupture	G, H.2	12.3
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	41.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	27.3
screws in holes	J.5.5.1	26.7

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	*kL*/*r*	10.9	21.5	0.00010 λ^2 - 0.089 λ + 12.8	121	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	121	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	*b*/*t*	10.9	8.5	14.7 - 0.440 λ	22	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	*b*/*t*	10.9	8.5	14.7 - 0.440 λ	16.7	122 /λ
flat elements supported on both edges	B.5.4.2	*b*/*t*	10.9	26.7	14.7 - 0.141 λ	52	382 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	10.9	21.5	12.4 - 0.068 λ	121	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	10.9	6.6	14.3 - 0.511 λ	18	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	10.9	42.7	14.7 - 0.088 λ	83	611 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	*b*/*t*	16.4	35.9	19.5 - 0.088 λ	111	1,085 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	*b*/*t*	16.4	6.7	19.5 - 0.472 λ	28	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	*b*/*t*	16.4	80.4	19.5 - 0.039 λ	249	2,431 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	21.4 - 1.203 λ	10.3	14.3 - 0.511 λ	18	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	16.4	23.3	19.5 - 0.135 λ	72	705 /λ
Elements - Shear							
flat elements supported on both edges	G.2	*b*/*t*	6.5	45.0	8.9 - 0.052 λ	114	38,665 /λ^2
flat elements supported on one edge	G.3	*b*/*t*	6.5	18.8	8.9 - 0.124 λ	48	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	6.5	74.0	11.5 - 0.067 λ	114	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	6.5	45.0	8.9 - 0.052 λ	114	38,665 /λ^2

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Table 2-13W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5086 - H34 ASTM B209 0.009 to 1.000 in. thick
5086 - H34 ASTM B210 0.010 to 0.450 in. thick

F_{tyw} = 14 k/in^2 E = 10,100 k/in^2
F_{cyw} = 14 k/in^2 k_t = 1
F_{tuw} = 35 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	17.9
axial tension stress on gross area	D.2a	8.5
Shear or torsion		
Shear or torsion rupture	G, H.2	10.8
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	35.9
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	23.9
screws in holes	J.5.5.1	23.3

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	8.5	21.9	0.00006 λ^2 - 0.059 λ + 9.8	138	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	138	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.2	11.2 - 0.292 λ	25	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.2	11.2 - 0.292 λ	19.1	107 /λ
flat elements supported on both edges	B.5.4.2	b/t	8.5	28.7	11.2 - 0.094 λ	60	333 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	21.9	9.5 - 0.046 λ	138	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	8.5	6.9	11.0 - 0.360 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	8.5	46.0	11.2 - 0.058 λ	96	534 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	12.7	36.3	14.8 - 0.058 λ	128	946 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	12.7	6.7	14.8 - 0.313 λ	32	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	12.7	81.4	14.8 - 0.026 λ	286	2,120 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	16.5 - 0.847 λ	11.3	11.0 - 0.360 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	12.7	23.6	14.8 - 0.089 λ	83	615 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.1	48.5	6.8 - 0.034 λ	131	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.1	20.2	6.8 - 0.082 λ	55	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.1	82.4	8.8 - 0.045 λ	131	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.1	48.5	6.8 - 0.034 λ	131	38,665 /λ^2

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Table 2-14W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5086 - H116 **ASTM B928 0.063 to 2.000 in. thick**
5086 - H32 **ASTM B209 0.020 to 2.000 in. thick**
5086 - H32 **ASTM B210 0.010 to 0.450 in. thick**

F_{tyw} = 14 k/in^2 E = 10,100 k/in^2
F_{cyw} = 14 k/in^2 k_t = 1
F_{tuw} = 35 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	17.9
axial tension stress on gross area	D.2a	8.5
Shear or torsion		
Shear or torsion rupture	G, H.2	10.8
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	35.9
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	23.9
screws in holes	J.5.5.1	23.3

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	8.5	21.9	0.00006 λ^2 - 0.059 λ + 9.8	138	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	138	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.2	11.2 - 0.292 λ	25	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.2	11.2 - 0.292 λ	19.1	107 /λ
flat elements supported on both edges	B.5.4.2	b/t	8.5	28.7	11.2 - 0.094 λ	60	333 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	21.9	9.5 - 0.046 λ	138	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	8.5	6.9	11.0 - 0.360 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	8.5	46.0	11.2 - 0.058 λ	96	534 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	12.7	36.3	14.8 - 0.058 λ	128	946 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	12.7	6.7	14.8 - 0.313 λ	32	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	12.7	81.4	14.8 - 0.026 λ	286	2,120 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	16.5 - 0.847 λ	11.3	11.0 - 0.360 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	12.7	23.6	14.8 - 0.089 λ	83	615 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.1	48.5	6.8 - 0.034 λ	131	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.1	20.2	6.8 - 0.082 λ	55	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.1	82.4	8.8 - 0.045 λ	131	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.1	48.5	6.8 - 0.034 λ	131	38,665 /λ^2

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Table 2-15W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5454 - H32 ASTM B209 0.020 to 2.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	7.3
Shear or torsion		
Shear or torsion rupture	G, H.2	9.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	31.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	21.1
screws in holes	J.5.5.1	20.7

F_{tyw} = 12 k/in^2 E = 10,100 k/in^2
F_{cyw} = 12 k/in^2 k_t = 1
F_{tuw} = 31 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	7.3	22.2	0.00004 λ^2 - 0.046 λ + 8.3	150	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	150	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.3	9.6	9.5 - 0.228 λ	28	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.3	9.6	9.5 - 0.228 λ	20.8	98 /λ
flat elements supported on both edges	B.5.4.2	b/t	7.3	30.0	9.5 - 0.073 λ	65	307 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.3	22.2	8.1 - 0.036 λ	150	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	7.3	7.1	9.3 - 0.291 λ	22	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	7.3	48.0	9.5 - 0.046 λ	104	491 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	10.9	36.4	12.6 - 0.045 λ	139	870 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	10.9	6.8	12.6 - 0.244 λ	34	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	10.9	81.5	12.6 - 0.020 λ	311	1,950 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	14.0 - 0.684 λ	11.9	9.3 - 0.291 λ	22	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	10.9	23.6	12.6 - 0.070 λ	90	566 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	4.4	21.1	5.7 - 0.064 λ	59	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	4.4	88.0	7.4 - 0.035 λ	142	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2

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Table 2-16W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

5454 - H34 ASTM B209 0.020 to 1.000 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	7.3
Shear or torsion		
Shear or torsion rupture	G, H.2	9.5
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	31.8
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	21.1
screws in holes	J.5.5.1	20.7

F_{tyw} = 12 k/in^2 E = 10,100 k/in^2
F_{cyw} = 12 k/in^2 k_t = 1
F_{tuw} = 31 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	7.3	22.2	0.00004 λ^2 - 0.046 λ + 8.3	150	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	150	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.3	9.6	9.5 - 0.228 λ	28	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.3	9.6	9.5 - 0.228 λ	20.8	98 /λ
flat elements supported on both edges	B.5.4.2	b/t	7.3	30.0	9.5 - 0.073 λ	65	307 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.3	22.2	8.1 - 0.036 λ	150	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	7.3	7.1	9.3 - 0.291 λ	22	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	7.3	48.0	9.5 - 0.046 λ	104	491 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	10.9	36.4	12.6 - 0.045 λ	139	870 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	10.9	6.8	12.6 - 0.244 λ	34	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	10.9	81.5	12.6 - 0.020 λ	311	1,950 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	14.0 - 0.684 λ	11.9	9.3 - 0.291 λ	22	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	10.9	23.6	12.6 - 0.070 λ	90	566 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	4.4	21.1	5.7 - 0.064 λ	59	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	4.4	88.0	7.4 - 0.035 λ	142	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	4.4	50.7	5.7 - 0.027 λ	142	38,665 /λ^2

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Table 2-17W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

Alloy-temper **6005A - T61** **ASTM B221 0.000 to 1.000 in. thick**

F_{tyw} = 15 k/in^2 E = 10,100 k/in^2
F_{cyw} = 15 k/in^2 k_t = 1
F_{tuw} = 24 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	9.1
Shear or torsion		
Shear or torsion rupture	G, H.2	7.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	24.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	16.4
screws in holes	J.5.5.1	16.0

		Slendemess λ	*F*/Ω for $\lambda \le \lambda_1$	λ_1	*F*/Ω for $\lambda_1 < \lambda < \lambda_2$	λ_2	*F*/Ω for $\lambda \ge \lambda_2$
Axial Compression							
member buckling	E.2	kL/r	9.1	21.8	$0.00007\,\lambda^2 - 0.066\,\lambda + 10.5$	133	$51{,}352/\lambda^2$
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	133	$60{,}414/\lambda^2$
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\,\lambda$	25	$2{,}417/\lambda^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\,\lambda$	18.4	$111/\lambda$
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	$12.0 - 0.105\,\lambda$	58	$346/\lambda$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	$10.2 - 0.051\,\lambda$	133	$60{,}414/\lambda^2$
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.1	6.8	$11.8 - 0.396\,\lambda$	20	$3{,}776/[\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.1	45.1	$12.0 - 0.065\,\lambda$	92	$554/\lambda$
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.6	36.2	$16.0 - 0.065\,\lambda$	123	$982/\lambda$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.6	6.7	$16.0 - 0.350\,\lambda$	30	$4{,}932/\lambda^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.6	81.2	$16.0 - 0.029\,\lambda$	275	$2{,}201/\lambda$
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	$17.7 - 0.933\,\lambda$	11.0	$11.8 - 0.396\,\lambda$	20	$3{,}776/[\lambda^2(1+\lambda/35)^2]$
flat elements - direct strength method	B.5.5.5	λ_{eq}	13.6	23.5	$16.0 - 0.100\,\lambda$	80	$638/\lambda$
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	$7.3 - 0.038\,\lambda$	126	$38{,}665/\lambda^2$
flat elements supported on one edge	G.3	b/t	5.5	19.8	$7.3 - 0.092\,\lambda$	53	$6{,}713/\lambda^2$
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.5	80.0	$9.5 - 0.050\,\lambda$	126	$50{,}264/\lambda^2$
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.5	47.5	$7.3 - 0.038\,\lambda$	126	$38{,}665/\lambda^2$

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Table 2-18W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6061 - T6 **ASTM B209 0.010 to 4.000 in. thick**
6061 - T651 **ASTM B209 0.010 to 4.000 in. thick**
6061 - T6 **ASTM B210 0.025 to 0.500 in. thick**
6061 - T6 **ASTM B211 0.125 to 8.000 in. thick**
6061 - T651 **ASTM B211 0.125 to 8.000 in. thick**
6061 - T6 **ASTM B632 0.010 to 0.625 in. thick**

F_{tyw} = 15 k/in^2 E = 10,100 k/in^2
F_{cyw} = 15 k/in^2 k_t = 1
F_{tuw} = 24 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	9.1
Shear or torsion		
Shear or torsion rupture	G, H.2	7.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	24.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	16.4
screws in holes	J.5.5.1	16.0

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	9.1	21.8	0.00007 λ^2 - 0.066 λ + 10.5	133	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	133	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	25	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	18.4	111 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	12.0 - 0.105 λ	58	346 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	10.2 - 0.051 λ	133	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.1	6.8	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.1	45.1	12.0 - 0.065 λ	92	554 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.6	36.2	16.0 - 0.065 λ	123	982 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.6	6.7	16.0 - 0.350 λ	30	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.6	81.2	16.0 - 0.029 λ	275	2,201 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	17.7 - 0.933 λ	11.0	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	13.6	23.5	16.0 - 0.100 λ	80	638 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.5	19.8	7.3 - 0.092 λ	53	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.5	80.0	9.5 - 0.050 λ	126	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2

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Table 2-19W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6061 - T6 **ASTM B221, B241, B429**
6061 - T6510 **ASTM B221**
6061 - T6511 **ASTM B221**
6061 - T6 **ASTM B247 0.000 to 4.000 thick**
6061 - T6 **ASTM B308 0.062 thick and greater**
6351 - T5 **ASTM B221 0.000 to 1.000 in. thick**

F_{tyw} = 15 k/in^2 E = 10,100 k/in^2
F_{cyw} = 15 k/in^2 k_t = 1
F_{tuw} = 24 k/in^2

Allowable Stresses F/Ω (k/in^2)	Section	F/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	9.1
Shear or torsion		
Shear or torsion rupture	G, H.2	7.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	24.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	16.4
screws in holes	J.5.5.1	16.0

		Slenderness λ	F/Ω for $\lambda \le \lambda_1$	λ_1	F/Ω for $\lambda_1 < \lambda < \lambda_2$	λ_2	F/Ω for $\lambda \ge \lambda_2$
Axial Compression							
member buckling	E.2	kL/r	9.1	21.8	0.00007 λ^2 - 0.066 λ + 10.5	133	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	133	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	25	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	18.4	111 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	12.0 - 0.105 λ	58	346 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	10.2 - 0.051 λ	133	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.1	6.8	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.1	45.1	12.0 - 0.065 λ	92	554 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.6	36.2	16.0 - 0.065 λ	123	982 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.6	6.7	16.0 - 0.350 λ	30	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.6	81.2	16.0 - 0.029 λ	275	2,201 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	17.7 - 0.933 λ	11.0	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	13.6	23.5	16.0 - 0.100 λ	80	638 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.5	19.8	7.3 - 0.092 λ	53	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.5	80.0	9.5 - 0.050 λ	126	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2

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Table 2-20W

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6063 - T5 **ASTM B221 0.000 to 0.500 in. thick**
6063 - T52 **ASTM B221 0.000 to 1.000 in. thick**

F_{tyw} = 8 k/in^2 E = 10,100 k/in^2
F_{cyw} = 8 k/in^2 k_t = 1
F_{tuw} = 17 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	8.7
axial tension stress on gross area	D.2a	4.8
Shear or torsion		
Shear or torsion rupture	G, H.2	5.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4	17.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	11.6
screws in holes	J.5.5.1	11.3

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	4.8	22.8	0.00002 λ^2 - 0.024 λ + 5.4	185	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	185	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	34	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	25.8	79 /λ
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	6.1 - 0.038 λ	81	247 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ$_s$	4.8	22.8	5.3 - 0.019 λ	185	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	4.8	7.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ$_{eq}$	4.8	53.7	6.1 - 0.024 λ	129	395 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	7.3	35.6	8.1 - 0.023 λ	173	699 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.3	6.6	8.1 - 0.127 λ	43	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.3	79.8	8.1 - 0.010 λ	387	1,567 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	9.2 - 0.389 λ	13.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ$_{eq}$	7.3	23.1	8.1 - 0.036 λ	112	455 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	2.9	23.6	3.7 - 0.033 λ	74	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	2.9	104.6	4.8 - 0.018 λ	177	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2

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Table 2-21W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6063 - T6 **ASTM B221, B241, B429 0.000 to 1.000 in. thick**

F_{tyw} = 8 k/in^2 E = 10,100 k/in^2
F_{cyw} = 8 k/in^2 k_t = 1
F_{tuw} = 17 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	8.7
axial tension stress on gross area	D.2a	4.8
Shear or torsion		
Shear or torsion rupture	G, H.2	5.2
Bearing		
bolts or rivets on holes	J.3.6a, J.4	17.4
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	11.6
screws in holes	J.5.5.1	11.3

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	4.8	22.8	0.00002 λ^2 - 0.024 λ + 5.4	185	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	185	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	34	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	6.1 - 0.119 λ	25.8	79 /λ
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	6.1 - 0.038 λ	81	247 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	4.8	22.8	5.3 - 0.019 λ	185	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	4.8	7.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	4.8	53.7	6.1 - 0.024 λ	129	395 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	7.3	35.6	8.1 - 0.023 λ	173	699 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.3	6.6	8.1 - 0.127 λ	43	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.3	79.8	8.1 - 0.010 λ	387	1,567 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	9.2 - 0.389 λ	13.7	6.1 - 0.165 λ	27	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	7.3	23.1	8.1 - 0.036 λ	112	455 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	2.9	23.6	3.7 - 0.033 λ	74	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	2.9	104.6	4.8 - 0.018 λ	177	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	2.9	56.7	3.7 - 0.014 λ	177	38,665 /λ^2

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Table 2-22W
ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6082 - T6 **ASTM B221 0.200 to 6.000 in. thick**
6082 - T6511 **ASTM B221 0.200 to 6.000 in. thick**

F_{tyw} = 16 k/in^2 E = 10,100 k/in^2
F_{cyw} = 16 k/in^2 k_t = 1
F_{tuw} = 28 k/in^2

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	14.4
axial tension stress on gross area	D.2a	9.7
Shear or torsion		
Shear or torsion rupture	G, H.2	8.6
Bearing		
bolts or rivets on holes	J.3.6a, J.4	28.7
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	19.1
screws in holes	J.5.5.1	18.7

		Slenderness λ	*F*/Ω for λ ≤ λ$_1$	λ$_1$	*F*/Ω for λ$_1$ < λ < λ$_2$	λ$_2$	*F*/Ω for λ ≥ λ$_2$
Axial Compression							
member buckling	E.2	kL/r	9.7	21.7	0.00008 λ^2 - 0.074 λ + 11.3	129	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	129	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.7	8.8	12.9 - 0.363 λ	24	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.7	8.8	12.9 - 0.363 λ	17.8	115 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.7	27.7	12.9 - 0.116 λ	56	358 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.7	21.7	10.9 - 0.057 λ	129	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.7	6.7	12.6 - 0.434 λ	19	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.7	44.2	12.9 - 0.073 λ	89	573 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	14.5	36.1	17.2 - 0.072 λ	119	1,017 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	14.5	6.7	17.2 - 0.389 λ	29	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	14.5	81.0	17.2 - 0.032 λ	266	2,280 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	18.9 - 1.021 λ	10.7	12.6 - 0.434 λ	19	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	14.5	23.5	17.2 - 0.111 λ	77	661 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.8	46.6	7.8 - 0.043 λ	122	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.8	19.4	7.8 - 0.102 λ	51	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.8	77.8	10.2 - 0.056 λ	122	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.8	46.6	7.8 - 0.043 λ	122	38,665 /λ^2

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Table 2-23W

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

6351 - T6 **ASTM B221 0.000 to 0.749 in. thick**

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	9.1
Shear or torsion		
Shear or torsion rupture	G, H.2	7.4
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	24.6
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	16.4
screws in holes	J.5.5.1	16.0

F_{tyw} = 15 k/in^2 E = 10,100 k/in^2
F_{cyw} = 15 k/in^2 k_t = 1
F_{tuw} = 24 k/in^2

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	9.1	21.8	0.00007 λ^2 - 0.066 λ + 10.5	133	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	133	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	25	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	12.0 - 0.327 λ	18.4	111 /λ
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	12.0 - 0.105 λ	58	346 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	10.2 - 0.051 λ	133	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	9.1	6.8	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)
flat elements - direct strength method	B.5.4.6	λ_{eq}	9.1	45.1	12.0 - 0.065 λ	92	554 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	13.6	36.2	16.0 - 0.065 λ	123	982 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	13.6	6.7	16.0 - 0.350 λ	30	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	13.6	81.2	16.0 - 0.029 λ	275	2,201 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	17.7 - 0.933 λ	11.0	11.8 - 0.396 λ	20	3,776 /[λ^2(1+λ/35)
flat elements - direct strength method	B.5.5.5	λ_{eq}	13.6	23.5	16.0 - 0.100 λ	80	638 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	5.5	19.8	7.3 - 0.092 λ	53	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	5.5	80.0	9.5 - 0.050 λ	126	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	5.5	47.5	7.3 - 0.038 λ	126	38,665 /λ^2

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Table 2-24W

ALLOWABLE STRESSES *F*/Ω FOR BUILDING-TYPE STRUCTURES (WELDED)

7005 - T53 ASTM B221 0.000 to 0.750 in. thick

Allowable Stresses *F*/Ω (k/in^2)	Section	*F*/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	20.5
axial tension stress on gross area	D.2a	14.5
Shear or torsion		
Shear or torsion rupture	G, H.2	12.3
Bearing		
bolts or rivets on holes	J.3.6a, J.4.6	41.0
bolts on slots, pins on holes, flat surfaces	J.3.6b, J.6.5, J.8	27.3
screws in holes	J.5.5.1	26.7

F_{tyw} = 24 k/in^2 F_{cyw} = 24 k/in^2 F_{tuw} = 40 k/in^2 E = 10,100 k/in^2 k_t = 1

		Slenderness λ	*F*/Ω for λ ≤ λ_1	λ_1	*F*/Ω for λ_1 < λ < λ_2	λ_2	*F*/Ω for λ ≥ λ_2
Axial Compression							
member buckling	E.2	kL/r	14.5	20.9	0.00019 λ^2 - 0.142 λ + 17.4	104	51,352 /λ^2
Flexure							
lateral-torsional buckling	F.4	see F.4.2		-	see F.4	104	60,414 /λ^2
Elements - Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.5	7.8	20.1 - 0.703 λ	19	2,417 /λ^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.5	7.8	20.1 - 0.703 λ	14.3	143 /λ
flat elements supported on both edges	B.5.4.2	b/t	14.5	24.5	20.1 - 0.225 λ	45	447 /λ
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.5	20.9	16.8 - 0.108 λ	104	60,414 /λ^2
round hollow elements	B.5.4.5	$(R_b/t)^{1/2}$	14.5	6.2	19.3 - 0.764 λ	16	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.4.6	λ_{eq}	14.5	39.2	20.1 - 0.141 λ	71	715 /λ
Elements - Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	21.8	34.9	26.7 - 0.141 λ	95	1,269 /λ
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	21.8	6.5	26.7 - 0.757 λ	24	4,932 /λ^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	21.8	78.2	26.7 - 0.063 λ	213	2,845 /λ
round hollow elements	B.5.5.4	$(R_b/t)^{1/2}$	28.9 - 1.799 λ	9.3	19.3 - 0.764 λ	16	3,776 /[λ^2(1+λ/35)^2]
flat elements - direct strength method	B.5.5.5	λ_{eq}	21.8	22.7	26.7 - 0.216 λ	62	825 /λ
Elements - Shear							
flat elements supported on both edges	G.2	b/t	8.7	41.3	12.1 - 0.083 λ	98	38,665 /λ^2
flat elements supported on one edge	G.3	b/t	8.7	17.2	12.1 - 0.199 λ	41	6,713 /λ^2
pipes and round or oval tubes	G.4	$2.9(R_b/t)^{5/8}(L_v/R_b)^{1/4}$	8.7	65.4	15.8 - 0.108 λ	98	50,264 /λ^2
Torsion							
pipes and round or oval tubes	H.2.1	$2.9(R_b/t)^{5/8}(L_s/R_b)^{1/4}$	8.7	41.3	12.1 - 0.083 λ	98	38,665 /λ^2

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Table 3-1

RECOMMENDED MINIMUM BEND RADII FOR 90-DEGREE COLD FORMING OF SHEET AND PLATE ① ② ③ ④ ⑤

ALLOY	TEMPER	RADII FOR VARIOUS THICKNESSES EXPRESSED IN TERMS OF THICKNESS "t"							
		1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
1100	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1t	1½t	2t	2½t
	H16	0	½t	1t	1½t	1½t	2½t	3t	4t
	H18	1t	1t	1½t	2½t	3t	3½t	4t	4½t
2014	O	0	0	0	½t	1t	1t	2½t	4t
	T3	1½t	2½t	3t	4t	5t	5t	6t	7t
	T4	1½t	2½t	3t	4t	5t	5t	6t	7t
	T6	3t	4t	4t	5t	6t	8t	8½t	9½t
2024	O	0	0	0	½t	1t	1t	2½t	4t
	T3	2½t	3t	4t	5t	5t	6t	7t	7½t
	T361⑥	3t	4t	5t	6t	6t	8t	8½t	9½t
	T4	2½t	3t	4t	5t	5t	6t	7t	7½t
	T81	4½t	5½t	6t	7½t	8t	9t	10t	10½t
	T861⑥	5t	6t	7t	8½t	9½t	10t	11½t	11½t
2036	T4	. .	1t	1t	. .	. .	. .	. .	. .
3003	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1t	1½t	2t	2½t
	H16	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H18	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t
3004	O	0	0	0	½t	1t	1t	1t	1½t
	H32	0	0	½t	1t	1t	1½t	1½t	2t
	H34	0	1t	1t	1½t	1½t	2½t	2½t	3t
	H36	1t	1t	1½t	2½t	3t	3½t	4t	4½t
	H38	1t	1½t	2½t	3t	4t	5t	5½t	6½t
3105	H25	½t	½t	½t	. .	. .	. .	. .	. .
5005	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1½t	1½t	2t	2½t
	H16	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H18	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t
	H32	0	0	0	½t	1t	1t	1½t	2t
	H34	0	0	0	1t	1½t	1½t	2t	2½t
	H36	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H38	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t

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Table 3-1

RECOMMENDED MINIMUM BEND RADII FOR 90-DEGREE COLD FORMING OF SHEET AND PLATE ① ② ③ ④ ⑤

ALLOY	TEMPER	RADII FOR VARIOUS THICKNESSES EXPRESSED IN TERMS OF THICKNESS "t"							
		1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
5050	O	0	0	0	½t	1t	1t	1½t	1½t
	H32	0	0	0	1t	1t	1½t	. .	. .
	H34	0	0	1t	1½t	1½t	2t	. .	. .
	H36	1t	1t	1½t	2t	2½t	3t	. .	. .
	H38	1t	1½t	2½t	3t	4t	5t	. .	. .
5052	O	0	0	0	½t	1t	1t	1½t	1½t
	H32	0	0	1t	1½t	1½t	1½t	1½t	2t
	H34	0	1t	1½t	2t	2t	2½t	2½t	3t
	H36	1t	1t	1½t	2½t	3t	3½t	4t	4½t
	H38	1t	1½t	2½t	3t	4t	5t	5½t	6½t
5083	O	. .	. .	½t	1t	1t	1t	1½t	1½t
	H32	. .	. .	1t	1½t	1½t	1½t	2t	2½t
	H321	. .	. .	1t	½	1½t	1½t	2t	2½t
5086	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	1½t	1½t	2t	2½t	3t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1½t	2t	2½t	3t	3½t	4t	4½t	5t
5154	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	1½t	1½t	2t	2½t	3½t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1t	1½t	2t	3t	3½t	4t	4½t	5t
	H38	1½t	2½t	3t	4t	5t	5t	6½t	6½t
5252	H25	0	0	1t	2t	. .	. .	. .	. .
	H28	1t	1½t	2½t	3t	. .	. .	. .	. .
5254	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	11½t	1½t	2t	2½t	3½t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1t	1½t	2t	3t	3½t	4t	4½t	5t
	H38	1½t	2½t	3t	4t	5t	5t	6½t	6½t
5454	O	0	½t	1t	1t	1t	1½t	1½t	2t
	H32	½t	½t	1t	2t	2t	2½t	3t	4t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
5456	O	. .	. .	1t	1t	1½t	1½t	2t	2t
	H32	. .	. .	. .	2t	2t	2½t	3t	3½t
	H321	. .	. .	. .	2t	2t	2½t	3t	3½t
5457	O	0	0	0	. .	. .	. .	. .	. .
5657	H25	0	0	0	1t	. .	. .	. .	. .
	H28	1t	1½t	2½t	3t	. .	. .	. .	. .
6061	O	0	0	0	1t	1t	1t	1½t	2t
	T4	0	0	1t	1½t	2½t	3t	3½t	4t
	T6	1t	1t	1½t	2½t	3t	3½t	4½t	5t
7050	T7	. .	. .	. .	. .	. .	8t	9t	9½t
7072	O	0	0	. .	. .	. .	. .	. .	. .
	H14	0	0	. .	. .	. .	. .	. .	. .
	H18	1t	1t	. .	. .	. .	. .	. .	. .
7075	O	0	0	1t	1t	1½t	2½t	3½t	4t
	T6	3t	4t	5t	6t	6t	8t	9t	9½t

① The radii listed are the minimum recommended for bending sheets and plates without fracturing in a standard press brake with air bend dies. Other types of bending operations may require larger radii or permit smaller radii. The minimum permissible radii will also vary with the design and condition of the tooling.

② Alclad sheet in the heat-treatable alloys can be bent over slightly smaller radii than the corresponding tempers of the bare alloy.

③ Heat-treatable alloys can be formed over appreciably smaller radii immediately after solution heat treatment.

④ The H112 temper (applicable to non-heat treatable alloys) is supplied in the as-fabricated condition without special property control but usually can be formed over radii applicable to the H14 (or H34) temper or smaller.

⑤ The reference test method is ASTM E290.

⑥ Tempers T361 and T861 formerly designated T36 and T86, respectively.

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Table 3-2
RECOMMENDED MINIMUM INSIDE RADII FOR 180° COLD BENDS, WIRE AND ROD*

Alloy and Temper	Approximate diameter, in.			
	0.062 (1/16)	0.125 (1/8)	0.250 (1/4)	0.500 (1/2)
1100-O	...	...	¼ to ½ *D*	¼ to ½ *D*
1350-H19	0 to 1*D*	0 to 1*D*	0 to 1*D*	0 to 1*D*
2011-T3	...	...	½ *D*	½ *D*
2011-T8	...	...	½ to 1*D*	1 to 1 ½ *D*
2017-T4, T451	...	...	½ to 1*D*	½ to 1 ½ *D*
2024-T4	...	...	1*D*	...
2024-T351	...	...	...	2 to 2 ½ *D*
5050-H38	0 to 1*D*	0 to 1*D*	1 to 2*D*	2 to 4*D*
5052-H38	0 to 1*D*	1 to 2*D*	2 to 4*D*	3 to 5*D*
5056-H34	0 to 1*D*	1 to 2*D*	2 to 4*D*	3 to 5*D*
5056-H38	0 to 1*D*	1 to 2*D*	2 to 4*D*	4 to 6*D*
6061-T6, T651	0 to 1*D*	0 to 1*D*	½ to 1 ½ *D*	½ to 1 ½ *D*
6061-T913	0 to 1*D*	1 to 2*D*	2 to 4*D*	4 to 6*D*
6262-T9	...	...	1 to 1 ½ *D*	1 to 1 ½ *D*
7075-T6, T651	½ to 1 ½ *D*	1 to 2*D*	1 ½ to 2 ½ *D*	2 to 3*D*

*Minimum permissible radius over which metal may be bent varies with nature of forming operation, type of forming equipment, design and condition of tools. Minimum working radius for a giving material or hardest alloy and temper for a giving radius can be ascertained only by actual trial under contemplated conditions of fabrications.

Table 3-3
SHEET THICKNESS FOR 180° COLD BENDING (METAL TO METAL)

Alloy and Temper	Maximum Metal Thickness In.
1100-0	.125
-H14	.063
2014-0	.063
2024-0	.063
3003-0	.125
-H14	.063
3004-0	.063
-H32	.031
-H34	.016
5005-0	.125
-H12	.063
-H32	.063
-H14	.031
-H34	.031

Alloy and Temper	Maximum Metal Thickness In.
5050-0	.063
-H34	.031
5052-0	.063
-H32	.031
-H34	.016
5086-0	.031
5154-H32	.016
6061-0	.063
-T4	.031
7075-0	.031

*Minimum permissible radius over which metal may be bent varies with nature of forming operation, type of forming equipment, design and condition of tools. Minimum working radius for a giving material or hardest alloy and temper for a giving radius can be ascertained only by actual trial under contemplated conditions of fabrications.

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Table 3-4
DEVELOPED LENGTH OF MATERIAL FOR 90° BENDS*

Material Thickness in.	Inside Radius of Bend (in.)																	
	Sharp Bend	1/64	1/32	3/64	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2	5/8
.016	.008	.033	.061	.086	.111	.135	.160	.184	.209	.258	.307	.356	.406	.503	.602	.700	.798	.994
.020	.011	.035	.063	.089	.114	.138	.163	.187	.212	.261	.310	.359	.408	.507	.605	.703	.801	.998
.025	.013	.038	.064	.092	.118	.142	.167	.191	.216	.265	.314	.363	.412	.511	.609	.707	.805	1.001
.032	.017	.041	.066	.094	.123	.148	.173	.197	.222	.271	.320	.369	.418	.516	.614	.712	.811	1.007
.040	.021	.045	.070	.097	.126	.153	.179	.203	.228	.277	.326	.375	.424	.522	.621	.719	.817	1.013
.051	.027	.051	.076	.100	.129	.155	.184	.212	.236	.285	.334	.383	.433	.531	.629	.727	.825	1.022
.057	.030	.054	.079	.103	.130	.156	.185	.214	.241	.290	.339	.388	.438	.536	.634	.732	.830	1.027
.063	.033	.057	.082	.106	.131	.158	.186	.216	.245	.294	.344	.393	.442	.540	.638	.736	.834	1.031
.072	.038	.062	.087	.111	.135	.161	.189	.220	.248	.302	.351	.400	.449	.547	.646	.744	.842	1.038
.081	.042	.067	.091	.116	.140	.165	.191	.224	.250	.307	.358	.407	.456	.554	.653	.751	.849	1.045
.091	.047	.072	.096	.121	.146	.170	.194	.227	.252	.312	.366	.415	.464	.562	.660	.758	.857	1.053
.102	.053	.078	.102	.127	.151	.176	.200	.230	.258	.316	.370	.424	.473	.571	.669	.767	.865	1.062
.109	.057	.082	.106	.131	.155	.180	.204	.232	.261	.319	.371	.429	.478	.577	.675	.773	.871	1.067
.125	.065	.090	.114	.139	.164	.188	.213	.237	.267	.324	.373	.434	.491	.589	.687	.785	.884	1.080
.156	.082	.106	.131	.155	.180	.204	.229	.253	.278	.332	.384	.444	.500	.614	.712	.810	.908	1.104
.188	.098	.123	.147	.172	.196	.221	.245	.270	.295	.344	.394	.454	.510	.624	.736	.834	.933	1.129
.250	.131	.155	.180	.204	.229	.254	.278	.303	.327	.376	.425	.474	.529	.643	.756	.869	.982	1.178
.313	.164	.188	.213	.237	.262	.286	.311	.335	.360	.409	.458	.507	.556	.662	.776	.889	1.002	1.227
.375	.196	.221	.245	.270	.295	.319	.344	.386	.393	.442	.491	.540	.589	.687	.797	.909	1.022	1.247
.500	.262	.286	.311	.335	.360	.384	.409	.433	.458	.507	.556	.605	.654	.753	.851	.949	1.061	1.285
.625	.328	.352	.377	.401	.426	.450	.475	.499	.524	.573	.622	.671	.720	.818	.916	1.014	1.113	1.323
.750	.393	.417	.442	.466	.491	.513	.540	.564	.589	.638	.687	.736	.785	.884	.982	1.080	1.178	1.374
.875	.458	.483	.507	.532	.556	.581	.605	.630	.654	.703	.753	.802	.851	.949	1.047	1.145	1.243	1.440
1.000	.524	.548	.573	.597	.622	.646	.671	.695	.720	.769	.818	.867	.916	1.014	1.113	1.211	1.309	1.505

*Developed Length = (Length Before Bending) - (Sum of the Flat Lengths)

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Table 3-4
DEVELOPED LENGTH OF MATERIAL FOR 90° BENDS* (Continued)

Material Thickness in.	Inside Radius of Bend (in.)																	
	¾	⅞	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½
.016	1.191	1.387	1.583	1.976	2.368	2.761	3.154	3.547	3.940	4.332	4.725	5.118	5.510	5.903	6.298	7.081	7.867	8.652
.020	1.194	1.390	1.587	1.979	2.372	2.765	3.157	3.550	3.943	4.335	4.728	5.121	5.514	5.905	6.299	7.084	7.870	8.655
.025	1.198	1.394	1.590	1.983	2.376	2.769	3.161	3.554	3.947	4.339	4.732	5.125	5.517	5.910	6.303	7.088	7.874	8.659
.032	1.203	1.400	1.596	1.989	2.381	2.774	3.167	3.559	3.952	4.345	4.738	5.130	5.523	5.916	6.308	7.094	7.879	8.665
.040	1.210	1.406	1.602	1.995	2.388	2.780	3.173	3.566	3.958	4.351	4.744	5.137	5.529	5.922	6.315	7.100	7.885	8.671
.051	1.218	1.414	1.611	2.003	2.396	2.789	3.181	3.574	3.967	4.360	4.752	5.145	5.538	5.930	6.323	7.109	7.894	8.679
.057	1.223	1.419	1.616	2.008	2.401	2.794	3.186	3.579	3.972	4.365	4.757	5.150	5.543	5.935	6.328	7.113	7.899	8.684
.063	1.227	1.423	1.620	2.013	2.405	2.798	3.191	3.583	3.977	4.369	4.761	5.154	5.547	5.940	6.332	7.118	7.903	8.688
.072	1.235	1.431	1.627	2.020	2.413	2.805	3.198	3.591	3.984	4.376	4.769	5.162	5.554	5.947	6.340	7.125	7.911	8.696
.081	1.242	1.438	1.634	2.027	2.420	2.812	3.205	3.598	3.990	4.383	4.776	5.169	5.561	5.954	6.347	7.132	7.917	8.703
.091	1.249	1.446	1.642	2.035	2.427	2.820	3.213	3.605	3.998	4.391	4.784	5.176	5.569	5.962	6.354	7.140	7.925	8.711
.102	1.258	1.454	1.651	2.043	2.436	2.829	3.222	3.614	4.007	4.400	4.792	5.185	5.578	5.971	6.363	7.149	7.934	8.719
.109	1.264	1.461	1.656	2.049	2.442	2.835	3.227	3.620	4.013	4.405	4.798	5.191	5.583	5.976	6.369	7.154	7.940	8.725
.125	1.301	1.473	1.669	2.062	2.454	2.847	3.240	3.632	4.025	4.418	4.811	5.203	5.596	5.989	6.381	7.167	7.952	8.738
.156	1.301	1.497	1.693	2.086	2.479	2.872	3.264	3.657	4.050	4.442	4.835	5.228	5.620	6.013	6.406	7.191	7.977	8.762
.188	1.325	1.522	1.718	2.111	2.503	2.896	3.289	3.681	4.074	4.467	4.860	5.252	5.645	6.038	6.430	7.216	8.001	8.787
.250	1.374	1.571	1.767	2.160	2.553	2.945	3.338	3.731	4.123	4.516	4.909	5.301	5.694	6.087	6.480	7.265	8.050	8.836
.313	1.423	1.620	1.816	2.209	2.602	2.994	3.387	3.780	4.172	4.565	4.958	5.350	5.743	6.136	6.529	7.314	8.099	8.885
.375	1.473	1.669	1.865	2.258	2.651	3.043	3.436	3.829	4.222	4.614	5.007	5.400	5.792	6.185	6.578	7.363	8.149	8.934
.500	1.511	1.737	1.964	2.356	2.749	3.142	3.584	3.027	4.320	4.712	5.105	5.498	5.891	6.283	6.676	7.461	8.247	9.032
.625	1.548	1.774	2.001	2.454	2.847	3.240	3.632	4.025	4.418	4.811	5.203	5.596	5.989	6.381	6.774	7.560	8.345	9.130
.750	1.585	1.812	2.038	2.491	2.915	3.338	3.731	4.123	4.516	4.909	5.301	5.694	6.087	6.480	6.872	7.658	8.443	9.228
.875	1.636	1.850	2.075	2.529	2.983	3.436	3.829	4.222	4.614	5.007	5.400	5.792	6.185	6.578	6.970	7.756	8.541	9.327
1.000	1.702	1.898	2.112	2.566	3.021	3.474	3.927	4.320	4.712	5.105	5.498	5.891	6.283	6.676	7.069	7.854	8.639	9.426

*Developed Length = (Length Before Bending) - (Sum of the Flat Lengths)

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Table 4-1

BEAM ALLOWABLE UNIFORM LOADS
ALUMINUM ASSOCIATION STANDARD CHANNELS, ALLOY 6061-T6

Depth	Wt	span (ft)																				
in.	lb/ft	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	0.577	4.43 0.03 3.90	2.22 0.14 1.63	1.48 0.31 0.94																		
2	1.07	8.56 0.03 7.97	4.28 0.14 3.59	2.85 0.31 2.21																		
3	1.14	13.77 0.02 13.06	6.89 0.09 5.72	4.59 0.20 3.40	3.44 0.35 2.29	2.75 0.54 1.54																
3	1.60	19.59 0.02 18.93	9.80 0.09 8.51	6.53 0.20 5.19	4.90 0.35 3.60	3.92 0.55 2.68																
4	1.74	28.63 0.02 28.09	14.32 0.07 12.63	9.54 0.15 7.61	7.16 0.26 5.18	5.73 0.41 3.79	4.77 0.59 2.72	4.09 0.80 1.92														
4	2.33	38.66 0.02 38.34	19.33 0.07 17.50	12.89 0.15 10.72	9.67 0.26 7.45	7.73 0.41 5.56	6.44 0.60 4.34	5.52 0.81 3.49														
5	2.21		22.90 0.05 20.68	15.27 0.12 12.54	11.45 0.21 8.58	9.16 0.32 6.27	7.63 0.47 4.69	6.54 0.63 3.26	5.73 0.83 2.39													
5	3.09		32.62 0.05 30.49	21.74 0.12 18.87	16.31 0.21 13.18	13.05 0.33 9.87	10.87 0.47 7.72	9.32 0.64 6.23	8.15 0.84 5.14													
6	2.83			23.33 0.10 19.64	17.50 0.17 13.50	14.00 0.27 9.91	11.67 0.39 7.59	10.00 0.53 5.49	8.75 0.69 3.99	7.78 0.88 3.03	7.00 1.08 2.39											
6	4.03			33.76 0.10 30.67	25.32 0.17 21.58	20.26 0.27 16.23	16.88 0.39 12.74	14.47 0.53 10.31	12.66 0.69 8.54	11.25 0.87 7.17	10.13 1.07 5.62											
7	3.21			29.95 0.08 26.45	22.46 0.14 18.25	17.97 0.23 13.42	14.98 0.33 10.28	12.84 0.44 7.69	11.23 0.58 5.50	9.98 0.73 4.12	8.99 0.91 3.20	8.17 1.10 2.56	7.49 1.30 2.09									
7	4.72				34.76 0.15 30.10	27.81 0.23 22.68	23.17 0.33 17.82	19.86 0.45 14.43	17.38 0.59 11.94	15.45 0.74 10.05	13.90 0.92 8.02	12.64 1.11 6.43	11.59 1.32 5.27									
8	4.15				34.30 0.13 27.91	27.44 0.20 20.69	22.86 0.29 15.98	19.60 0.40 12.69	17.15 0.52 9.51	15.24 0.66 7.11	13.72 0.82 5.51	12.47 0.99 4.39	11.43 1.18 3.59	10.55 1.38 2.99	9.80 1.60 2.53						
8	5.79				47.86 0.13 41.96	38.29 0.20 31.69	31.91 0.29 24.96	27.35 0.40 20.24	23.93 0.52 16.77	21.27 0.66 14.13	19.15 0.81 11.83	17.41 0.98 9.43	15.95 1.17 7.69	14.73 1.37 6.40	13.68 1.59 5.40						
9	4.98					35.17 0.18 27.65	29.31 0.26 21.40	25.12 0.35 17.02	21.98 0.46 13.53	19.54 0.58 10.01	17.58 0.72 7.69	15.99 0.87 6.09	14.65 1.04 4.94	13.53 1.22 4.09	12.56 1.41 3.44	11.72 1.62 2.93					
9	6.97					51.17 0.18 42.85	42.64 0.26 33.81	36.55 0.36 27.45	31.98 0.47 22.77	28.43 0.59 19.20	25.58 0.73 16.41	23.26 0.88 13.46	21.32 1.05 10.94	19.68 1.23 9.06	18.27 1.43 7.63	17.06 1.64 6.52					
10	6.14						41.20 0.24 30.45	35.32 0.32 24.38	30.90 0.42 19.91	27.47 0.54 15.70	24.72 0.66 12.04	22.48 0.80 9.52	20.60 0.95 7.71	19.02 1.12 6.37	17.66 1.30 5.35	16.48 1.49 4.56	15.45 1.69 3.94	14.54 1.91 3.43			
10	8.36						57.31 0.24 45.98	49.13 0.32 37.46	42.99 0.42 31.17	38.21 0.53 26.37	34.39 0.66 22.60	31.26 0.80 19.57	28.66 0.95 15.97	26.45 1.12 13.20	24.56 1.29 11.10	22.93 1.49 9.47	21.49 1.69 8.17	20.23 1.91 7.13			
12	8.27							56.70 0.27 41.38	49.61 0.35 34.05	44.10 0.45 28.45	39.69 0.55 23.21	36.08 0.67 18.19	33.07 0.80 14.61	30.53 0.93 11.99	28.35 1.08 10.01	26.46 1.24 8.48	24.81 1.41 7.28	23.35 1.60 6.32	22.05 1.79 5.53	20.89 1.99 4.89	19.84 2.21 4.35	18.90 2.44 3.90
12	11.8							84.28 0.27 67.86	73.74 0.35 56.89	65.55 0.44 48.47	58.99 0.55 41.84	53.63 0.66 36.50	49.16 0.79 32.12	45.38 0.93 28.48	42.14 1.07 23.97	39.33 1.23 20.35	36.87 1.40 17.50	34.70 1.58 15.21	32.77 1.77 13.35	31.05 1.98 11.81	29.50 2.19 10.53	28.09 2.41 9.44
14	13.9							116.60 0.22 100.92	102.03 0.29 85.07	90.69 0.37 72.85	81.62 0.45 63.16	74.20 0.55 55.32	68.02 0.65 48.87	62.79 0.77 43.47	58.30 0.89 38.91	54.41 1.02 34.45	51.01 1.16 29.34	48.01 1.31 25.27	45.35 1.47 21.99	42.96 1.64 19.31	40.81 1.81 17.09	38.87 2.00 15.24

Notes

1. Load is applied at beam's neutral axis on a simply supported single span braced against twisting at supports.
2. Building-type structure.
3. For each beam size, first line is total load (k) for laterally braced beam, second line is deflection (in.) for laterally braced beam, and third line is total load (k) for beam not laterally braced.

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Table 4-2

BEAM ALLOWABLE UNIFORM LOADS
ALUMINUM ASSOCIATION STANDARD W-SHAPES, ALLOY 6061-T6

Depth	Wt	span (ft)																				
in.	lb/ft	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3	1.64	21.05 0.02 20.74	10.52 0.08 9.42	7.02 0.19 5.75	5.26 0.33 3.99	4.21 0.52 2.97																
3	2.03	26.11 0.02 25.75	13.06 0.09 11.76	8.70 0.19 7.25	6.53 0.34 5.09	5.22 0.54 3.83																
4	2.31	39.88 0.02 39.88	19.94 0.06 18.31	13.29 0.14 11.23	9.97 0.25 7.78	7.98 0.40 5.77	6.65 0.57 4.48	5.70 0.77 3.37														
4	2.79	48.46 0.02 48.46	24.23 0.06 22.30	16.15 0.14 13.76	12.11 0.26 9.61	9.69 0.40 7.21	8.08 0.58 5.65	6.92 0.79 4.57														
5	3.70		39.95 0.05 37.57	26.63 0.12 23.32	19.97 0.20 16.35	15.98 0.32 12.27	13.32 0.46 9.63	11.41 0.63 7.79	9.99 0.82 6.45													
6	4.03			34.73 0.09 31.01	26.05 0.17 21.74	20.84 0.26 16.27	17.37 0.38 12.70	14.88 0.52 10.21	13.02 0.68 8.23	11.58 0.85 6.19	10.42 1.06 4.83											
6	4.69			40.66 0.10 36.41	30.50 0.17 25.62	24.40 0.27 19.27	20.33 0.38 15.13	17.43 0.52 12.25	15.25 0.68 10.14	13.55 0.86 8.20	12.20 1.07 6.44											
7	5.80				44.04 0.15 37.93	35.23 0.23 28.63	29.36 0.33 22.55	25.17 0.45 18.29	22.02 0.59 15.16	19.57 0.74 12.78	17.62 0.91 10.17	16.01 1.11 8.14	14.68 1.32 6.66								
8	6.18				53.43 0.13 46.78	42.74 0.20 35.35	35.62 0.29 27.82	30.53 0.39 22.52	26.71 0.51 18.62	23.75 0.65 15.63	21.37 0.80 12.48	19.43 0.96 9.85	17.81 1.15 7.96	16.44 1.35 6.57	15.26 1.56 5.52						
8	7.02				60.99 0.13 53.56	48.80 0.20 40.57	40.66 0.29 32.03	34.85 0.39 26.03	30.50 0.51 21.62	27.11 0.65 18.25	24.40 0.80 15.59	22.18 0.97 12.38	20.33 1.15 10.07	18.77 1.35 8.35	17.43 1.57 7.04						
9	8.36					65.40 0.18 55.64	54.50 0.26 44.09	46.71 0.35 35.94	40.87 0.46 29.93	36.33 0.58 25.33	32.70 0.71 21.71	29.73 0.86 18.32	27.25 1.03 14.81	25.15 1.21 12.22	23.36 1.40 10.25	21.80 1.61 8.73					
10	8.65						62.49 0.23 51.77	53.56 0.31 42.30	46.87 0.40 35.27	41.66 0.51 29.87	37.49 0.63 25.61	34.08 0.77 22.16	31.24 0.91 17.73	28.84 1.07 14.48	26.78 1.24 12.05	25.00 1.42 10.17	23.43 1.62 8.70	22.05 1.83 7.53			
10	10.3						74.42 0.23 61.98	63.79 0.31 50.79	55.81 0.41 42.50	49.61 0.52 36.15	44.65 0.64 31.15	40.59 0.77 27.12	37.21 0.92 23.43	34.35 1.08 19.28	31.89 1.25 16.14	29.77 1.43 13.71	27.91 1.63 11.80	26.27 1.84 10.26			
12	11.7							86.86 0.26 71.63	76.00 0.34 60.08	67.56 0.43 51.17	60.80 0.53 44.12	55.27 0.64 38.41	50.67 0.76 33.71	46.77 0.89 28.84	43.43 1.04 23.80	40.53 1.19 19.96	38.00 1.35 16.96	35.76 1.53 14.58	33.78 1.71 12.67	32.00 1.91 11.10	30.40 2.12 9.81	28.95 2.33 8.73
12	14.3							108.31 0.26 90.43	94.77 0.34 76.15	84.24 0.43 65.16	75.82 0.53 56.48	68.93 0.64 49.47	63.18 0.77 43.70	58.32 0.90 38.89	54.16 1.04 34.62	50.55 1.20 29.25	47.39 1.36 25.04	44.60 1.54 21.67	42.12 1.73 18.95	39.90 1.92 16.71	37.91 2.13 14.84	36.10 2.35 13.28
14	16.0							142.18 0.22 122.35	124.41 0.29 103.32	110.59 0.37 88.62	99.53 0.45 76.95	90.48 0.55 67.48	82.94 0.65 59.66	76.56 0.77 53.12	71.09 0.89 47.57	66.35 1.02 42.29	62.20 1.16 35.82	58.55 1.31 30.70	55.29 1.47 26.60	52.38 1.64 23.26	49.76 1.81 20.50	47.39 2.00 18.21

Notes

1. Load is applied at beam's neutral axis on a simply supported single span braced against twisting at supports.
2. Building-type structure.
3. For each beam size, first line is total load (k) for laterally braced beam, second line is deflection (in.) for laterally braced beam, and third line is total load (k) for beam not laterally braced.

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Table 4-3
ALLOWABLE LOADS (LB/FT^2) ON ASTM B632 6061-T6 ALUMINUM TREAD PLATE

Thickness in.	Long span	Short span 1'-0"	1'-6"	2'-0"	2'-6"	3'-0"	3'-6"	4'-0"
0.188	1'-0"	833						
	1'-6"	440	247					
	2'-0"	333	151	104				
	2'-6"	300	117	70	53			
	3'-0"	277	99	55	38	31		
	3'-6"	270	92	47	31	23	19	
	4'-0"	264	87	42	26	19	15	13
	infinity	260	77	33	17	10	6	4
0.250	1'-0"	1975						
	1'-6"	1043	585					
	2'-0"	790	358	247				
	2'-6"	711	276	166	126			
	3'-0"	657	234	130	91	73		
	3'-6"	641	217	111	73	55	46	
	4'-0"	626	206	99	62	45	36	31
	infinity	617	183	77	39	23	14	10
0.375	1'-0"	6664						
	1'-6"	3519	1975					
	2'-0"	2666	1208	833				
	2'-6"	2401	933	560	427			
	3'-0"	2216	790	440	307	247		
	3'-6"	2164	733	376	246	185	155	
	4'-0"	2114	696	333	209	151	121	104
	infinity	2082	617	260	133	77	49	33
0.500	1'-0"	15797						
	1'-6"	8341	4681					
	2'-0"	6319	2865	1975				
	2'-6"	5691	2212	1326	1011			
	3'-0"	5254	1872	1043	729	585		
	3'-6"	5129	1737	892	583	439	368	
	4'-0"	5010	1650	790	495	358	286	247
	infinity	4936	1462	617	316	183	115	77

Allowable loads in this table are calculated using Roark's Formulas for Stress and Strain, 6th edition, Table 26, Case 1a assuming that deflections are limited to the short span divided by 150, all plate edges are simply suported, the allowable flexural stress is 31.8 ksi, and the plate is uniformly loaded.

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Table 4-4

MAXIMUM SPANS (IN.)
Corrugated And V-Beam Roofing And Siding

Design Load (psf)	Number of Equal Spans					
	One		Two		Three	
	Strength	Deflection	Strength	Deflection	Strength	Deflection
Corrugated Roofing and Siding – 0.024" thick						
20	79	61	79	–	88	76
25	70	57	70	–	79	70
30	64	54	64	–	72	66
35	60	51	60	–	67	63
40	56	49	56	–	63	60
45	53	47	53	–	59	58
50	50	45	50	–	56	56
Corrugated Roofing and Siding – 0.032" thick						
20	92	67	92	90	102	83
25	82	63	82	–	92	77
30	75	59	75	–	84	73
35	70	56	70	–	78	69
40	65	54	65	–	73	66
45	62	52	62	–	69	64
50	58	50	58	–	65	62
V-Beam Roofing and Siding – 0.032" thick, 4 7/8" Pitch						
20	128	110	128	–	144	136
25	115	102	115	–	129	127
30	105	97	105	–	118	–
35	98	92	98	–	109	–
40	92	88	92	–	102	–
45	86	85	86	–	97	–
50	82	82	82	–	92	–
55	78	–	78	–	87	–
60	75	–	75	–	84	–
V-Beam Roofing and Siding – 0.040" thick, 4 7/8" Pitch						
20	150	118	150	–	167	146
25	134	110	134	–	150	136
30	123	104	123	–	137	128
35	114	99	114	–	127	122
40	107	94	107	–	119	117
45	101	91	101	–	113	112
50	96	88	96	–	107	–
55	91	85	91	–	102	–
60	87	83	87	–	98	–

Notes

1. Maximum spans are calculated in accordance with the *Specification for Aluminum Structures* for allowable strength design of building-type structures.
2. Material is Alclad 3004-H151, -H261, or –H361 (which are stucco embossed tempers) or Alclad 3004-H16. Dimensions are given in Part V Table 25 and section properties are given in Part V Table 26.
3. The deflection limit is 1/60 of the span.

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Table 4-4

MAXIMUM SPANS (IN.) (Continued)
Corrugated And V-Beam Roofing And Siding

Design Load (psf)	Number of Equal Spans					
	One		Two		Three	
	Strength	Deflection	Strength	Deflection	Strength	Deflection
V-Beam Roofing and Siding – 0.050" thick, 4 7/8" Pitch						
20	171	127	171	170	191	157
25	154	118	154	–	172	146
30	141	111	141	–	158	138
35	131	106	131	–	146	131
40	122	102	122	–	137	125
45	116	98	116	–	129	121
50	110	94	110	–	123	117
55	105	92	105	–	117	113
60	100	89	100	–	112	110
V-Beam Roofing and Siding – 0.032" thick, 5 1/3" Pitch						
20	128	114	128	–	143	141
25	115	106	115	–	129	–
30	105	100	105	–	118	–
35	98	95	98	–	109	–
40	91	91	91	–	102	–
45	86	–	86	–	96	–
50	82	–	82	–	91	–
55	78	–	78	–	87	–
60	75	–	75	–	84	–
V-Beam Roofing and Siding – 0.040" thick, 5 1/3" Pitch						
20	153	123	153	–	171	151
25	137	114	137	–	154	141
30	126	108	126	–	141	133
35	117	102	117	–	130	126
40	109	98	109	–	122	121
45	103	94	103	–	115	–
50	98	91	98	–	110	–
55	93	88	93	–	104	–
60	90	86	90	–	100	–
V-Beam Roofing and Siding – 0.050" thick, 5 1/3" Pitch						
20	176	132	176	176	197	163
25	158	123	158	–	177	151
30	145	116	145	–	162	143
35	134	110	134	–	150	136
40	126	105	126	–	141	130
45	119	101	119	–	133	125
50	113	98	113	–	126	121
55	108	95	108	–	120	117
60	103	92	103	–	115	114

Notes

1. Maximum spans are calculated in accordance with the *Specification for Aluminum Structures* for allowable strength design of building-type structures.
2. Material is Alclad 3004-H151, -H261, or –H361 (which are stucco embossed tempers) or Alclad 3004-H16. Dimensions are given in Part V Table 25 and section properties are given in Part V Table 26.
3. The deflection limit is 1/60 of the span.

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Table 4-5
MAXIMUM SPANS (IN.) COMMERCIAL RIBBED SIDING

Design Load (psf)	Number of Equal Spans											
	One				Two				Three			
	Str[1]	Str[2]	Defl[1]	Defl[2]	Str[1]	Str[2]	Defl[1]	Defl[2]	Str[1]	Str[2]	Defl[1]	Defl[2]
Ribbed Siding – 0.032" thick, 4" Pitch												
20	98	101		85	101	98	–		113	110	106	
25	88	91		79	91	88	–		101	98	98	
30	80	83		75	83	80	–		93	90	93	
35	75	77		71	77	75	–		86	83	–	
40	70	72		68	72	70	–		80	78	–	
45	66	68		66	68	66	–		76	74	–	
50	63	64		63	64	63	–		72	70	–	
Ribbed Siding – 0.040" thick, 4" Pitch												
20	118	120		92	120	118	–		134	132	113	
25	106	107		85	107	106	–		120	118	105	
30	97	98		80	98	97	–		110	108	99	
35	90	91		76	91	90	–		102	100	94	
40	84	85		73	85	84	–		95	94	90	
45	79	80		70	80	79	–		90	89	87	
50	75	76		68	76	75	–		85	84	84	
Ribbed Siding – 0.032" thick, 8" Pitch												
20	62	77	74	–	77	62	–	–	78	69	–	–
25	56	69	–	–	69	56	–	–	70	62	–	–
30	51	63	–	–	63	51	–	–	64	57	–	–
35	47	59	–	–	59	47	–	–	59	53	–	–
40	44	55	–	–	55	44	–	–	55	49	–	–
45	42	52	–	–	52	42	–	–	52	47	–	–
50	40	49	–	–	49	40	–	–	49	44	–	–
Ribbed Siding – 0.040" thick, 8" Pitch												
20	75	91	80	84	91	75	–	–	94	84	–	–
25	67	82	74	79	82	67	–	–	84	75	–	–
30	62	75	70	74	75	62	–	–	77	69	–	–
35	57	69	67	–	69	57	–	–	71	64	–	–
40	54	65	64	–	65	54	–	–	67	60	–	–
45	51	61	–	–	61	51	–	–	63	56	–	–
50	48	58	–	–	58	48	–	–	60	54	–	–

Notes

1. Wide flat is on loaded side; load is toward neutral axis.
2. Narrow flat is on loaded side; load is toward neutral axis.
3. Maximum spans are calculated in accordance with the *Specification for Aluminum Structures* for allowable strength design of building-type structures.
4. Material is Alclad 3004-H151, -H261, or –H361 (which are stucco embossed tempers) or Alclad 3004-H16. Dimensions are given in Part V Table 25 and section properties are given in Part V Table 26.
5. The deflection limit is 1/60 of the span

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Table 4-6
DEFLECTIONS AND ALLOWABLE LOADS FOR 6061-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
1	0.125	39	*U*	lb/ft^2	676	433	300	221	169	134									
I/bar	0.0104		D_u	in.	0.234	0.365	0.526	0.715	0.934	1.183									
I/ft	0.1042		*C*	lb/ft	676	541	451	386	338	300									
λ	36.8		D_c	in.	0.187	0.292	0.420	0.572	0.748	0.946									
1	0.1875	44	*U*	lb/ft^2	1014	649	451	331	253	200									
I/bar	0.0156		D_u	in.	0.234	0.365	0.526	0.715	0.934	1.183									
I/ft	0.1563		*C*	lb/ft	1014	811	676	579	507	451									
λ	24.5		D_c	in.	0.187	0.292	0.420	0.572	0.748	0.946									
1	0.25	47	*U*	lb/ft^2	1352	865	601	441	338	267	216	179	150						
I/bar	0.0208		D_u	in.	0.234	0.365	0.526	0.715	0.934	1.183	1.460	1.767	2.102						
I/ft	0.2083		*C*	lb/ft	1352	1082	901	773	676	601	541	492	451						
λ	18.4		D_c	in.	0.187	0.292	0.420	0.572	0.748	0.946	1.168	1.413	1.682						
1.25	0.125	47	*U*	lb/ft^2	1056	676	469	345	264	209	169	140	117						
I/bar	0.0203		D_u	in.	0.187	0.292	0.420	0.572	0.748	0.946	1.168	1.413	1.682						
I/ft	0.2035		*C*	lb/ft	1056	845	704	604	528	469	422	384	352						
λ	41.1		D_c	in.	0.150	0.234	0.336	0.458	0.598	0.757	0.934	1.131	1.346						
1.25	0.1875	51	*U*	lb/ft^2	1584	1014	704	517	396	313	253	209	176	150	129				
I/bar	0.0305		D_u	in.	0.187	0.292	0.420	0.572	0.748	0.946	1.168	1.413	1.682	1.974	2.289				
I/ft	0.3052		*C*	lb/ft	1584	1267	1056	905	792	704	634	576	528	487	453				
λ	27.4		D_c	in.	0.150	0.234	0.336	0.458	0.598	0.757	0.934	1.131	1.346	1.579	1.831				
1.25	0.25	55	*U*	lb/ft^2	2112	1352	939	690	528	417	338	279	235	200	172				
I/bar	0.0407		D_u	in.	0.187	0.292	0.420	0.572	0.748	0.946	1.168	1.413	1.682	1.974	2.289				
I/ft	0.4069		*C*	lb/ft	2112	1690	1408	1207	1056	939	845	768	704	650	604				
λ	20.6		D_c	in.	0.150	0.234	0.336	0.458	0.598	0.757	0.934	1.131	1.346	1.579	1.831				
1.5	0.125	53	*U*	lb/ft^2	1521	973	676	497	380	300	243	201	169	144	124	108	95	84	75
I/bar	0.0352		D_u	in.	0.156	0.243	0.350	0.477	0.623	0.788	0.973	1.178	1.402	1.645	1.908	2.190	2.492	2.813	3.154
I/ft	0.3516		*C*	lb/ft	1521	1217	1014	869	760	676	608	553	507	468	435	406	380	358	338

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Table 4-6
DEFLECTIONS AND ALLOWABLE LOADS FOR 6061-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
λ	45.1		D_c	in.	0.125	0.195	0.280	0.382	0.498	0.631	0.779	0.942	1.121	1.316	1.526	1.752	1.993	2.250	2.523
1.5	0.1875	59	U	lb/ft^2	2281	1460	1014	745	570	451	365	302	253	216	186	162	143	126	113
I/bar	0.0527		D_u	in.	0.156	0.243	0.350	0.477	0.623	0.788	0.973	1.178	1.402	1.645	1.908	2.190	2.492	2.813	3.154
I/ft	0.5273		C	lb/ft	2281	1825	1521	1304	1141	1014	913	830	760	702	652	608	570	537	507
λ	30.0		D_c	in.	0.125	0.195	0.280	0.382	0.498	0.631	0.779	0.942	1.121	1.316	1.526	1.752	1.993	2.250	2.523
1.5	0.25	63	U	lb/ft^2	3042	1947	1352	993	760	601	487	402	338	288	248	216	190	168	150
I/bar	0.0703		D_u	in.	0.156	0.243	0.350	0.477	0.623	0.788	0.973	1.178	1.402	1.645	1.908	2.190	2.492	2.813	3.154
I/ft	0.7031		C	lb/ft	3042	2433	2028	1738	1521	1352	1217	1106	1014	936	869	811	760	716	676
λ	22.5		D_c	in.	0.125	0.195	0.280	0.382	0.498	0.631	0.779	0.942	1.121	1.316	1.526	1.752	1.993	2.250	2.523
1.75	0.1875	66	U	lb/ft^2	3105	1987	1380	1014	776	613	497	411	345	294	253	221	194	172	153
I/bar	0.0837		D_u	in.	0.133	0.209	0.300	0.409	0.534	0.676	0.834	1.010	1.201	1.410	1.635	1.877	2.136	2.411	2.703
I/ft	0.8374		C	lb/ft	3105	2484	2070	1774	1553	1380	1242	1129	1035	955	887	828	776	731	690
λ	32.5		D_c	in.	0.107	0.167	0.240	0.327	0.427	0.541	0.667	0.808	0.961	1.128	1.308	1.502	1.709	1.929	2.163
1.75	0.25	71	U	lb/ft^2	4140	2650	1840	1352	1035	818	662	547	460	392	338	294	259	229	204
I/bar	0.1117		D_u	in.	0.133	0.209	0.300	0.409	0.534	0.676	0.834	1.010	1.201	1.410	1.635	1.877	2.136	2.411	2.703
I/ft	1.1165		C	lb/ft	4140	3312	2760	2366	2070	1840	1656	1506	1380	1274	1183	1104	1035	974	920
λ	24.3		D_c	in.	0.107	0.167	0.240	0.327	0.427	0.541	0.667	0.808	0.961	1.128	1.308	1.502	1.709	1.929	2.163
2	0.1875	73	U	lb/ft^2	4056	2596	1803	1324	1014	801	649	536	451	384	331	288	253	225	200
I/bar	0.1250		D_u	in.	0.117	0.183	0.263	0.358	0.467	0.591	0.730	0.883	1.051	1.234	1.431	1.643	1.869	2.110	2.365
I/ft	1.2500		C	lb/ft	4056	3245	2704	2318	2028	1803	1622	1475	1352	1248	1159	1082	1014	954	901
λ	34.7		D_c	in.	0.093	0.146	0.210	0.286	0.374	0.473	0.584	0.707	0.841	0.987	1.145	1.314	1.495	1.688	1.892
2	0.25	79	U	lb/ft^2	5408	3461	2403	1766	1352	1068	865	715	601	512	441	385	338	299	267
I/bar	0.1667		D_u	in.	0.117	0.183	0.263	0.358	0.467	0.591	0.730	0.883	1.051	1.234	1.431	1.643	1.869	2.110	2.365
I/ft	1.6667		C	lb/ft	5408	4326	3605	3090	2704	2403	2163	1966	1803	1664	1545	1442	1352	1272	1202

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Table 4-6
DEFLECTIONS AND ALLOWABLE LOADS FOR 6061-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
λ	26.0		D_c	in.	0.093	0.146	0.210	0.286	0.374	0.473	0.584	0.707	0.841	0.987	1.145	1.314	1.495	1.688	1.892
2.25	0.1875	80	U	lb/ft^2	5133	3285	2281	1676	1283	1014	821	679	570	486	419	365	321	284	253
I/bar	0.1780		D_u	in.	0.104	0.162	0.234	0.318	0.415	0.526	0.649	0.785	0.934	1.097	1.272	1.460	1.661	1.875	2.102
I/ft	1.7798		C	lb/ft	5133	4106	3422	2933	2566	2281	2053	1867	1711	1579	1467	1369	1283	1208	1141
λ	36.8		D_c	in.	0.083	0.130	0.187	0.254	0.332	0.420	0.519	0.628	0.748	0.877	1.017	1.168	1.329	1.500	1.682
2.25	0.25	86	U	lb/ft^2	6844	4380	3042	2235	1711	1352	1095	905	760	648	559	487	428	379	338
I/bar	0.2373		D_u	in.	0.104	0.162	0.234	0.318	0.415	0.526	0.649	0.785	0.934	1.097	1.272	1.460	1.661	1.875	2.102
I/ft	2.3730		C	lb/ft	6844	5475	4563	3911	3422	3042	2738	2489	2281	2106	1955	1825	1711	1610	1521
λ	27.6		D_c	in.	0.083	0.130	0.187	0.254	0.332	0.420	0.519	0.628	0.748	0.877	1.017	1.168	1.329	1.500	1.682
2.5	0.1875	87	U	lb/ft^2	6337	4056	2816	2069	1584	1252	1014	838	704	600	517	451	396	351	313
I/bar	0.2441		D_u	in.	0.093	0.146	0.210	0.286	0.374	0.473	0.584	0.707	0.841	0.987	1.145	1.314	1.495	1.688	1.892
I/ft	2.4414		C	lb/ft	6337	5070	4225	3621	3168	2816	2535	2304	2112	1950	1811	1690	1584	1491	1408
λ	38.8		D_c	in.	0.075	0.117	0.168	0.229	0.299	0.378	0.467	0.565	0.673	0.790	0.916	1.051	1.196	1.350	1.514
2.5	0.25	93	U	lb/ft^2	8449	5408	3755	2759	2112	1669	1352	1117	939	800	690	601	528	468	417
I/bar	0.3255		D_u	in.	0.093	0.146	0.210	0.286	0.374	0.473	0.584	0.707	0.841	0.987	1.145	1.314	1.495	1.688	1.892
I/ft	3.2552		C	lb/ft	8449	6759	5633	4828	4225	3755	3380	3072	2816	2600	2414	2253	2112	1988	1878
λ	29.1		D_c	in.	0.075	0.117	0.168	0.229	0.299	0.378	0.467	0.565	0.673	0.790	0.916	1.051	1.196	1.350	1.514

Notes
1. Allowable loads are for building-type structures.
2. L_{max} is the maximum span (in.) supporting 100 psf live load with no more than 0.25" deflection.
3. U is the maximum allowable uniform load.
4. D_u is the deflection at the maximum allowable uniform load.
5. C is maximum allowable concentrated load.
6. D_c is the deflection at the maximum allowable concentrated load.
7. NAAMM MBG531 also provides aluminum grating span tables.

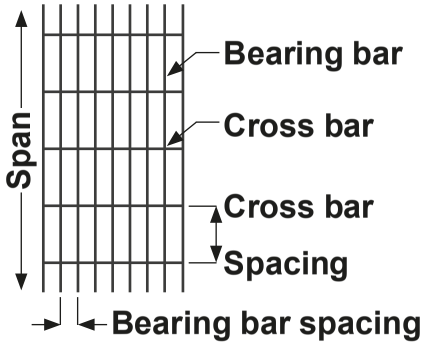

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Table 4-7
DEFLECTIONS AND ALLOWABLE LOADS FOR 6063-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
1	0.125	39	U	lb/ft^2	530	339	236	173	133	105									
I/bar	0.0104		D_u	in.	0.183	0.286	0.412	0.561	0.733	0.928									
I/ft	0.1042		C	lb/ft	530	424	354	303	265	236									
λ	36.8		D_c	in.	0.147	0.229	0.330	0.449	0.587	0.742									
1	0.1875	44	U	lb/ft^2	796	509	354	260	199	157									
I/bar	0.0156		D_u	in.	0.183	0.286	0.412	0.561	0.733	0.928									
I/ft	0.1563		C	lb/ft	796	636	530	455	398	354									
λ	24.5		D_c	in.	0.147	0.229	0.330	0.449	0.587	0.742									
1	0.25	47	U	lb/ft^2	1061	679	471	346	265	210	170	140	118						
I/bar	0.0208		D_u	in.	0.183	0.286	0.412	0.561	0.733	0.928	1.146	1.386	1.650						
I/ft	0.2083		C	lb/ft	1061	849	707	606	530	471	424	386	354						
λ	18.4		D_c	in.	0.147	0.229	0.330	0.449	0.587	0.742	0.917	1.109	1.320						
1.25	0.125	47	U	lb/ft^2	829	530	368	271	207	164	133	110	92						
I/bar	0.0203		D_u	in.	0.147	0.229	0.330	0.449	0.587	0.742	0.917	1.109	1.320						
I/ft	0.2035		C	lb/ft	829	663	553	474	414	368	332	301	276						
λ	41.1		D_c	in.	0.117	0.183	0.264	0.359	0.469	0.594	0.733	0.887	1.056						
1.25	0.1875	51	U	lb/ft^2	1243	796	553	406	311	246	199	164	138	118	101				
I/bar	0.0305		D_u	in.	0.147	0.229	0.330	0.449	0.587	0.742	0.917	1.109	1.320	1.549	1.796				
I/ft	0.3052		C	lb/ft	1243	995	829	710	622	553	497	452	414	383	355				
λ	27.4		D_c	in.	0.117	0.183	0.264	0.359	0.469	0.594	0.733	0.887	1.056	1.239	1.437				
1.25	0.25	55	U	lb/ft^2	1658	1061	737	541	414	327	265	219	184	157	135				
I/bar	0.0407		D_u	in.	0.147	0.229	0.330	0.449	0.587	0.742	0.917	1.109	1.320	1.549	1.796				
I/ft	0.4069		C	lb/ft	1658	1326	1105	947	829	737	663	603	553	510	474				

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Table 4-7
DEFLECTIONS AND ALLOWABLE LOADS FOR 6061-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
λ	20.6		D_c	in.	0.117	0.183	0.264	0.359	0.469	0.594	0.733	0.887	1.056	1.239	1.437				
1.5	0.125	53	U	lb/ft^2	1193	764	530	390	298	236	191	158	133	113	97	85	75	66	59
I/bar	0.0352		D_u	in.	0.122	0.191	0.275	0.374	0.489	0.619	0.764	0.924	1.100	1.291	1.497	1.719	1.955	2.207	2.475
I/ft	0.3516		C	lb/ft	1193	955	796	682	597	530	477	434	398	367	341	318	298	281	265
λ	45.1		D_c	in.	0.098	0.153	0.220	0.299	0.391	0.495	0.611	0.739	0.880	1.033	1.198	1.375	1.564	1.766	1.980
1.5	0.1875	59	U	lb/ft^2	1790	1146	796	585	448	354	286	237	199	169	146	127	112	99	88
I/bar	0.0527		D_u	in.	0.122	0.191	0.275	0.374	0.489	0.619	0.764	0.924	1.100	1.291	1.497	1.719	1.955	2.207	2.475
I/ft	0.5273		C	lb/ft	1790	1432	1193	1023	895	796	716	651	597	551	511	477	448	421	398
λ	30.0		D_c	in.	0.098	0.153	0.220	0.299	0.391	0.495	0.611	0.739	0.880	1.033	1.198	1.375	1.564	1.766	1.980
1.5	0.25	63	U	lb/ft^2	2387	1528	1061	779	597	471	382	316	265	226	195	170	149	132	118
I/bar	0.0703		D_u	in.	0.122	0.191	0.275	0.374	0.489	0.619	0.764	0.924	1.100	1.291	1.497	1.719	1.955	2.207	2.475
I/ft	0.7031		C	lb/ft	2387	1909	1591	1364	1193	1061	955	868	796	734	682	636	597	562	530
λ	22.5		D_c	in.	0.098	0.153	0.220	0.299	0.391	0.495	0.611	0.739	0.880	1.033	1.198	1.375	1.564	1.766	1.980
1.75	0.1875	66	U	lb/ft^2	2437	1559	1083	796	609	481	390	322	271	231	199	173	152	135	120
I/bar	0.0837		D_u	in.	0.105	0.164	0.236	0.321	0.419	0.530	0.655	0.792	0.943	1.106	1.283	1.473	1.676	1.892	2.121
I/ft	0.8374		C	lb/ft	2437	1949	1624	1392	1218	1083	975	886	812	750	696	650	609	573	541
λ	32.5		D_c	in.	0.084	0.131	0.189	0.257	0.335	0.424	0.524	0.634	0.754	0.885	1.027	1.178	1.341	1.514	1.697
1.75	0.25	71	U	lb/ft^2	3249	2079	1444	1061	812	642	520	430	361	308	265	231	203	180	160
I/bar	0.1117		D_u	in.	0.105	0.164	0.236	0.321	0.419	0.530	0.655	0.792	0.943	1.106	1.283	1.473	1.676	1.892	2.121
I/ft	1.1165		C	lb/ft	3249	2599	2166	1856	1624	1444	1300	1181	1083	1000	928	866	812	764	722
λ	24.3		D_c	in.	0.084	0.131	0.189	0.257	0.335	0.424	0.524	0.634	0.754	0.885	1.027	1.178	1.341	1.514	1.697
2	0.1875	73	U	lb/ft^2	3182	2037	1414	1039	796	629	509	421	354	301	260	226	199	176	157
I/bar	0.1250		D_u	in.	0.092	0.143	0.206	0.281	0.367	0.464	0.573	0.693	0.825	0.968	1.123	1.289	1.466	1.656	1.856
I/ft	1.2500		C	lb/ft	3182	2546	2122	1819	1591	1414	1273	1157	1061	979	909	849	796	749	707

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Table 4-7
DEFLECTIONS AND ALLOWABLE LOADS FOR 6063-T6 ALUMINUM BAR GRATING

Type P-19
bearing bar spacing 1 3/16in. cross bar spacing 4in.

Bearing Bar depth	Bearing Bar thickness	L_{max}			Span (in.) 24	30	36	42	48	54	60	66	72	78	84	90	96	102	108
λ	36.8		D_c	in.	0.065	0.102	0.147	0.200	0.261	0.330	0.407	0.493	0.587	0.688	0.798	0.917	1.043	1.177	1.320
2.25	0.25	86	U	lb/ft^2	5370	3437	2387	1754	1343	1061	859	710	597	508	438	382	336	297	265
I/bar	0.2373		D_u	in.	0.081	0.127	0.183	0.250	0.326	0.412	0.509	0.616	0.733	0.861	0.998	1.146	1.304	1.472	1.650
I/ft	2.3730		C	lb/ft	5370	4296	3580	3069	2685	2387	2148	1953	1790	1652	1534	1432	1343	1264	1193
λ	27.6		D_c	in.	0.065	0.102	0.147	0.200	0.261	0.330	0.407	0.493	0.587	0.688	0.798	0.917	1.043	1.177	1.320
2.5	0.1875	87	U	lb/ft^2	4973	3182	2210	1624	1243	982	796	658	553	471	406	354	311	275	246
I/bar	0.2441		D_u	in.	0.073	0.115	0.165	0.225	0.293	0.371	0.458	0.555	0.660	0.774	0.898	1.031	1.173	1.324	1.485
I/ft	2.4414		C	lb/ft	4973	3978	3315	2841	2486	2210	1989	1808	1658	1530	1421	1326	1243	1170	1105
λ	38.8		D_c	in.	0.059	0.092	0.132	0.180	0.235	0.297	0.367	0.444	0.528	0.620	0.719	0.825	0.939	1.060	1.188
2.5	0.25	93	U	lb/ft^2	6630	4243	2947	2165	1658	1310	1061	877	737	628	541	471	414	367	327
I/bar	0.3255		D_u	in.	0.073	0.115	0.165	0.225	0.293	0.371	0.458	0.555	0.660	0.774	0.898	1.031	1.173	1.324	1.485
I/ft	3.2552		C	lb/ft	6630	5304	4420	3789	3315	2947	2652	2411	2210	2040	1894	1768	1658	1560	1473
λ	29.1		D_c	in.	0.059	0.092	0.132	0.180	0.235	0.297	0.367	0.444	0.528	0.620	0.719	0.825	0.939	1.060	1.188

Notes
1. Allowable loads are for building-type structures.
2. L_{max} is the maximum span (in.) supporting 100 psf live load with no more than 0.25" deflection.
3. U is the maximum allowable uniform load.
4. D_u is the deflection at the maximum allowable uniform load.
5. C is maximum allowable concentrated load.
6. D_c is the deflection at the maximum allowable concentrated load.
7. NAAMM MBG531 also provides aluminum grating span tables.

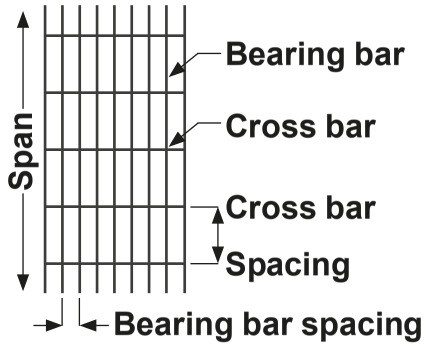

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Table 5-1

NOMINAL TENSILE AND SINGLE SHEAR STRENGTHS FOR 2024-T4 AND 7075-T73 MACHINE SCREWS

nominal Size	major diameter	threads per inch	thread type	root area	minor diameter	2024-T4		7075-T73	
	D	n		A_r		tensile strength	shear strength	tensile strength	shear strength
	in.	/in.		in^2	in.	lb	lb	lb	lb
4	0.112	40	UNC	0.005	0.0822	329	196	361	218
4	0.112	48	UNF	0.006	0.0872	370	221	406	245
5	0.125	40	UNC	0.007	0.0952	442	264	484	292
5	0.125	44	UNF	0.008	0.0979	467	279	512	309
6	0.138	32	UNC	0.008	0.1008	495	295	542	327
6	0.138	40	UNF	0.009	0.1082	570	340	626	377
8	0.164	32	UNC	0.013	0.1268	783	467	858	518
8	0.164	36	UNF	0.013	0.1309	835	498	915	552
10	0.190	24	UNC	0.015	0.1404	960	573	1050	635
10	0.190	32	UNF	0.018	0.1528	1140	678	1250	752
12	0.216	24	UNC	0.022	0.1664	1350	804	1480	891
12	0.216	28	UNF	0.024	0.1735	1470	874	1610	969
1/4	0.250	20	UNC	0.028	0.1905	1770	1050	1940	1170
1/4	0.250	28	UNF	0.034	0.2075	2100	1250	2300	1390
5/16	0.3125	18	UNC	0.048	0.2463	2950	1760	3240	1950
5/16	0.3125	24	UNF	0.054	0.2629	3360	2010	3690	2230
3/8	0.375	16	UNC	0.071	0.3006	4400	2630	4820	2910
3/8	0.375	24	UNF	0.083	0.3254	5160	3080	5650	3410

Notes

1. UNC = Unified National Course Thread Series; UNF = Unified National Fine Thread Series
2. Area at root of threads (A_r) is used to compute strengths using the nominal minor diameter for external threads (Class 2A) given in ASME B1.1-1989; $A_r = (\pi/4)(D - 1.191/n)^2$
3. Obtain available strengths by dividing the strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).
4. Strengths in this table are computed using:
   for 2024-T4, F_{tu} = 62 ksi and F_{su} = 37 ksi;
   for 7075-T73, F_{tu} = 68 ksi and F_{su} = 41 ksi.

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Table 5-2

NOMINAL SINGLE SHEAR STRENGTHS FOR 2024-T4 AND 7075-T73 TYPE AB AND B SHEET METAL SCREWS

Nominal Size	Shear Strength (lb) 2024-T4	Shear Strength (lb) 7075-T73
4	95	216
5	235	260
6	285	316
7	345	382
8	391	433
10	529	586
12	716	793
14	995	1100

Notes

1. Obtain available strengths by dividing the strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).
2. Strengths in this table are computed using:
   for 2024-T4, F_{su} = 37 ksi;
   for 7075-T73, F_{su} = 41 ksi.

Table 5-3

NOMINAL TENSILE AND SINGLE SHEAR STRENGTHS FOR ALUMINUM BOLTS AND CAP SCREWS

					2024-T4			7075-T73			6061-T6		
						shear strength			shear strength			shear strength	
nominal size	major diameter	threads per in.	minor diameter	root area	tensile strength	threads in shear plane	threads not in shear plane	tensile strength	threads in shear plane	threads not in shear plane	tensile strength	threads in shear plane	threads not in shear plane
	D	n		A_r	P_{nt}	P_{nv}	P_{nv}	P_{nt}	P_{nv}	P_{nv}	P_{nt}	P_{nv}	P_{nv}
	in.	/in.	in.	in^2	k	k	k	k	k	k	k	k	k
10	0.190	24	0.1404	0.015	0.96	0.57	1.05	1.05	0.63	1.16	0.65	0.39	0.71
12	0.216	24	0.1664	0.022	1.35	0.80	1.36	1.48	0.89	1.50	0.91	0.54	0.92
1/4	0.250	20	0.1905	0.028	1.77	1.05	1.82	1.94	1.17	2.01	1.20	0.71	1.23
5/16	0.313	18	0.2463	0.048	2.95	1.76	2.84	3.24	1.95	3.14	2.00	1.19	1.92
3/8	0.375	16	0.3006	0.071	4.40	2.63	4.09	4.82	2.91	4.53	2.98	1.77	2.76
7/16	0.438	14	0.3524	0.098	6.05	3.61	5.56	6.63	4.00	6.16	4.10	2.44	3.76
1/2	0.500	13	0.4084	0.131	8.12	4.85	7.26	8.91	5.37	8.05	5.50	3.27	4.91
9/16	0.563	12	0.4633	0.169	10.45	6.24	9.19	11.46	6.91	10.19	7.08	4.21	6.21
5/8	0.625	11	0.5167	0.210	13.00	7.76	11.35	14.26	8.60	12.58	8.81	5.24	7.67
3/4	0.750	10	0.6309	0.313	19.38	11.57	16.35	21.26	12.82	18.11	13.13	7.82	11.04
7/8	0.875	9	0.7427	0.433	26.86	16.03	22.25	29.46	17.76	24.65	18.19	10.83	15.03
1	1.000	8	0.8511	0.569	35.28	21.05	29.06	38.69	23.33	32.20	23.90	14.22	19.63

Notes

1. Class 2A external threads, UNC (Unified National Course Thread Series)
2. Area at root of threads (A_r) is used to compute strengths for tension and single shear with threads in shear plane using the nominal minor diameter for external threads (Class 2A) given in ASME B1.1-1989; $A_r = (\pi/4)(D - 1.191/n)^2$. Area of basic major diameter $(\pi/4)D^2$ is used to compute strengths for single shear with no threads in shear plane.
3. Obtain available strengths by dividing the strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).
4. Strengths in this table are computed using:
   for 2024-T4, F_{tu} = 62 ksi and F_{su} = 37 ksi; for 7075-T73, F_{tu} = 68 ksi and F_{su} = 41 ksi; for 6061-T6, F_{tu} = 42 ksi and F_{su} = 25 ksi.

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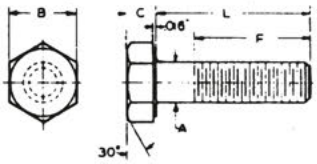
Table 5-4
BOLT DIMENSIONS

(American Standard B18.2)



DIMENSIONS IN INCHES

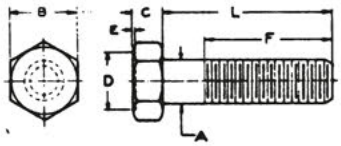
a. Cap Screws – Finished Hexagon Head Bolts
(ANSI Standard B18.2.1)

Threads are Class 2A free fit.
Bright finish, up to ¾ in. diam. and/or up to 4 in. length.
Larger sizes, machine finish.

Nominal size or basic major diameter	Thread size	Length, ranges in.*	Body diameter A in.	Width across flats B in.	Head height C in.	Under Head Fillet Radius in.	Thread Length Usable ① ‡	Thread Length Usable F. in. ② ‡
¼	¼-20	½ to 4¾	0.2500 0.2450	7/16	5/32	0.009 0.023	¾	—
5/16	5/16-18	½ to 6	0.3125 0.3065	½	13/64	0.009 0.023	7/8	—
⅜	⅜-16	½ to 7	0.3750 0.3690	9/16	15/64	0.009 0.023	1	1¼
½	½-13	¾ to 8	0.5000 0.4930	¾	5/16	0.009 0.023	1¼	1½
5/8	5/8-11	1 to 8	0.6250 0.6170	15/16	25/64	0.021 0.041	1½	1¾
¾	¾-10	1 to 8	0.7500 0.7410	1⅛	15/32	0.041 0.062	1¾	2
7/8	7/8-9	2 to 8	0.8750 0.8660	1 5/16	35/64	0.041 0.062	2	2¼
1	1 -8	2 to 8	1.0000 0.9900	1½	39/64	0.062 0.093	2¼	2½

* Available in 1/8 in. increments to one inch length and ¼ in. increments for lengths over one inch.
‡ ① Bolts 6 in. in length and less, ② Bolts over 6 in. in length.

b. Economy Bolts—Special Hexagon Head Bolts
(These special bolts with upset heads are in most cases an economical and satisfactory substitute for finished head bolts)
Threads are Class 2A free fit.
Bright finish up to ¾ in. diam. and/or up to 4 in. in length.
Larger sizes, machine finish.



Nominal size or basic major diameter †	Thread size	Length, ranges in.*	Body diameter A in.	Width across flats B in.	Head height C in.	Approximate diameter recess D in.	Approximate depth recess E in.
10	10-24	½ to 4	0.1900 0.1835	5/16	7/64	0.260	0.010
¼	¼-20	½ to 4¾	0.2500 0.2435	7/16	11/64	0.375	0.010
5/16	5/16-18	½ to 6	0.3125 0.3055	½	7/32	0.416	0.012
⅜	⅜-16	½ to 7	0.3750 0.3675	9/16	¼	0.468	0.016
½	½-13	¾ to 7½	0.5000 0.4930	¾	11/32	0.625	0.019
5/8	5/8-11	1 to 7½	0.6250 0.6170	15/16	27/64	0.781	0.025
¾	¾-10	1 to 7½	0.7500 0.7410	1⅛	½	0.938	0.031
7/8	7/8-9	1 to 7¼	0.875 0.867	1 5/16	37/64	1.078	0.035
1	1-8	1 to 7¼	1.000 0.991	1½	21/32	1.234	0.042

* Available in 1/8 in. increments to one inch length and ¼ in. increments for lengths over one inch.
† The maximum radius of the under head fillet is 1/32 in. for sizes up through 1/2 in., 1/16 in. for sizes 5/8 in. through 7/8 in. and 3/32 in. in. for the one inch size.

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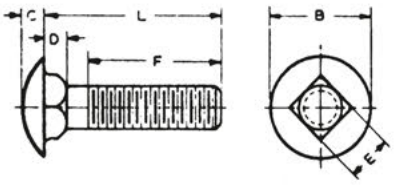
Table 5-4
BOLT DIMENSIONS (Continued)

c. Carriage Bolts, Round Head Square Neck
(ANSI Standard B18.5)

Threads are Class 2A free fit.

Bright finish



Nominal size or basic major diameter †	Thread size ‡	Length ranges in.*	Head diameter (minimum) B in.	Head height (minimum) C in.	Minimum depth of square D in.	Width of square (maximum) E in.	Minimum thread length F in.	
							Bolts 6 in. in length and less.	Bolts over 6 in. in length.
10	10-24	1/2 to 4	7/16	3/32	3/32	0.199	3/8	—
1/4	1/4-20	1/2 to 4 3/4	9/16	1/8	1/8	0.260	3/4	—
5/16	5/16-18	3/4 to 6	11/16	5/32	5/32	0.324	7/8	—
3/8	3/8-16	3/4 to 7	25/32	3/16	3/16	0.388	1	1 1/4
1/2	1/2-13	1 to 8	1 1/32	1/4	1/4	0.515	1 1/4	1 1/2
5/8	5/8-11	1 1/2 to 8	1 7/32	5/16	5/16	0.642	1 1/2	1 3/4
3/4	3/4-10	1 1/2 to 8	1 15/32	3/8	3/8	0.768	1 3/4	2
7/8	7/8-9	2 to 8	1 23/32	7/16	7/16	0.895	2	2 1/4
1	1-8	2 to 8	1 31/32	1/2	1/2	1.022	2 1/4	2 1/2

* Available in 1/16 in. increments to one inch length and 1/8 in. increments over one inch.
† Radius of fillet under head of bolt for sizes No. 10 to ½ inch inclusive is 1/64 to 1/32 inch, and for larger sizes is 1/32 to 1/16 inch
‡ Bolts have rolled threads and undersize unthreaded section.

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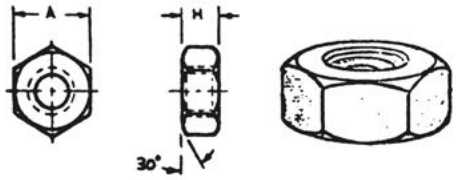
Table 5-5
NUT DIMENSIONS

a. Hexagon Bolt Nuts
Double-Chamfered, Double Countersunk
(ANSI Standard B18.2.2)

All threads are Class 2B free fit.



Nominal size in.	Threads per inch coarse	Width across flats A in.	Thickness H in.	Approximate weight (lb) per 1000 pieces
1/4	20	7/16	7/32	2.81
5/16	18	1/2	17/64	4.14
3/8	16	9/16	21/64	6.10
1/2	13	3/4	7/16	14.3
5/8	11	15/16	35/64	27.9
3/4	10	1 1/8	41/64	46.6
7/8	9	1 5/16	3/4	74.0
1	8	1 1/2	55/64	110.
1 1/8	7	1 11/16	31/32	158.
1 1/4	7	1 7/8	1 1/16	212.

b. Square Bolt Nuts
Top Chamfered
(ANSI Standard B18.2.2)

All threads are Class 2B free fit.

Nominal size in.	Threads per in. coarse	Width across flats A in.	Thickness H in.	Approximate weight (lb) per 1000 pieces
1/4	20	7/16	7/32	3.40
5/16	18	9/16	17/64	6.95
3/8	16	5/8	21/64	9.97
1/2	13	13/16	7/16	22.0
5/8	11	1	35/64	43.4
3/4	10	1 1/8	21/32	59.1
7/8	9	1 5/16	49/64	93.7
1	8	1 1/2	7/8	140.

Table 5-6
INTERNAL THREAD STRIPPING AREA FOR CLASS 2B UNC THREADS

Nominal Size Threads/in.	Nominal Diameter (in.)	Internal Thread Stripping Area A_{sn} (in^2/in. of engagement)
8 – 32	0.164	0.334
10 – 24	0.190	0.401
12 – 24	0.216	0.458
¼ – 20	0.250	0.539
5/16 – 18	0.3125	0.682
3/8 – 16	0.375	0.828

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Table 6-1
NOMINAL TENSILE STRENGTH OF CJP GROOVE WELDS (KSI)

		Filler								
		1100	2319	4043	4047	5183	5356	5554	5556	5654
Base Metal	F_{tuw}	11	35	24	25	40	35	31	42	30
1060	8	8		8	8					
1100	11	11		11	11					
2219	35		35							
3003	14	**11**		14	14					
Alclad 3003	13	**11**		13	13					
3004	22					22	22		22	
Alclad 3004	21					21	21		21	
5005	15			15	15	15	15		15	
5050	18			18	18	18	18		18	
5052	25					25	25		25	
5083	40					40			40	
5086	35					35	35		35	
5154	30					30	30		30	30
5454	31					31	31	31	31	
5456	42					**40**			42	
6005A	24			24	24	24	24		24	
6061	24			24	24	24	24		24	
6063	17			17	17	17	17		17	
6082	28			**24**	**25**	28	28		28	
6351	24			24	24	24	24		24	
7005	40					40	**35**		40	

Notes
1. Tensile ultimate strength = F_{tuw}
2. Strengths are for the base metal welded to itself.
3. **Bold** values indicate the filler governs the joint strength.
4. Obtain available strengths by dividing the nominal strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).

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Table 6-2
NOMINAL TENSILE STRENGTH OF PJP GROOVE WELDS (KSI)

		Filler								
		1100	2319	4043	4047	5183	5356	5554	5556	5654
Base Metal	F_{tuw}	11	35	24	25	40	35	31	42	30
1060	8	4.8		4.8	4.8					
1100	11	6.6		6.6	6.6					
2219	35		21.0							
3003	14	**6.6**		8.4	8.4					
Alclad 3003	13	**6.6**		7.8	7.8					
3004	22					13.2	13.2		13.2	
Alclad 3004	21					12.6	12.6		12.6	
5005	15			9.0	9.0	9.0	9.0		9.0	
5050	18			10.8	10.8	10.8	10.8		10.8	
5052	25					15.0	15.0		15.0	
5083	40					24.0			24.0	
5086	35					21.0	21.0		21.0	
5154	30					18.0	18.0		18.0	18.0
5454	31					18.6	18.6	18.6	18.6	
5456	42					**24.0**			25.2	
6005A	24			14.4	14.4	14.4	14.4		14.4	
6061	24			14.4	14.4	14.4	14.4		14.4	
6063	17			10.2	10.2	10.2	10.2		10.2	
6082	28			**14.4**	**15.0**	16.8	16.8		16.8	
6351	24			14.4	14.4	14.4	14.4		14.4	
7005	40					24.0	21.0		24.0	

Notes
1. Tensile ultimate strength = F_{tuw}
2. Strengths are for the base metal welded to itself.
3. **Bold** values indicate the filler governs the joint strength.
4. Obtain available strengths by dividing the nominal strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).

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Table 6-3
NOMINAL SHEAR STRENGTH OF FILLET WELDS (KSI)

		Filler								
		1100	2319	4043	4047	5183	5356	5554	5556	5654
Base Metal	F_{tuw}	11	35	24	25	40	35	31	42	30
1060	8	**5.6**		6.8	6.8					
1100	11	**5.6**		9.3	9.3					
2219	35		**17.9**							
3003	14	**5.6**		11.9	11.9					
Alclad 3003	13	**5.6**		11.0	11.0					
3004	22					18.7	**17.9**		18.7	
Alclad 3004	21					17.8	17.8		17.8	
5005	15			**12.2**	12.7	12.7	12.7		12.7	
5050	18			**12.2**	**12.8**	15.3	15.3		15.3	
5052	25					**20.4**	**17.9**		21.2	
5083	40					**20.4**			**21.4**	
5086	35					**20.4**	**17.9**		**21.4**	
5154	30					**20.4**	**17.9**		**21.4**	**15.3**
5454	31					**20.4**	**17.9**	15.8	**21.4**	
5456	42					**20.4**			**21.4**	
6005A	24			**12.2**	**12.8**	20.4	**17.9**		20.4	
6061	24			**12.2**	**12.8**	20.4	**17.9**		20.4	
6063	17			**12.2**	**12.8**	14.4	14.4		14.4	
6082	28			**12.2**	**12.8**	**20.4**	**17.9**		**21.4**	
6351	24			**12.2**	**12.8**	**20.4**	**17.9**		20.4	
7005	40					**20.4**	**17.9**		**21.4**	

Notes
1. Tensile ultimate strength = F_{tuw}
2. Strengths are for the base metal welded to itself.
3. **Bold** values indicate the filler governs the joint strength.
4. Obtain available strengths by dividing the nominal strengths in this table by the appropriate safety factor Ω or multiplying by the appropriate resistance factor ϕ (see Part I).

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BEAMS

Flexural stress at extreme fiber: $f = Mc/I = M/S$
- M = bending moment
- I = moment of inertia
- $S = I/c$ = section modulus
- c = distance to extreme fiber

Flexural stress at any fiber: $f = My/I$
- y = distance from neutral axis to fiber.

Average vertical shear stress: $v = V/A$
- V = shear load
- A = area of cross section

Horizontal shearing stress at any section A-A: $v = VQ/I\,b$
- Q = static moment about the neutral axis of the entire section of that portion of the cross section lying outside of section A-A
- b = width at section A-A

(Intensity of vertical shear is equal to that of horizontal shear acting normal to it at the same point and both are usually a maximum at mid-height of beam.)

Slope and deflection at any point: $EI\,\frac{d^2y}{dx^2} = M$ (Basic differential equation for beam)

x and y are abscissa and ordinate respectively of a point on the neutral axis, referred to axes of rectangular co-ordinates through a selected point of support.

(First integration gives slopes; second integration gives deflections. Constants of integration must be determined.)

CONTINUOUS BEAMS (Theorem of Three Moments)

Uniform load: $$M_a\frac{l_1}{I_1} + 2M_b\left(\frac{l_1}{I_1}+\frac{l_2}{I_2}\right) + M_c\frac{l_2}{I_2} = -\tfrac{1}{4}\left(\frac{w_1 l_1^3}{I_1}+\frac{w_2 l_2^3}{I_2}\right)$$

Concentrated loads:

$$M_a\frac{l_1}{I_1} + 2M_b\left(\frac{l_1}{I_1}+\frac{l_2}{I_2}\right) + M_c\frac{l_2}{I_2} = -\frac{P_1 a_1 b_1}{I_1}\left(1+\frac{a_1}{l_1}\right) - \frac{P_2 a_2 b_2}{I_2}\left(1+\frac{b_2}{l_2}\right)$$

Considering any two consecutive spans in any continuous structure:

M_a, M_b, M_c	=	moments at left, center, and right supports, respectively, of any pair of adjacent spans.
l_1 and l_2	=	lengths of left and right spans, respectively, of the pair.
I_1 and I_2	=	moments of inertia of left and right spans, respectively.
w_1 and w_2	=	loads per unit of length on left and right spans, respectively.
P_1 and P_2	=	concentrated loads on left and right spans, respectively.
a_1 and a_2	=	distance of concentrated loads from left support in left and right spans, respectively.
b_1 and b_2	=	distance of concentrated loads from right support in left and right spans, respectively.

The above equations are for beams with moment of inertia constant in each span but differing in different spans, continuous over three or more supports. By writing such an equation for each successive pair of spans and introducing the known values (usually zero) of end moments, all other moments can be found.

COLUMNS

Concentrically loaded: stress $f = P/A$; P = column load, A = area of cross section
Eccentrically loaded: stress $f = P/A + Mc/I = P/A\,(1 + ec/r^2)$

Bending in plane of principal axis. Deflection not considered.

e = eccentricity of load, r = radius of gyration.

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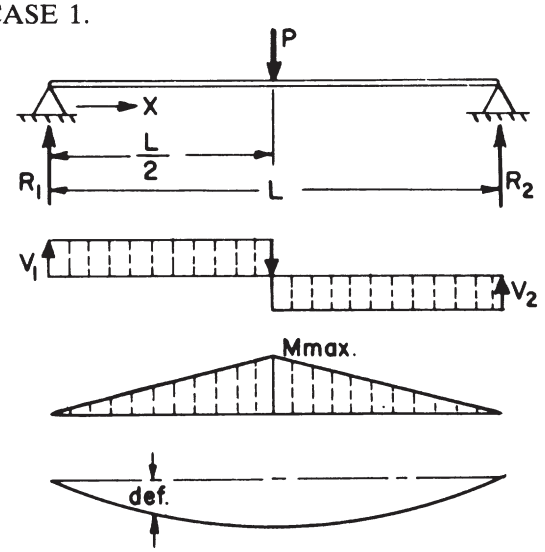
CASE 1.



Concentrated load P at center

Reactions: $R_1 = R_2 = \frac{P}{2}$

Maximum shear forces:

$$V_1 = +P/2;\ V_2 = -P/2$$

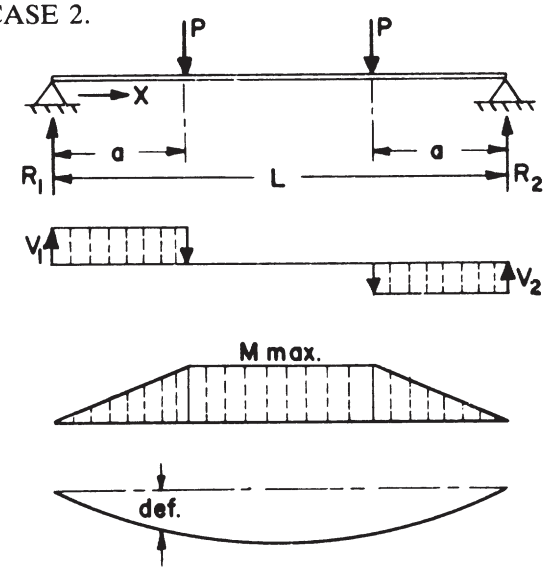
Maximum bending moment:

$$M_{max} = \frac{PL}{4} \text{ at center}$$

Maximum deflection $= \frac{PL^3}{48EI}$ at center

$$\text{def.} = \frac{Px}{48EI}(3L^2 - 4x^2),\quad o \le x \le \frac{L}{2}$$

CASE 2.



Two equal concentrated loads P equi-distant from the center

Reactions: $R_1 = R_2 = P$

Maximum shear forces:

$$V_1 = +P\ ;\ V_2 = -P$$

Maximum bending moment:

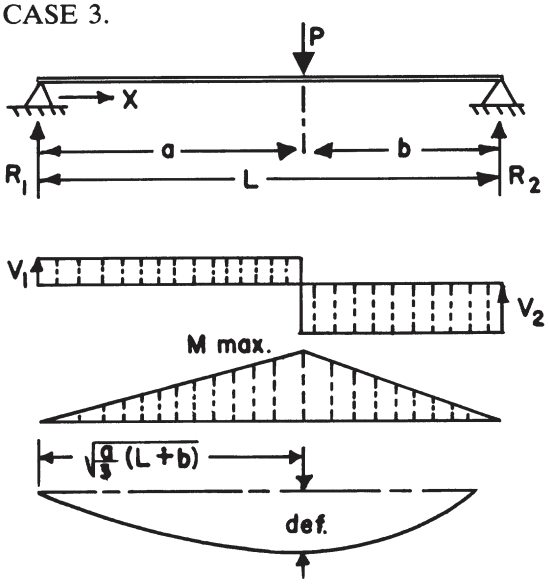
$$M_{max} = Pa, \text{ between loads}$$

Maximum deflection $= \frac{Pa}{24EI}(3L^2 - 4a^2)$

$$\text{def.} = \frac{Px}{6EI}(3La - 3a^2 - x^2),\quad o \le x \le a$$

$$= \frac{Pa}{6EI}(3Lx - 3x^2 - a^2),\quad a \le x \le (L - a)$$

CASE 3.



Concentrated load P at any point

Reactions: $R_1 = \frac{Pb}{L}$; $R_2 = \frac{Pa}{L}$

Shear forces: $V_1 = +R_1$; $V_2 = -R_2$

Maximum bending moment:

$$M_{max} = \frac{Pab}{L}, \text{ at } x = a$$

$$M = \frac{Pbx}{L},\ o \le x \le a;\ M = \frac{Pa}{L}(L - x),\ a \le x \le L$$

Maximum deflection $= \frac{Pab\ (L + b)\ \sqrt{3a\ (L + b)}}{27\ EIL}$

at $x = \sqrt{a\ (L + b)/3}$ when a > b

deflection under load $= \frac{Pa^2b^2}{3\ EIL}$, $x = a$

$$\text{def.} = \frac{Pbx}{6\ EIL}(L^2 - b^2 - x^2),\quad o \le x \le a$$

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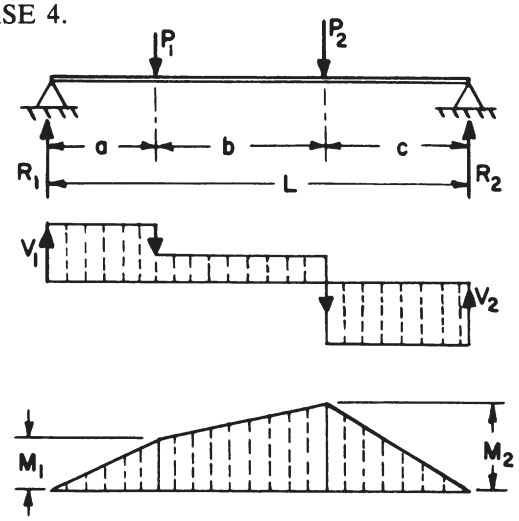
CASE 4.



Two *unequal* concentrated loads unsymmetrically located

Reactions: $R_1 = \dfrac{P_1 (L - a) + P_2 c}{L}$

$R_2 = \dfrac{P_2 (L - c) + P_1 a}{L}$

Shear forces: $V_1 = +R_1$

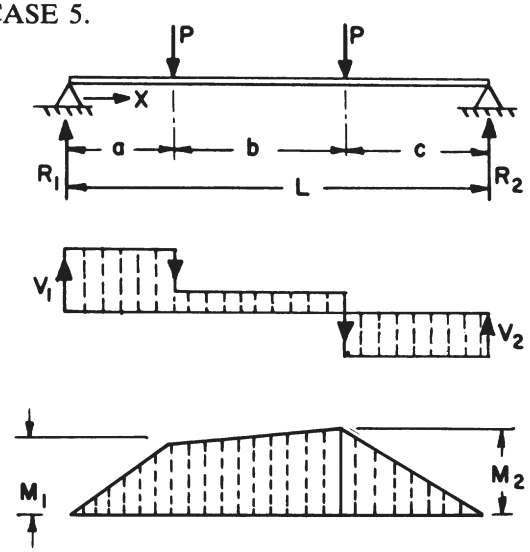
$V_2 = -R_2$

Bending moments:

$M_1 = R_1 a$, maximum if $R_1 < P_1$

$M_2 = R_2 c$, maximum if $R_2 < P_2$

CASE 5.



Two *equal* concentrated loads unsymmetrically located

Reactions: $R_1 = \dfrac{P (L - a + c)}{L}$

$R_2 = \dfrac{P (L - c + a)}{L}$

Shear forces: $V_1 = +R_1$

$V_2 = -R_2$

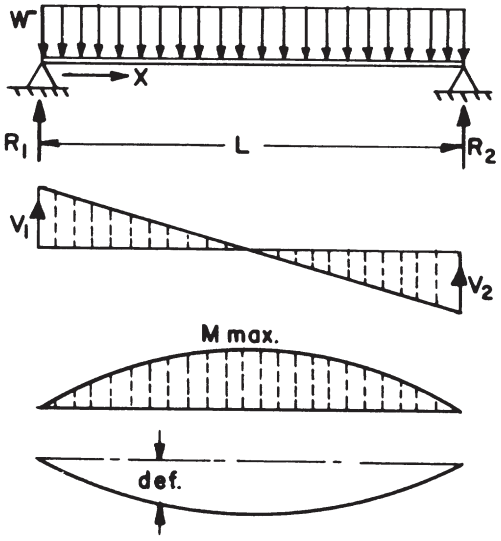
Bending moments:

$M_1 = R_1 a$, maximum if $a > c$

$M_2 = R_2 c$, maximum if $a < c$

$M = R_1 x - P (x - a), \quad a \leq x \leq (a + b)$

CASE 6.



Uniformly distributed loading of w lb/in total load $W = wL$

Reactions: $R_1 = R_2 = \dfrac{wL}{2} = \dfrac{W}{2}$

Shear $= w\left(\dfrac{L}{2} - x\right), \quad o \leq x \leq L$

Maximum bending moment $= \dfrac{wL^2}{8} = \dfrac{WL}{8}$, at center

$M = \dfrac{wx}{2}(L - x) = \dfrac{Wx}{2L}(L - x), \quad o \leq x \leq L$

Maximum deflection $= \dfrac{5\, wL^4}{384\, EI} = \dfrac{5\, WL^3}{384\, EI}$, at center

$\text{def.} = \dfrac{wx}{24\, EI}(L^3 - 2Lx^2 + x^3), \quad o \leq x \leq L$

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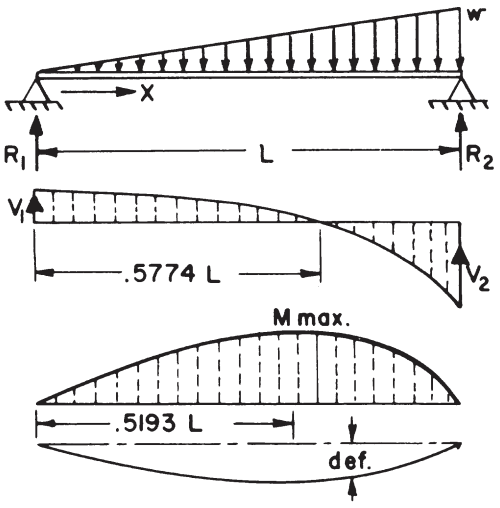
CASE 7.



Distributed load increasing uniformly to one end

Total load $W = \frac{wL}{2}$, max. loading = w lb/in

Reactions: $R_1 = \frac{W}{3} = \frac{wL}{6}$

$R_2 = \frac{2W}{3} = \frac{wL}{3}$

Shear forces: $V_1 = +R_1; V_2 = -R_2$

$V = \frac{W}{3} - \frac{Wx^2}{L^2}, o \leq x \leq L$

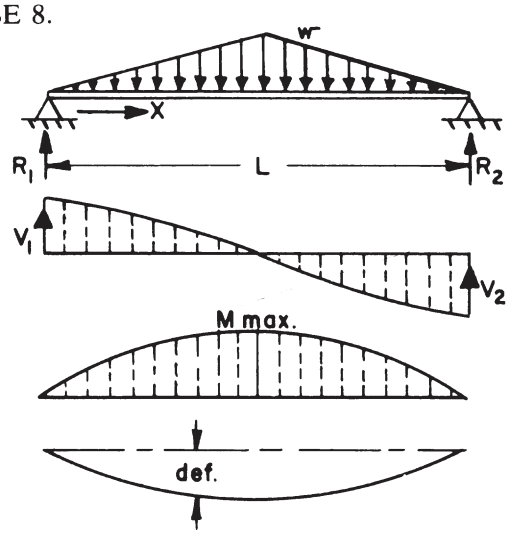
Maximum bending moment = $0.1283WL$, $x = 0.5774L$

$M = \frac{Wx}{3L^2}(L^2 - x^2), o \leq x \leq L$

Maximum deflection $= 0.01304 \frac{WL^3}{EI}$, $x = 0.5193L$

def. $= \frac{Wx}{180\,EIL^2}(3x^4 - 10L^2x^2 + 7L^4), \quad o \leq x \leq L$

CASE 8.



Distributed load increasing toward center

Total load W = $\frac{wL}{2}$, max. loading = w lb/in

Reactions: $R_1 = R_2 = \frac{W}{2} = \frac{wL}{4}$

Shear forces: $V_1 = +R_1; V_2 = -R_2$

$V = \frac{W}{2L^2}(L^2 - 4x^2), o \leq x \leq \frac{L}{2}$

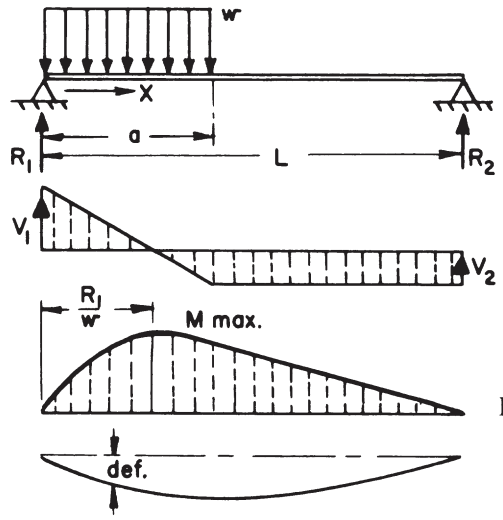
Maximum bending moment $= \frac{WL}{6} = \frac{wL^2}{12}$

$M = \frac{Wx}{2}\left(1 - \frac{4x^2}{3L^2}\right), \quad o \leq x \leq \frac{L}{2}$

Maximum deflection $= \frac{WL^3}{60\,EI} = \frac{wL^4}{120\,EI}$, $x = \frac{L}{2}$

def. $= \frac{Wx}{480\,EIL^2}(5L^2 - 4x^2)^2, \quad o \leq x \leq \frac{L}{2}$

CASE 9.



Load uniformly distributed at left end of beam

Total load = wa

Reactions: $R_1 = \frac{wa}{2L}(2L - a); R_2 = \frac{wa^2}{2L}$

Shear forces: $V_1 = +R_1; V_2 = -R_2$

$V = R_1 - wx, o \leq x \leq a$

Maximum bending moment:

$= \frac{wa^2}{8L^2}(2L - a)^2, x = \frac{R_1}{w}$

$M = R_1x - \frac{wx^2}{2}, o \leq x \leq a$

Def. $= \frac{wx}{24\,EIL}[a^2(2L - a)^2 - 2ax^2(2L - a) + Lx^3], \quad o \leq x \leq a$

$= \frac{wa^2(L - x)}{24\,EIL}(4Lx - 2x^2 - a^2), a \leq x \leq L$

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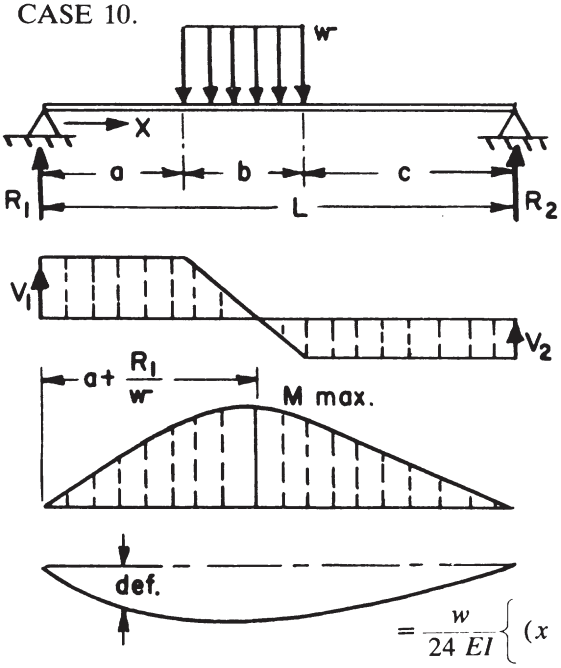
CASE 10.



Partially distributed uniform load

Total load $= wb$

Reactions: $R_1 = \frac{wb}{2L}(2c + b)$

$R_2 = \frac{wb}{2L}(2a + b)$

Shear forces: $V_1 = +R_1$; $V_2 = -R_2$

$V = R_1 - w(x - a), a \leq x \leq a + b$

Maximum bending moment

$= \frac{wb}{8L^2}(2c + b)\,[4aL + b\,(2c + b)], x = a + \frac{R_1}{w}$

Deflection:

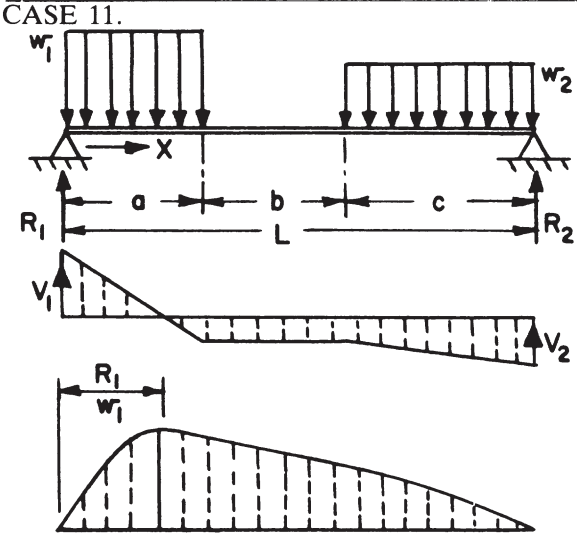
$= \frac{w}{24\,EI}\left[\frac{b\,(b + 2c)x}{L}\right]\left[-2x^2 + 2a\,(2L - a) + b\,(b + 2c)\right]$

for $o \leq x \leq a$

$= \frac{w}{24\,EI}\left\{(x - a)^4 + \left[\frac{b\,(b + 2c)x}{L}\right]\left[-2x^2 + 2a\,(2L - a) + b\,(b + 2c)\right]\right\}$

for $a \leq x \leq a + b$

CASE 11.



Partially distributed uniform load at each end

Total load $= w_1a + w_2c$

Reactions: $R_1 = \frac{w_1a\,(2L - a) + w_2c^2}{2L}$

$R_2 = \frac{w_2c\,(2L - c) + w_1a^2}{2L}$

Shear forces: $V_1 = +R_1$; $V_2 = -R_2$

Maximum bending moment

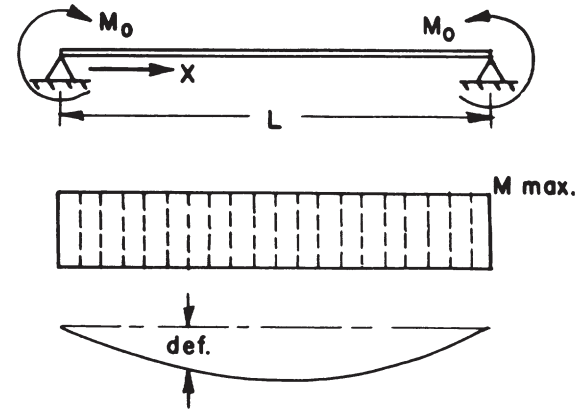
$= \frac{R_1^2}{2w_1}$, when $R_1 < w_1a$

$M = R_1x - \frac{w_1x^2}{2}, o \leq x \leq a$

$M = R_1x - \frac{w_1a}{2}(2x - a), a \leq x \leq a + b$

$M = R_2\,(L - x) - \frac{w_2\,(L - x)^2}{2}, a + b \leq x \leq L$

CASE 12.



Two equal and opposite moments, M_0, at ends

Reactions: both zero

Shear forces: zero at all points

Maximum bending moment $= M_o$

$M = M_o$ at all points

Maximum deflection $= \frac{M_oL^2}{8\,EI}, x = \frac{L}{2}$

def. $= \frac{M_ox}{2\,EI}(L - x), o \leq x \leq L$

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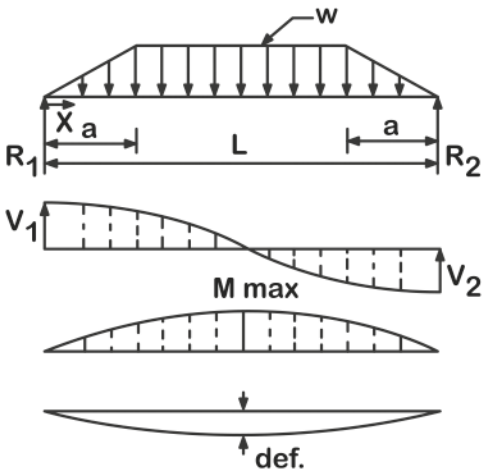
CASE 12A.



Trapezoidally distributed load:

Total Load: $W = w(L - a)$

Max. Load: w

Reactions: $R_1 = W/2$, $R_2 = W/2$

Shear Forces: $V_1 = R_1$; $V_2 = -R_2$

Maximum bending moment =

$$\frac{w}{24}(3L^2 - 4a^2),\ x = \frac{L}{2}$$

Maximum deflection =

$$\frac{wL^4}{1920EI}\left[25 - 40\left(\frac{a}{L}\right)^2 + 16\left(\frac{a}{L}\right)^4\right],\ x = \frac{L}{2}$$

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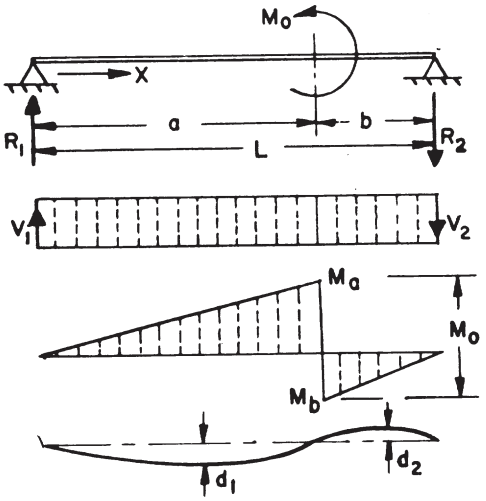
CASE 13.



Moment, M_o, applied at $x = a$

Reactions: $R_1 = +\frac{M_o}{L}$; $R_2 = -\frac{M_o}{L}$

Shear force $V = +\frac{M_o}{L}$, $o \leq x \leq L$

Bending moment: $M_a = \frac{M_o a}{L}$, $M_b = -\frac{M_o b}{L}$

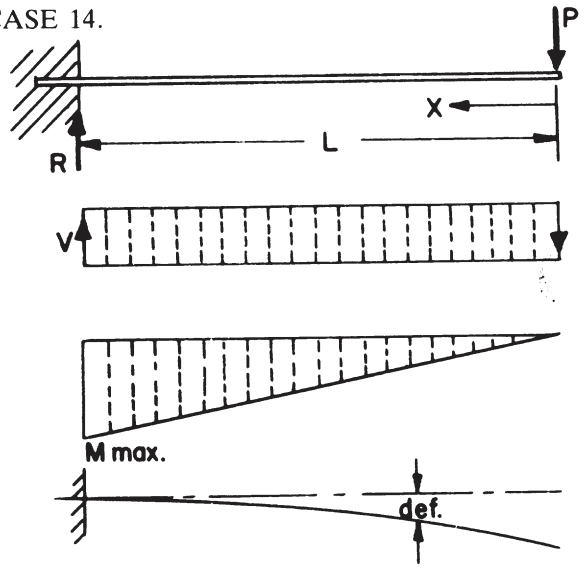
$$M_a - M_b = M_o$$

Deflection:

$$d_1 = \frac{M_o}{6\,EI}\left[\left(6a - \frac{3a^2}{L} - 2L\right)x - \frac{x^3}{L}\right],\ o \leq x \leq a$$

$$d_2 = \frac{M_o}{6\,EI}\left[3a^2 + 3x^2 - \frac{x^3}{L} - \left(2L + \frac{3a^2}{L}\right)x\right],\ a \leq x \leq L$$

CASE 14.



Concentrated load, P, at free end of cantilever beam

Reaction: $R = P$, at fixed end

Shear force $V = -P$, $o \leq x \leq L$

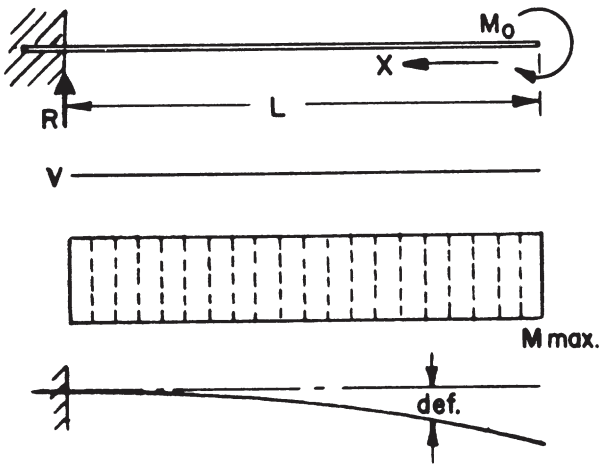
Maximum bending moment $= -PL$, $x = L$

Bending moment: $M = -Px$, $o \leq x \leq L$

Maximum deflection $= \frac{PL^3}{3\,EI}$, at free end, $x = o$

$$\text{def.} = \frac{P}{6\,EI}(2L^3 - 3L^2x + x^3),\ o \leq x \leq L$$

CASE 15.



Moment, $-M_o$, at free end of cantilever beam

Reaction: $R = o$

Shear force: $V = o$, $o \leq x \leq L$

Maximum bending moment $= -M_o$

Bending moment $= -M_o$, $o \leq x \leq L$

Maximum deflection $= \frac{M_o L^2}{2\,EI}$, at free end

$$\text{def.} = \frac{M_o (L - x)^2}{2\,EI},\ o \leq x \leq L$$

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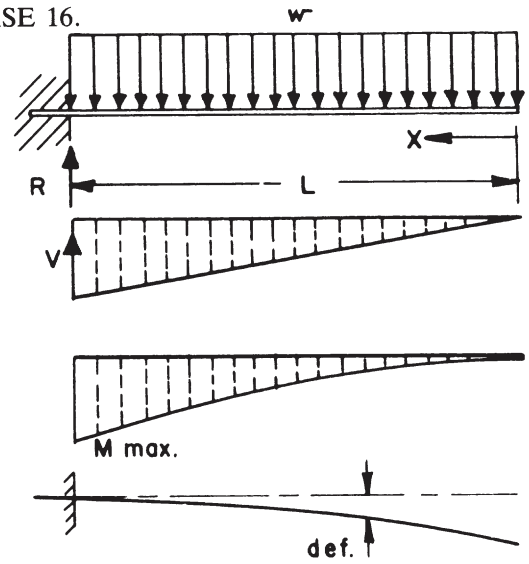
CASE 16.



Uniformly distributed loading of w lb/in

Total load $W = wL$

Reaction: $R = W = wL$

Maximum shear force $= -W = -wL$, at $x = L$

Shear force $= -wx$, $o \leq x \leq L$

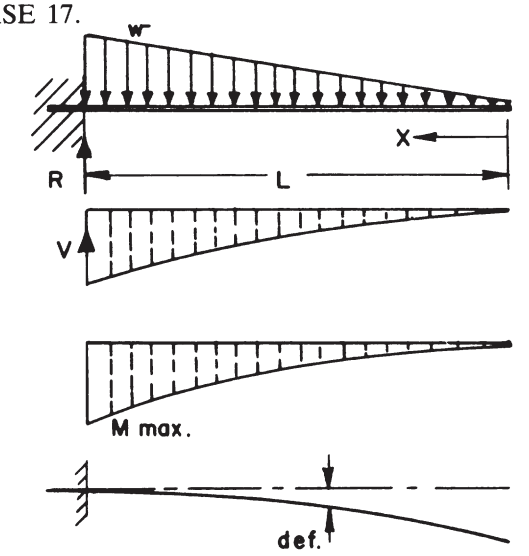
Maximum bending moment $= -\frac{WL}{2} = -\frac{wL^2}{2}$, at fixed end

Bending moment: $M = -\frac{Wx^2}{2L} = -\frac{wx^2}{2}$, $o \leq x \leq L$

Maximum deflection $= \frac{WL^3}{8\,EI} = \frac{wL^4}{8\,EI}$, at free end

$$\text{def} = \frac{w}{24\,EI}(x^4 - 4L^3x + 3L^4),\ o \leq x \leq L$$

CASE 17.



Distributed loading, increasing uniformly to fixed end

Total load $= W = \frac{wL}{2}$

Reaction: $R = W = \frac{wL}{2}$

Maximum shear force $= -W = -\frac{wL}{2}$, at $x = L$

Shear force $= -\frac{Wx^2}{L^2}$, $o \leq x \leq L$

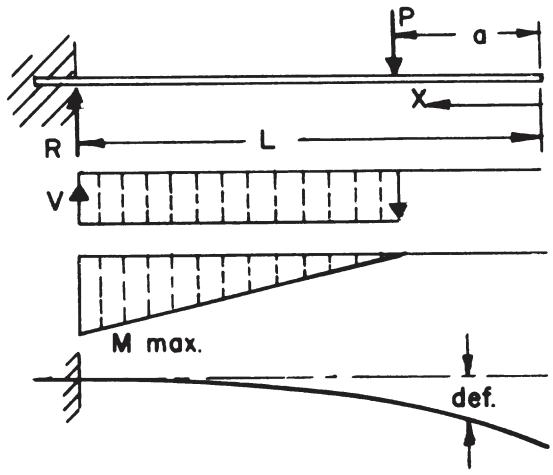
Maximum bending moment $= -\frac{WL}{3}$, at fixed end

Bending moment $= -\frac{Wx^3}{3L^2}$, $o \leq x \leq L$

Maximum deflection $= \frac{WL^3}{15\,EI}$, at free end

$$\text{def.} = \frac{W}{60\,EIL^2}(x^5 - 5L^4x + 4L^5),\ o \leq x \leq L$$

CASE 18.



Concentrated load, P, inboard of free end

Reaction: $R = P$

Shear force: $V = 0$, $o \leq x < a$

$V = -P$, $a < x \leq L$

Maximum bending moment $= -P\,(L - a)$, at fixed end

Maximum deflection $= \frac{P\,(L - a)^2}{6\,EI}(2L + a)$

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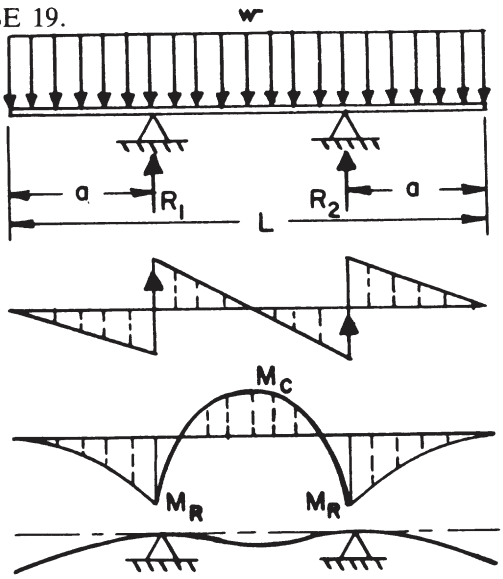
CASE 19.



Uniformly distributed loading of w lb/in
Total load, $W = wL$

Reactions: $R_1 = R_2 = \frac{W}{2}$

Shear forces:
$V = wa$, just outboard of supports
$V = \frac{w}{2}(L - 2a)$, just inboard of supports

Bending moments:

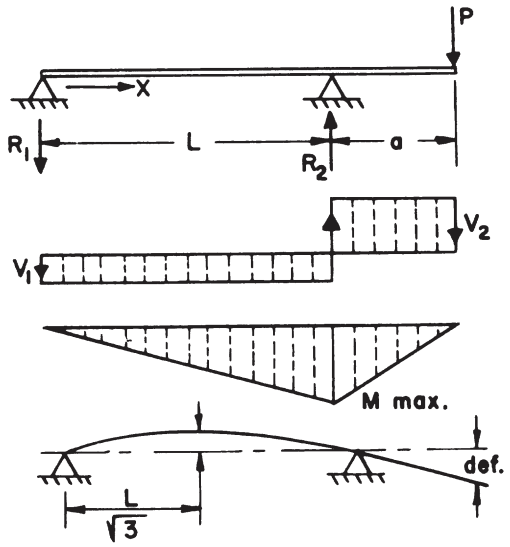
$$M_R = -\frac{wa^2}{2} = -\frac{Wa^2}{2L}, \text{ at supports}$$

$$M_c = \frac{W}{8}(L - 4a), \text{ at center}$$

$$\text{def.} = \frac{W\,(L-2a)^3}{384\,EI}\left[\frac{5}{L}(L - 2a) - \frac{24}{L}\left(\frac{a^2}{L - 2a}\right)\right], \text{ at center}$$

$$\text{def.} = \frac{W\,(L - 2a)^3 a}{24\,EIL}\left[-1 + 6\left(\frac{a}{L - 2a}\right)^2 + 3\left(\frac{a}{L - 2a}\right)^3\right], \text{ at ends}$$

CASE 20.



Concentrated load, P, at end of overhang

Reactions: $R_1 = -\frac{Pa}{L}$

$$R_2 = \frac{P}{L}(L + a)$$

Shear forces: $V_1 = -\frac{Pa}{L}$

$$V_2 = P$$

Maximum bending moment:
$M_{max} = -Pa$, at right support

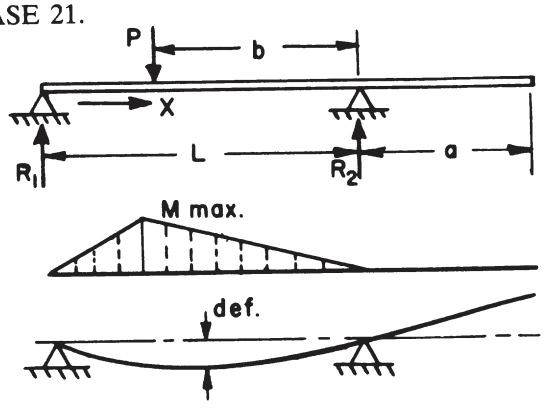
Deflections:

Maximum downward def. $= \frac{Pa^2}{3\,EI}(L + a)$, at load

Maximum upward deflection; at $x = \frac{L}{\sqrt{3}}$

$$= \frac{PaL^2}{9\sqrt{3}\,EI} = 0.06415\,\frac{PaL^2}{EI}$$

CASE 21.



Concentrated load, P, between supports

Reactions: $R_1 = \frac{Pb}{L}$; $R_2 = \frac{P\,(L-b)}{L}$

Maximum bending moment $= \frac{Pb\,(L - b)}{L}$, at load

Maximum downward deflection

$$= \frac{Pb\,(L^2 - b^2)\sqrt{3\,(L^2 - b^2)}}{27\,EIL}, \text{ at } x = \frac{\sqrt{3\,(L^2 - b^2)}}{3}$$

Maximum upward deflection

$$= -\frac{Pab}{6\,EI}\left(2L + \frac{b^2}{L} - 3b\right), \text{ at end of overhang}$$

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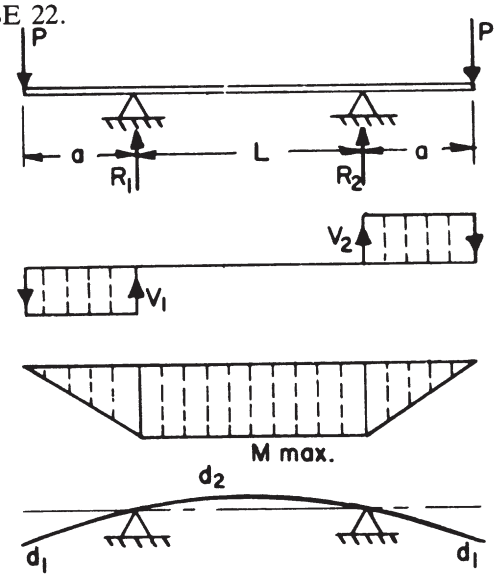
CASE 22.



Two equal loads, P, at ends of overhang

Reactions: $R_1 = R_2 = P$

Shear forces: $V_1 = -P$; $V_2 = +P$

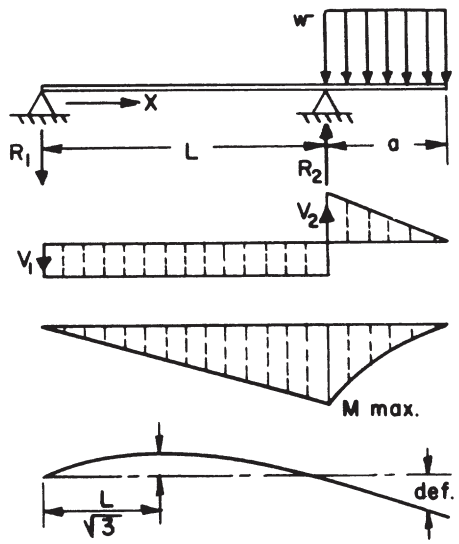
Maximum bending moment $= -Pa$, between supports

Deflections:

$$d_1 = \frac{Pa^2}{3\,EI}\left(a + \frac{3}{2}L\right), \text{ at point of load}$$

$$d_2 = -\frac{PL^2a}{8\,EI}, \text{ at center point}$$

CASE 23.



Uniformly distributed loading, w lb/in on overhang

Total load $= wa$

Reactions: $R_1 = -\frac{wa^2}{2L}$

$$R_2 = \frac{wa}{2L}(2L + a)$$

Shear forces: $V_1 = R_1$

$V_2 = wa$

Maximum bending moment:

$$M_{max} = -\frac{wa^2}{2}, \text{ at right support}$$

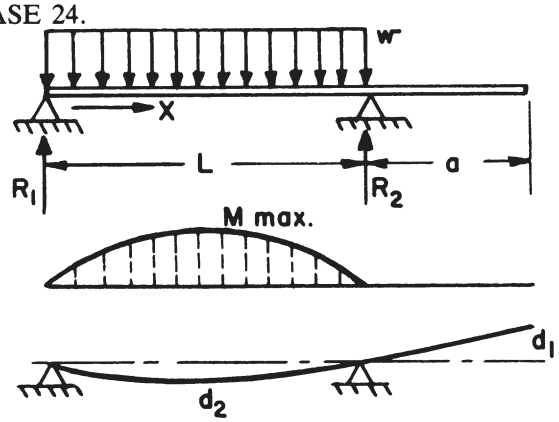
Deflection at end of overhang:

$$d_1 = \frac{wa^3}{24\,EI}(4L + 3a)$$

Maximum deflection between supports:

$$d_2 = -\frac{wa^2L^2}{18\sqrt{3}\,EI} = -0.03208\,\frac{wa^2L^2}{EI}$$

CASE 24.



Uniformly distributed loading, w lb/in between supports

Total load $= wL$

Reactions: $R_1 = R_2 = \frac{wL}{2}$

Maximum bending moment $= \frac{wL^2}{8}$, $x = \frac{L}{2}$

Deflection at end of overhang:

$$d_1 = -\frac{wL^3a}{24\,EI}$$

Maximum deflection between supports:

$$d_2 = \frac{5wL^4}{384\,EI}$$

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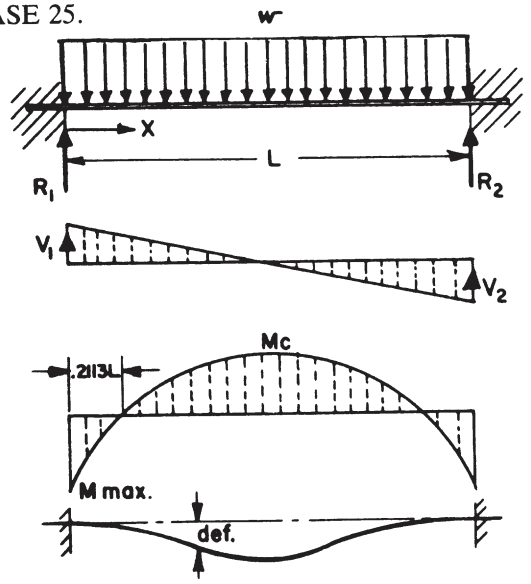
CASE 25.



Uniformly distributed load, w lb/in

Total load $W = wL$

Reactions: $R_1 = R_2 = \frac{W}{2}$

Shear forces: $V_1 = +\frac{W}{2}$

$V_2 = -\frac{W}{2}$

Maximum (negative) bending moment

$M_{max} = -\frac{wL^2}{12} = -\frac{WL}{12}$, at end

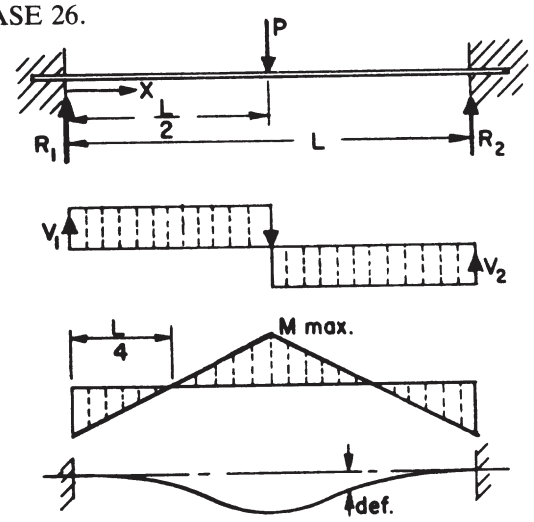
Maximum (positive) bending moment

$M_c = \frac{wL^2}{24} = \frac{WL}{24}$, at center

Maximum deflection $= \frac{wL^4}{384\,EI} = \frac{WL^3}{384\,EI}$, at center

def. $= \frac{wx^2}{24\,EI}(L - x)^2, \quad o \leq x \leq L$

CASE 26.



Concentrated load, P, at center

Reactions: $R_1 = R_2 = \frac{P}{2}$

Shear forces: $V_1 = +\frac{P}{2}$; $V_2 = -\frac{P}{2}$

Maximum bending moment

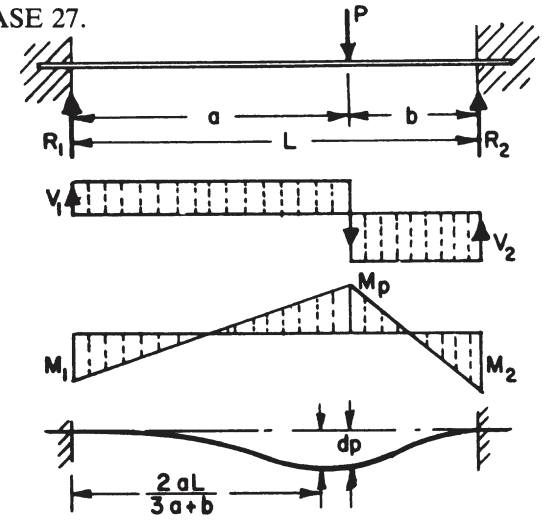
$M_{max} = \frac{PL}{8}$, at center

$M_{max} = -\frac{PL}{8}$, at ends

Maximum deflection $= \frac{PL^3}{192\,EI}$, at center

def. $= \frac{Px^2}{48\,EI}(3L - 4x), \quad o \leq x \leq \frac{L}{2}$

CASE 27.



Concentrated load, P, at any point

Reactions: $R_1 = \frac{Pb^2}{L^3}(3a + b)$

$R_2 = \frac{Pa^2}{L^3}(3b + a)$

Shear forces: $V_1 = R_1$; $V_2 = -R_2$

Bending moments:

$M_1 = -\frac{Pab^2}{L^2}$, max. when $a < b$

$M_2 = -\frac{Pa^2b}{L^2}$, max. when $a > b$

$M_p = +\frac{2Pa^2b^2}{L^3}$, at point of load

Deflection $= \frac{Pa^3b^3}{3\,EIL^3}$, at point of load

Max. def. $= \frac{2Pa^3b^2}{3\,EI\,(3a + b)^2}$, at $x = \frac{2aL}{3a + b}$, for $a > b$

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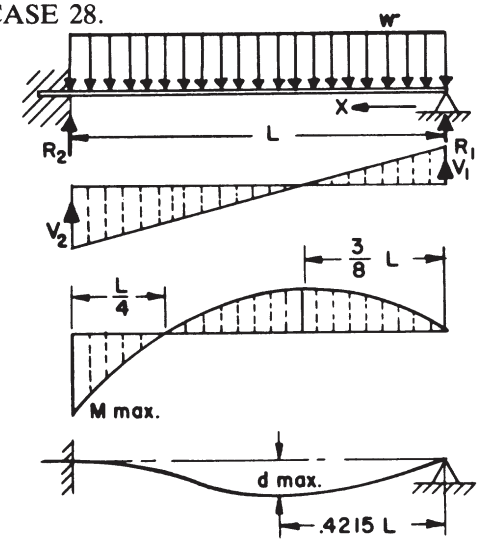
CASE 28.



Uniformly distributed load, w lb/in

Total load $W = wL$

Reactions: $R_1 = \frac{3wL}{8}$, $R_2 = \frac{5wL}{8}$

Shear forces: $V_1 = + R_1$; $V_2 = - R_2$

Bending moments:

Max. negative moment $= -\frac{wL^2}{8}$, at left end

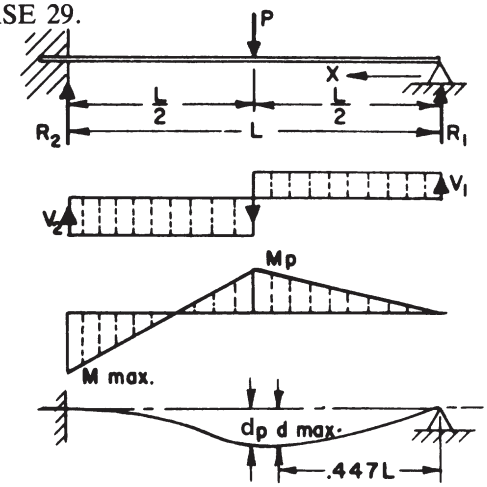
Max. positive moment $= \frac{9}{128} wL^2$, $x = \frac{3}{8}L$

$M = \frac{3wLx}{8} - \frac{wx^2}{2}$, $o \leq x \leq L$

Maximum deflection $= \frac{wL^4}{185EI}$, $x = 0.4215\ L$

def. $= \frac{wx}{48EI}(L^3 - 3Lx^2 + 2x^3)$, $o \leq x \leq L$

CASE 29.



Concentrated load, P, at center

Reactions: $R_1 = \frac{5}{16}P$; $R_2 = \frac{11}{16}P$

Shear forces: $V_1 = R_1$; $V_2 = - R_2$

Bending moments:

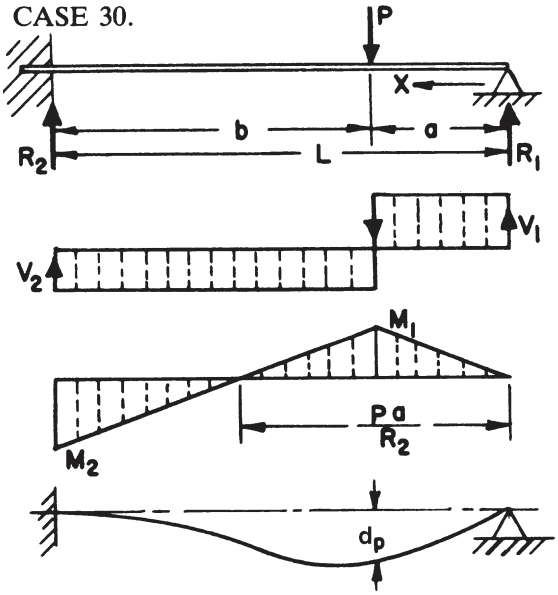
Max. negative moment $= -\frac{3\ PL}{16}$, at fixed end

Max. positive moment $= \frac{5\ PL}{32}$, at center

Maximum deflection $= 0.009317\ \frac{PL^3}{EI}$, at $x = 0.447\ L$

Deflection at center under load $= \frac{7\ PL^3}{768\ EI}$

CASE 30.



Concentrated load, P, at any point

Reactions: $R_1 = \frac{Pb^2}{2L^3}(a + 2L)$, $R_2 = \frac{Pa}{2L^3}(3L^2 - a^2)$

Shear forces: $V_1 = R_1$; $V_2 = - R_2$

Bending moments:

Max. negative moment, $M_2 = -\frac{Pab}{2L^2}(a + L)$, at fixed end

Max. positive moment, $M_1 = \frac{Pab^2}{2L^3}(a + 2L)$, at load

Deflections: $d_p = \frac{Pa^2b^3}{12\ EIL^3}(3L + a)$, at load

$d_{max} = \frac{Pa\ (L^2 - a^2)^3}{3\ EI\ (3L^2 - a^2)^2}$, at $x = \frac{L^2 + a^2}{3L^2 - a^2}L$, when $a < 0.414\ L$

$d_{max} = \frac{Pab^2}{6\ EI}\sqrt{\frac{a}{2L + a}}$, at $x = L\sqrt{\frac{a}{2L + a}}$, when $a > 0.414\ L$

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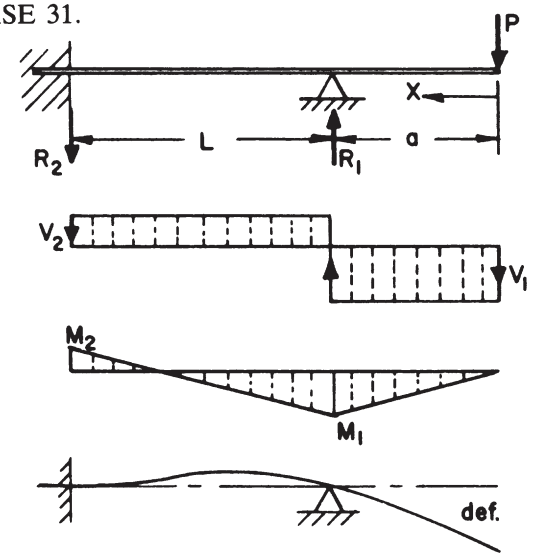
CASE 31.



Concentrated load, P, at end of overhang

Reactions: $R_1 = P\left(1 + \frac{3a}{2L}\right)$

$$R_2 = -\frac{3\,Pa}{2\,L}$$

Shear forces: $V_1 = -P$

$$V_2 = \frac{3\,Pa}{2\,L}$$

Bending moments:

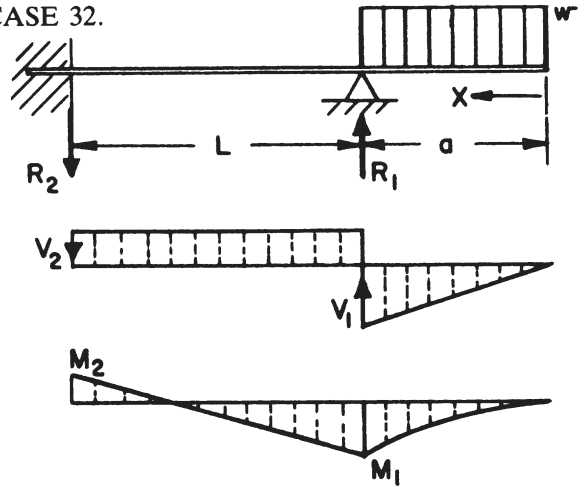
$M_1 = -Pa$, at R_1

$M_2 = \frac{Pa}{2}$, at fixed end

Deflection at end of overhang

$$\text{def.} = \frac{PL^3}{EI}\left(\frac{a^2}{4\,L^2} + \frac{a^3}{3\,L^3}\right)$$

CASE 32.



Distributed load, w lb/in. on overhang

Reactions: $R_1 = wa\left(1 + \frac{3a}{4\,L}\right)$

$$R_2 = -\frac{3\,wa^2}{4\,L}$$

Shear forces: $V_1 = -wa$

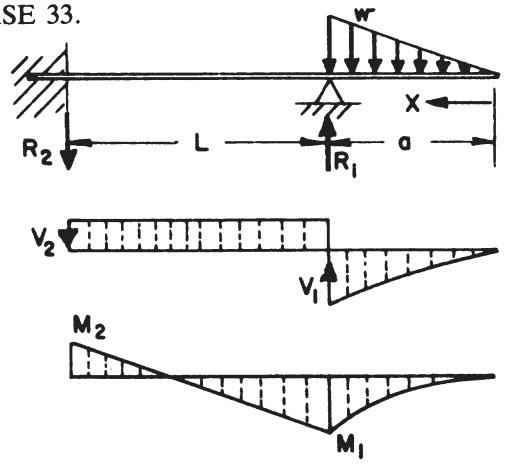
$$V_2 = \frac{3\,wa^2}{4\,L}$$

Bending moments:

$M_1 = -\frac{wa^2}{2}$, at R_1

$M_2 = \frac{wa^2}{4}$, at fixed end

CASE 33.



Distributed triangular loading of w lb/in. maximum intensity on overhang

Reactions: $R_1 = \frac{wa}{2}\left(1 + \frac{a}{2\,L}\right)$

$$R_2 = -\frac{wa^2}{4\,L}$$

Shear forces: $V_1 = -\frac{wa}{2}$

$$V_2 = \frac{wa^2}{4\,L}$$

Bending moments:

$M_1 = -\frac{wa^2}{6}$, at R_1

$M_2 = \frac{wa^2}{12}$, at fixed end

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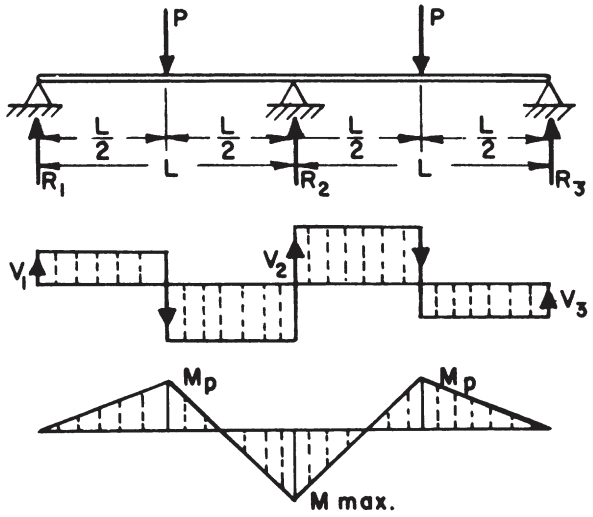
CASE 34. Continuous beam of two equal spans—equal concentrated loads, P, at center of each span



Reactions: $R_1 = R_3 = \frac{5}{16} P$

$R_2 = 1.375\ P$

Shear forces: $V_1 = -V_3 = \frac{5}{16} P$

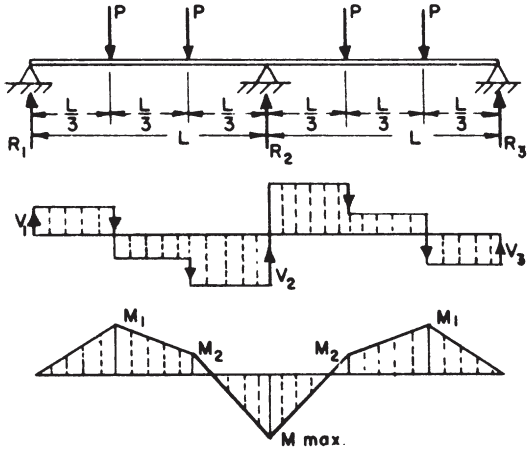
$V_2 = \pm \frac{11}{16} P$

Bending moments:

$M_{max} = -\frac{6}{32} PL$, at R_2

$M_p = \frac{5}{32} PL$, at point of load

CASE 35. Continuous beam of two equal spans—concentrated loads, P, at third points of each span



Reactions: $R_1 = R_3 = \frac{2}{3} P$

$R_2 = \frac{8}{3} P$

Shear forces: $V_1 = -V_3 = \frac{2}{3} P$

$V_2 = \pm \frac{4}{3} P$

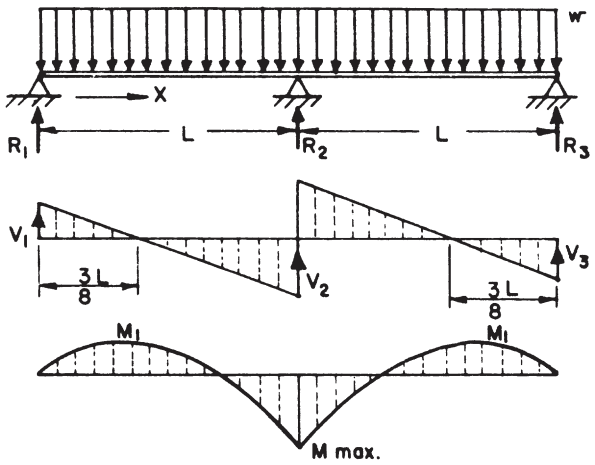
Bending moments:

$M_{max} = -\frac{1}{3} PL$, at R_2

$M_1 = \frac{2}{9} PL$

$M_2 = \frac{1}{9} PL$

CASE 36 Continuous beam of two equal spans—uniformly distributed load of w lb/in.



Reactions: $R_1 = R_3 = \frac{3}{8} wL$

$R_2 = 1.25\ wL$

Shear forces:

$V_1 = -V_3 = \frac{3}{8} wL$

$V_2 = \pm \frac{5}{8} wL$

Bending moments:

$M_{max} = -\frac{1}{8} wL^2$

$M_1 = \frac{9}{128} wL^2$

Maximum deflection $= 0.00541 \frac{wL^4}{EI}$

at $x = 0.4215\ L$

Def. $= \frac{w}{48\ EI}(L^3x - 3\ Lx^3 + 2x^4)$, $o \leq x \leq L$

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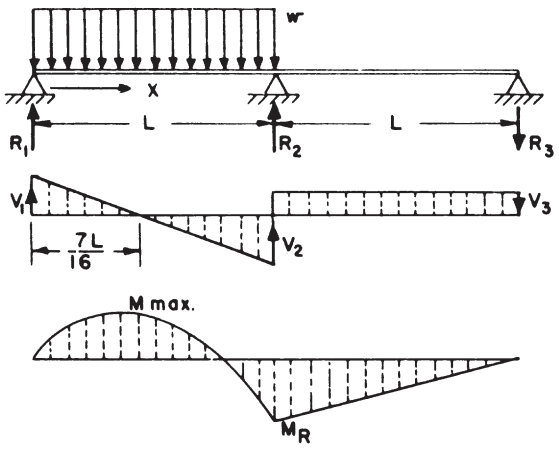
CASE 37. Continuous beam of two equal spans—uniformly distributed load of w lb/in. on one span



Reactions: $R_1 = \frac{7}{16} wL,\ R_2 = \frac{5}{8} wL,\ R_3 = -\frac{1}{16} wL$

Shear forces: $V_1 = \frac{7}{16} wL,\ V_2 = -\frac{9}{16} wL,\ V_3 = \frac{1}{16} wL$

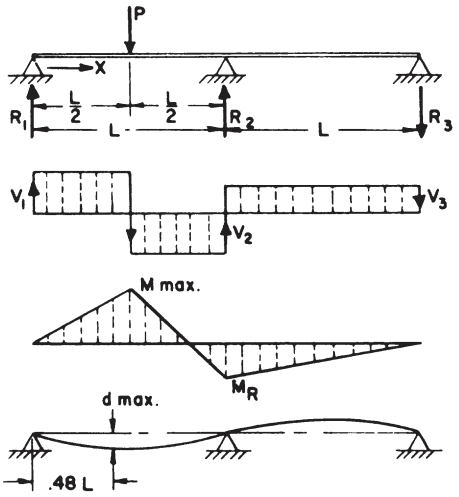
Bending moments:

$$M_{max} = \frac{49}{512} wL^2, \text{ at } x = \frac{7}{16} L$$

$$M_R = -\frac{1}{16} wL^2, \text{ at } R_2$$

$$M = \frac{wx}{16}(7L - 8x),\ o \le x \le L$$

CASE 38. Continuous beam of two equal spans—concentrated load, P, at center of one span.



Reactions: $R_1 = \frac{13}{32} P,\ R_2 = \frac{11}{16} P,\ R_3 = -\frac{3}{32} P$

Shear forces: $V_1 = \frac{13}{32} P,\ V_2 = -\frac{19}{32} P,\ V_3 = \frac{3}{32} P$

Bending moments:

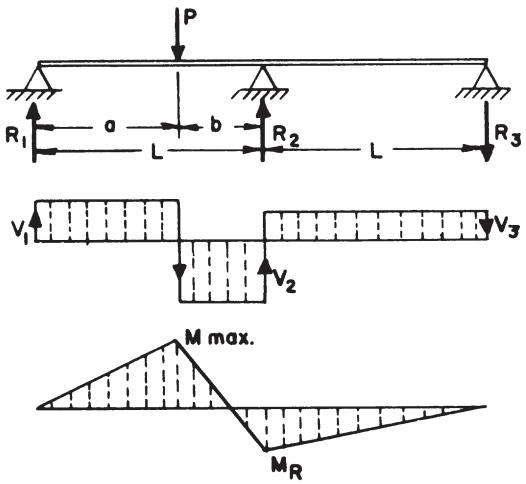
$$M_{max} = \frac{13}{64} PL, \text{ at point of load}$$

$$M_R = -\frac{3}{32} PL, \text{ at support } R_2$$

Maximum deflection:

$$d_{max} = \frac{0.96\ PL^3}{64\ EI}, \text{ at } x = 0.48L$$

CASE 39. Continuous beam of two equal spans—concentrated load, P, at any point on one span.



Reactions: $R_1 = \frac{Pb}{4L^3}[4L^2 - a(L + a)]$

$$R_2 = \frac{Pa}{2L^3}[2L^2 + b(L + a)]$$

$$R_3 = -\frac{Pab}{4L^3}(L + a)$$

Shear forces: $V_1 = \frac{Pb}{4L^3}[4L^2 - a(L + a)]$

$$V_2 = -\frac{Pa}{4L^3}[4L^2 + b(L + a)]$$

$$V_3 = \frac{Pab}{4L^3}(L + a)$$

Bending moments: $M_{max} = \frac{Pab}{4L^3}[4L^2 - a(L + a)]$

$$M_R = -\frac{Pab}{4L^2}(L + a)$$

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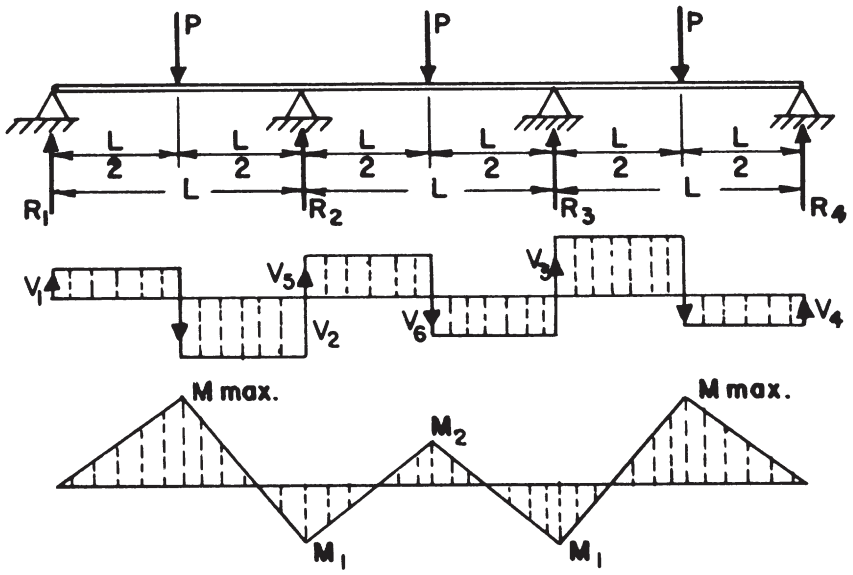
CASE 40. Continuous beam of three equal spans—concentrated load, P, at center of each span



Reactions: $R_1 = R_4 = \frac{7}{20} P$

$R_2 = R_3 = \frac{23}{20} P$

Shear forces:

$V_1 = -V_4 = \frac{7}{20} P$

$V_3 = -V_2 = \frac{13}{20} P$

$V_5 = -V_6 = \frac{P}{2}$

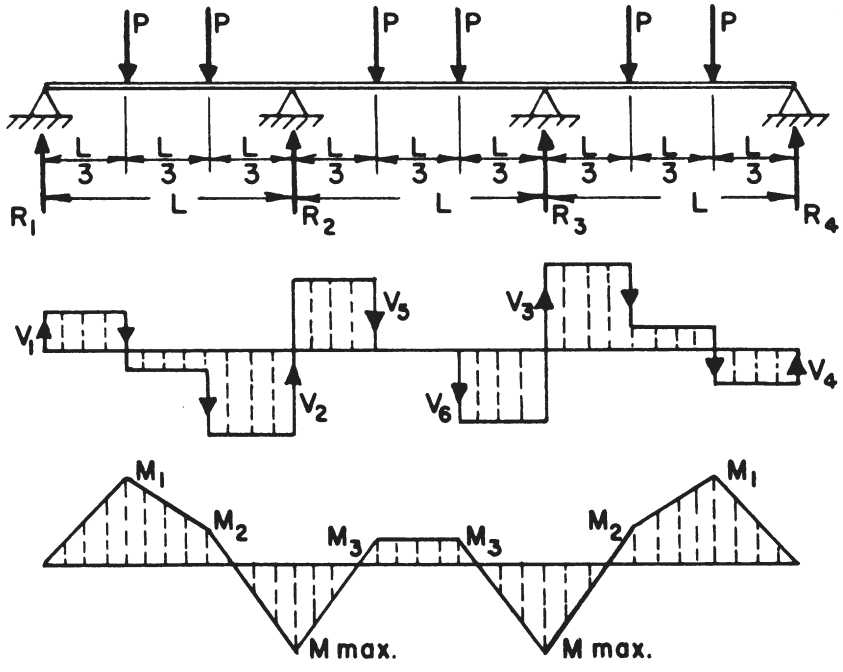
Bending moments:

$M_{max} = \frac{7}{40} PL$

$M_1 = -\frac{3}{20} PL$

$M_2 = \frac{1}{10} PL$

CASE 41. Continuous beam of three equal spans—concentrated loads, P, at third points of each span



Reactions:

$R_1 = R_4 = \frac{11}{15} P$

$R_2 = R_3 = \frac{34}{15} P$

Shear forces:

$V_1 = -V_4 = \frac{11}{15} P$

$V_3 = -V_2 = \frac{19}{15} P$

$V_5 = -V_6 = P$

Bending moments:

$M_{max} = -\frac{12}{45} PL$

$M_1 = \frac{11}{45} PL$

$M_2 = \frac{7}{45} PL$

$M_3 = \frac{3}{45} PL$

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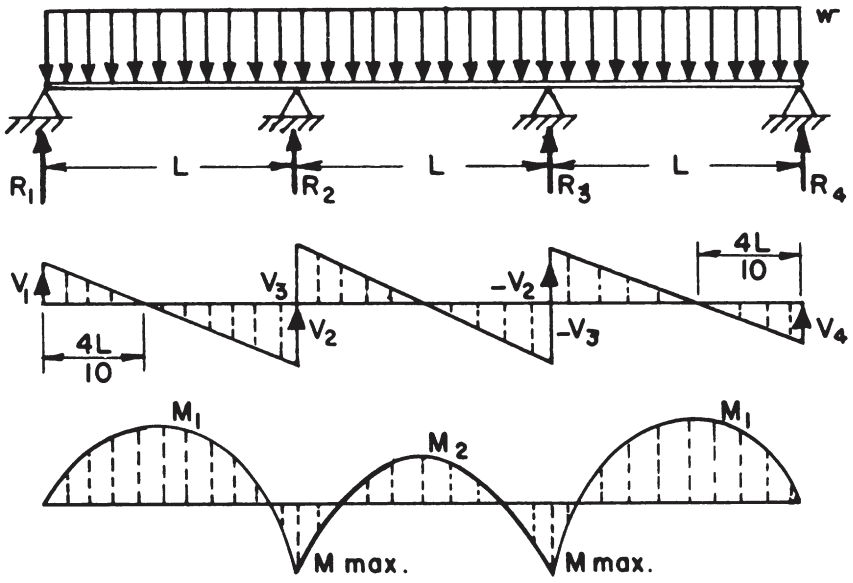
CASE 42. Continuous beam of three equal spans—uniformly distributed load



Loading: w lb/in

Reactions:

$$R_1 = R_4 = \frac{4wL}{10}$$

$$R_2 = R_3 = \frac{11wL}{10}$$

Shear forces:

$$V_1 = -V_4 = \frac{4wL}{10}$$

$$V_2 = -\frac{6wL}{10}$$

$$V_3 = \frac{5wL}{10}$$

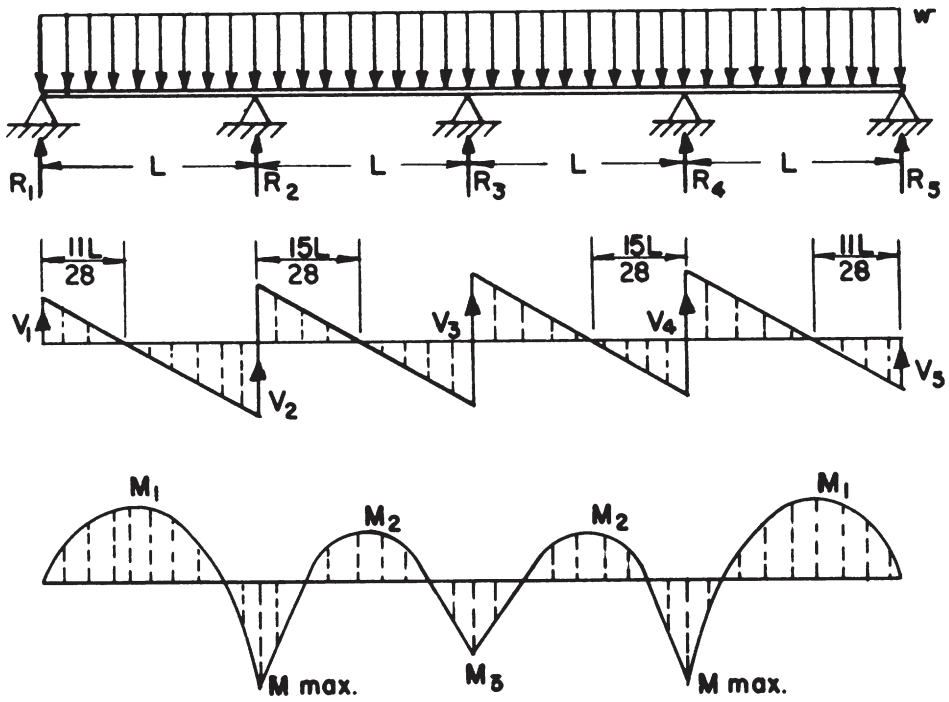
Bending moments:

$$M_{max} = -\frac{wL^2}{10}, \text{ at } R_2 \text{ and } R_3$$

$$M_1 = \frac{4wL^2}{50}, \text{ at } 0.4L \text{ from } R_1 \text{ and } R_4$$

$$M_2 = \frac{wL^2}{40}, \text{ at center}$$

CASE 43. Continuous beam of four equal spans—uniformly distributed load



Loading: w lb/in

Reactions: $R_1 = R_5 = \frac{11wL}{28}$

$$R_2 = R_4 = \frac{32wL}{28}$$

$$R_3 = \frac{26wL}{28}$$

Shear forces:

$$V_1 = -V_5 = \frac{11wL}{28}$$

$$V_4 = -V_2 = \frac{17wL}{28}$$

$$V_3 = \frac{13wL}{28}$$

Bending moments:

$$M_{max} = -\frac{168wL^2}{1568}, \text{ at } R_2 \text{ and } R_4$$

$$M_1 = \frac{121wL^2}{1568}$$

$$M_2 = \frac{57wL^2}{1568}$$

$$M_3 = -\frac{112wL^2}{1568}$$

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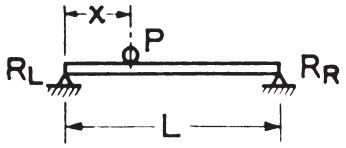
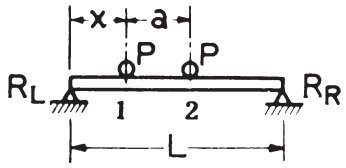
CASE 44. **SIMPLE BEAM**
One Concentrated Moving Load



R_L max $= V_L$ max (at $x = 0$) $= P$

M max $\left(\text{at point of load, when } x = \frac{L}{2}\right) = \frac{PL}{4}$

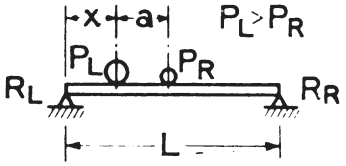
CASE 45. **SIMPLE BEAM**
Two Equal Concentrated Moving Loads



$$R_L \text{ max} = V_L \text{ max (at } x = 0) = P\left(2 - \frac{a}{L}\right)$$

$$M \text{ max} \begin{cases} \left[\begin{array}{l}\text{when } a < (2 - \sqrt{2})\, L = 0.586L \\ \text{under load 1 at } x = \frac{1}{2}\left(L - \frac{a}{2}\right)\end{array}\right] = \frac{P}{2L}\left(L - \frac{a}{2}\right)^2 \\ \left[\begin{array}{c}\text{when } a > (2 - \sqrt{2})\, L = 0.586L \\ \text{with one load at center of span} \\ \text{(other load is then off span)}\end{array}\right] = \frac{PL}{4} \end{cases}$$

CASE 46. **SIMPLE BEAM**
Two Unequal Concentrated Moving Loads

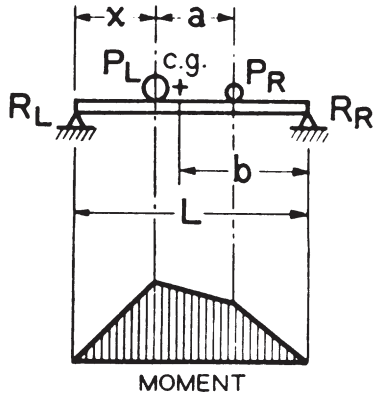


$$R_L \text{ max} = V_L \text{ max (at } x = 0) = P_L + P_R\frac{L - a}{L}$$

$$M \text{ max} \begin{cases} \left[\text{under } P_L, \text{ at x} = \frac{1}{2}\left(L - \frac{P_R a}{P_L + P_R}\right)\right] = (P_L + P_R)\frac{x^2}{L} \\ \left[\begin{array}{l}M \text{ max may occur with larger load at} \\ \text{center of span and other load off span}\end{array}\right] = \frac{P_L L}{4} \end{cases}$$

CASE 47.

GENERAL RULES FOR SIMPLE BEAMS CARRYING CONCENTRATED MOVING LOADS



Maximum shear due to moving concentrated loads occurs at one support when one of the loads is at that support. With several moving loads, the point of maximum shear must be determined by trial.
Maximum bending moment produced by moving concentrated loads occurs under one of the loads when that load is as far from one support as the center of gravity of all the moving loads on the beam is from the other support.
In the diagram, maximum bending moment occurs under load P_L when $x = b$. It should also be noted that this condition occurs when the center line of the span is midway between the center of gravity of the loads and the nearest concentrated load.

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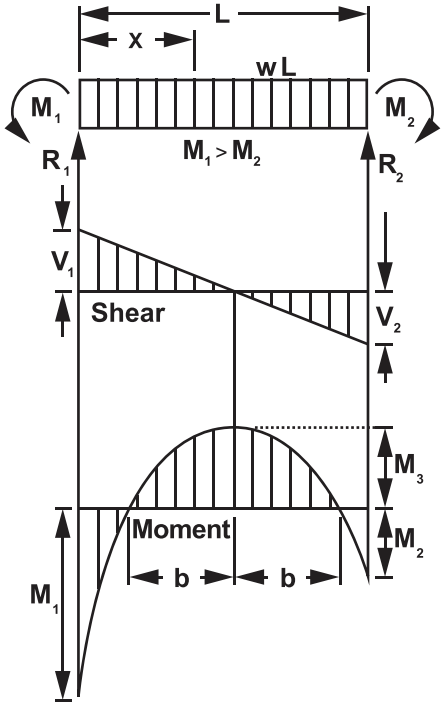
CASE 48. Uniformly distributed load and variable end moments.



$$R_1 = V_1 = \frac{wL}{2} + \frac{M_1 - M_2}{L}$$

$$R_2 = V_2 = \frac{wL}{2} - \frac{M_1 - M_2}{L}$$

$$V_x = w\left(\frac{L}{2} - x\right) + \frac{M_1 - M_2}{L}$$

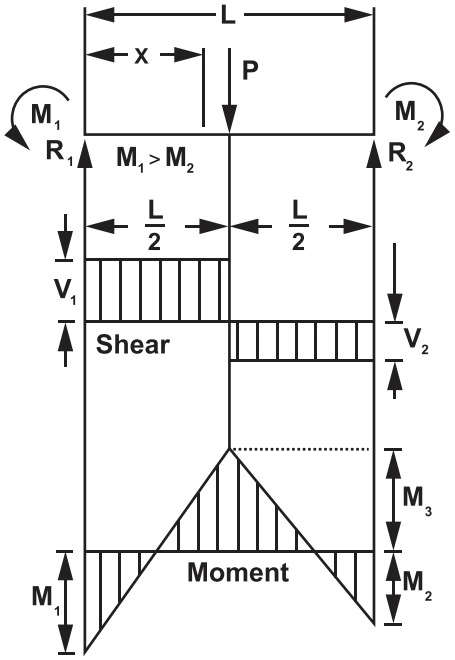
$$M_3 \quad \left(at\ x = \frac{L}{2} + \frac{M_1 - M_2}{wL}\right) = \frac{wL^2}{8} - \frac{M_1 + M_2}{2} + \frac{(M_1 - M_2)^2}{2wL^2}$$

$$M_x = \frac{wx}{2}(L - x) + \left(\frac{M_1 - M_2}{L}\right)x - M_1$$

$$b\ (to\ locate\ inflection\ points) = \sqrt{\frac{L^2}{4} - \left(\frac{M_1 + M_2}{w}\right) + \left(\frac{M_1 - M_2}{wL}\right)^2}$$

$$\Delta_x = \frac{wx}{24EI}\left[x^3 - \left(2L + \frac{4M_1}{wL} - \frac{4M_2}{wL}\right)x^2 + \frac{12M_1}{w}x + L^3 - \frac{8M_1L}{w} - \frac{4M_2L}{w}\right]$$

CASE 49. Concentrated load at center and variable end moments.



$$R_1 = V_1 = \frac{P}{2} + \frac{M_1 - M_2}{L}$$

$$R_2 = V_2 = \frac{P}{2} - \frac{M_1 - M_2}{L}$$

$$M_3 \quad (at\ center) = \frac{PL}{4} - \frac{M_1 + M_2}{2}$$

$$M_x \quad \left(when\ x < \frac{L}{2}\right) = \left(\frac{P}{2} + \frac{M_1 - M_2}{L}\right)x - M_1$$

$$M_x \quad \left(when\ x > \frac{L}{2}\right) = \frac{P}{2}(L - x) + \frac{(M_1 - M_2)x}{L} - M_1$$

$$\Delta_x \quad \left(when\ x < \frac{L}{2}\right) = \frac{Px}{48EI}\left(3L^2 - 4x^2 - \frac{8(L-x)}{PL}\left[M_1(2L - x) + M_2(L + x)\right]\right)$$

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PART VII
ILLUSTRATIVE EXAMPLES

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

Part VII

Illustrative Examples

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VII
Illustrative Examples

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This part of the Design Manual illustrates the use of Part I, the *Specification for Aluminum Structures*. Terms and symbols used in Part VII are consistent with those used in the *Specification for Aluminum Structures,* which should be consulted for their definitions. References in Part VII to section and table numbers are to the section and table numbers in the *Specification for Aluminum Structures.*

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CORRELATION OF SPECIFICATION SECTIONS AND ILLUSTRATIVE EXAMPLES

Type of Stress	Type of Member and Element	Section Number	Main Examples	Other Examples
ELEMENTS IN UNIFORM COMPRESSION	Flat elements supported on one edge	B.5.4.1	10, 11, 21	3, 9, 13 16, 22, 23, 26
	Flat elements supported on both edges	B.5.4.2	12, 22	4, 9, 11, 20, 24, 29
	Pipes and round tubes	B.5.4.5	14	12
ELEMENTS IN FLEXURE	Flat elements supported on tension edge, compression edge free	B.5.5.2	23	
	Flat elements supported on both edges	B.5.5.1	24	3, 16, 20, 21, 22, 23
	Flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	25	
TENSION, axial	Tension members	D.2	1	2
COMPRESSION, axial	Columns	E.2	9	10, 11, 12, 14
FLEXURE	Open shapes	F.2, F.3, F.4	15, 16	3, 21, 22, 23, 26, 28
	Round tubes	F.2, F.3, F.4	18	5
	Bar	F.2, F.4	19	6
	Closed shapes	F.2, F.3, F.4	20	4
SHEAR	Flat elements supported on both edges	G.2	26	3, 4, 15, 20, 21, 22, 23
	Round Tubes	G.4	5	
BEARING	On rivets	J.4.6	7	
	On pins	J.6.5	8	

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Example 1
ROD IN AXIAL TENSION
Illustrating Section D.2

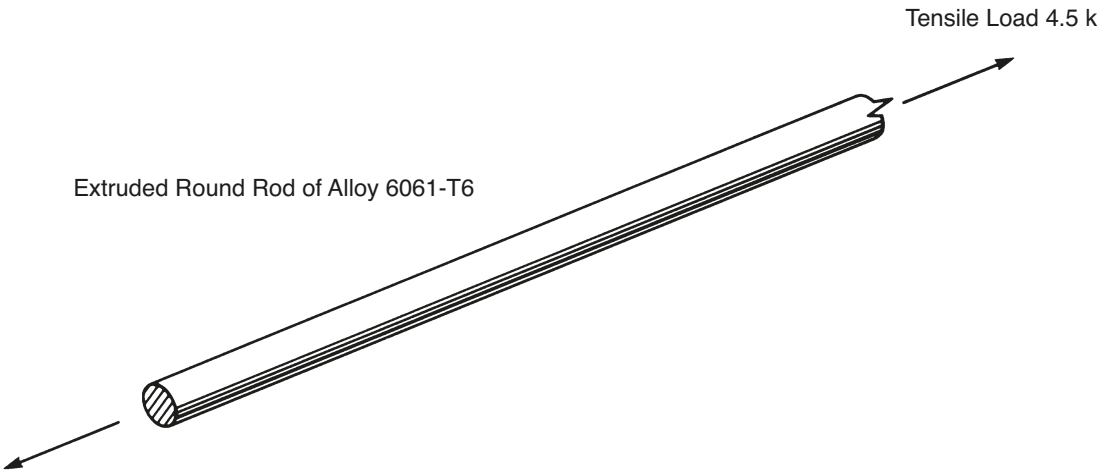

Figure 1

GIVEN:

1. Required ASD axial tension force: 4.50 k
2. Alloy-temper: 6061-T6
3. Product specification: ASTM B221

FIND:

Diameter of smallest standard rod that will safely resist the load.

SOLUTION:

From Part VI Table 2-19, Section D.2: Allowable tensile stress: The net section allowable stress is less than the gross section allowable stress and the net section is less than the gross section, so only the net section needs to be considered.

F/Ω = 19.5 ksi on the net section

Given load P = 4.50 k

Required area $A = \dfrac{P}{F/\Omega}$ = (4.5 k)/(19.5 k/in^2) = 0.231 in^2

From Part VI, Table 5-3, the smallest diameter for A = 0.231 in^2 is 3/4 in. with a root area of 0.313 in^2, so use D = 3/4 in.

NOTE: Long slender members have little resistance to lateral loads. Therefore, tension members with large slenderness ratios L/r should be avoided unless such members can also resist vibration and lateral loads such as wind, dead load, and the weight of workmen and equipment.

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Example 2
RECTANGULAR BAR IN AXIAL TENSION
Illustrating Section D.2

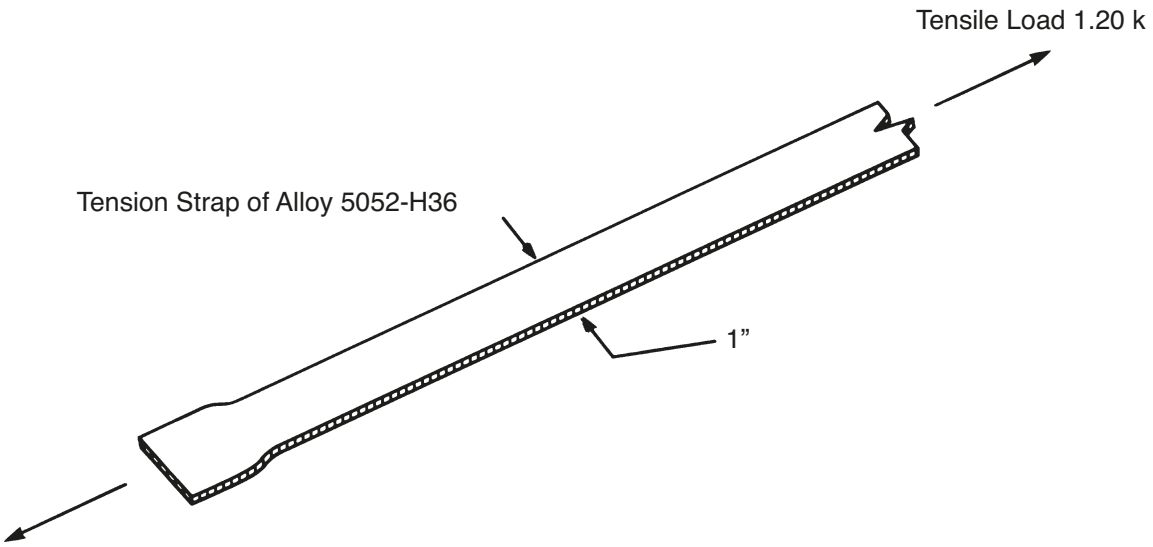

Figure 2

GIVEN:

1. Required ASD axial tension force: 1.20 k
2. Alloy-temper: 5052-H36
3. Product specification: ASTM B209

FIND:

The thickness of a 1 in. wide bar which will safely resist the load. Assume that the ends of the bar are connected so that the net section is sufficiently large that it does not govern the tensile strength of the bar.

SOLUTION:

From Section D.2, the allowable tensile strength for yielding in the gross section is

$$P_n = F_{ty} A_g / \Omega_t = 1.20 \text{ k}$$

Reading F_{ty} from Table A.4.3 as 29 ksi, the required gross area is

$$A_g = P_n \, \Omega_t / F_{ty} = (1.20\,\text{k})(1.65)/(29\ \text{k/in}^2) = 0.0683\ \text{in}^2$$

The required thickness for 1.00 in. width is

$$t = 0.0683\ \text{in}^2/(1.00\ \text{in.}) = 0.0683\ \text{in.}$$

From Part V, Table 3, the minimum commonly used thickness ≥ 0.0683 in. is $t = 0.071$ in.

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Example 3
W-SHAPE IN FLEXURE AND SHEAR
Illustrating Sections F.2, F.3, and G.2

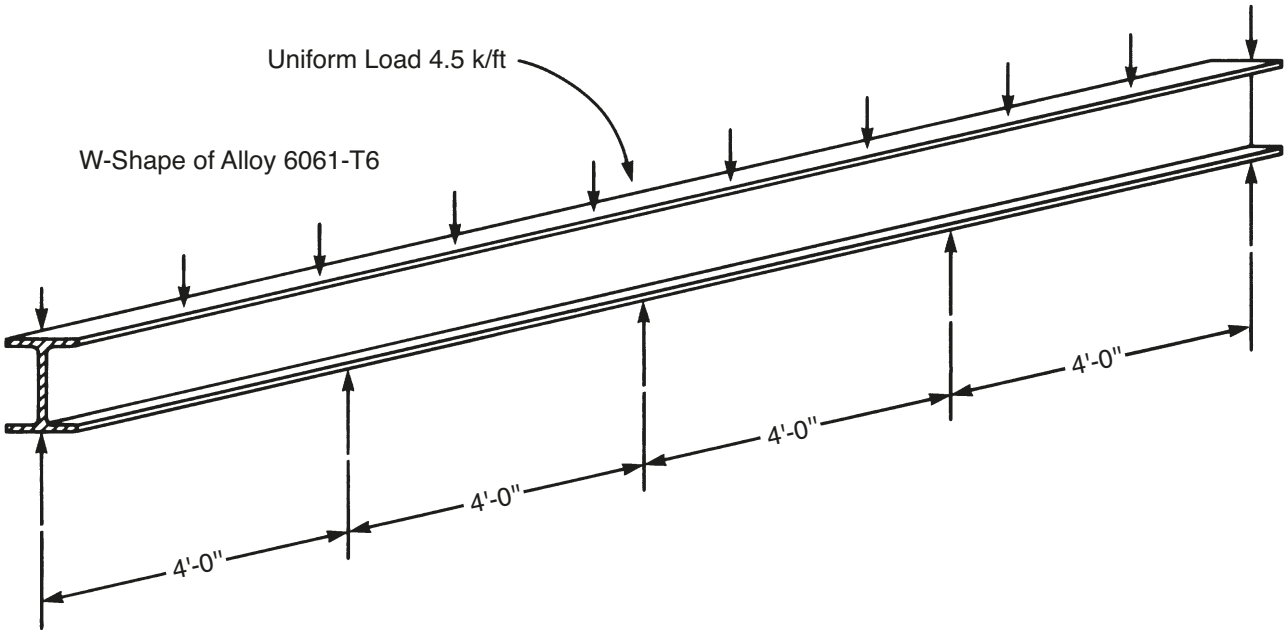

Figure 3

GIVEN:

1. Uniform load of 4.50 k/ft including dead load
2. Beam length 16 ft with continuous lateral support
3. Vertical support spacing 4 ft o.c.
   (first support at end of beam)
4. Alloy-temper: 6061-T6
5. Product specification: ASTM B221

FIND:

The size of the lightest Aluminum Association standard W-shape that will safely support the load using ASD.

SOLUTION:

From Part VI Beam Formulas Case 43 continuous beam of four equal spans, uniformly distributed load:

Load w = (4.50 k/ft)(ft /12 in.) = 0.375 k /in.

The maximum required bending moment is

$M = -168\ wL^2/1568 = -168(0.375\text{ k/in})(48\text{ in})^2/1568$
$= -92.6$ in-k

The negative sign for the bending moment M indicates that the top flange of the beam is in tension. The point of maximum stress is at the first interior support.

Section F.1 gives a safety factor of 1.95 for the rupture limit state and 1.65 for all other limit states.

The allowable moment for the limit state of yielding given in Section F.2 is $M_{np}/\Omega = ZF_{cy}/\Omega$, assuming that for a W-shape, $Z < 1.5S$. Using F_{cy} = 35 ksi (see Tables A.4.1 and A.4.3), Ω = 1.65, and setting the allowable yield moment equal to the required moment:

$ZF_{cy}/\Omega = Z(35\text{ k/in}^2)/1.65 = 92.6$ in-k

gives $Z = 4.36$ in^3.

The allowable moment for the limit state of rupture given in Section F.2 is $M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$; using F_{tu} = 38 ksi and k_t = 1.0 (see Table A.4.3), Ω = 1.95, and setting the allowable moment equal to the required moment:

$ZF_{tu}/k_t/\Omega = Z(38\text{ k/in}^2)/1.0/1.95 = 92.6$ in-k

gives $Z = 4.75$ in^3. Since this exceeds the plastic modulus required for the yield limit state, use $Z = 4.75$ in^3 to select a trial beam. The smallest Aluminum Association standard W-shape for which $Z > 4.75$ in^3 is an AW 5 x 3.70, for which $Z = 6.31$ in^3

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Now check the beam for local buckling according to Section F.3.

a) The flange is in uniform compression, so the strength is given in Section B.5.4. Section B.5.4.1 addresses flat elements supported on one edge; from Part VI, Table 2-19

   $b/t = (3.50 - 0.19)/[(2)(0.32)] = 5.2 < 6.7 = \lambda_1$ so
   $F/\Omega = 21.2$ ksi

   Since the flange slenderness is less than λ_1, deducting the web-flange fillets from the flange width will not change the flange's local buckling stress.

b) The web is in flexure so the strength is given by Section B.5.5.1, flat elements in flexure supported on both edges. Since the beam is symmetric about the bending axis, $c_c = -c_o$, and $m = 0.65$.

   $b/t = (5.00 - 2(0.32))/0.19 = 22.9 < \lambda_1 = 33.1$, so

   $F/\Omega = 31.8$ ksi

For an AW 5 x 3.70, with a section modulus $S = 5.58$ in^3, the stress in the flange is

$f = M/S = (92.6 \text{ in-k})/(5.58 \text{ in}^3) = 16.6 \text{ ksi} < 21.2 \text{ ksi}$

so the AW 5 x 3.70 is acceptable for local buckling using the limiting element method (Section F.3.3).

For the limit states of shear yielding and buckling, web shear is addressed by Section G.2, flat webs supported on both edges.

$b/t = 22.9 < 35.3 = \lambda_1$, so $F_s/\Omega = 12.7$ ksi

For the limit state of shear rupture, Table 2-19 gives an allowable stress of 11.7 ksi.

From Part VI Beam Formulas Case 43, continuous beam of four equal spans.

$V = 17wL/28 = 17(0.375 \text{ k/in.})(48 \text{ in.})/28 = 10.9$ k, maximum web shear

The required web area is

$A = V/(F_s/\Omega) = (10.9 \text{ k})/(11.7 \text{ k/in}^2) = 0.93 \text{ in}^2$

For AW 5 × 3.70

$A_w = dt_w = (5.00)\ 0.19$

$= 0.95 \text{ in}^2 > 0.93 \text{ in}^2$

The AW 5 × 3.70 is therefore the lightest satisfactory beam.

NOTES: The building code should be checked to see if analysis for other loading conditions (such as alternate span loading) is required in addition to the load addressed above. Generally, the use of the formula $M = \pm wL^2/8$ satisfies all building code requirements for uniformly loaded beams supported on both ends.

If holes will be drilled in the flange at or near points of high tensile stress, it may be necessary to use a larger beam. This may be determined by multiplying the computed flange stress at the section under consideration by the ratio of the gross area of the flange to the net area of the flange and comparing the result with the allowable stress.

Web crippling at supports should be checked; see Example 4.

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Example 4
SQUARE TUBE IN FLEXURE AND SHEAR
Illustrating Sections F.2, F.3.3, G.2, and J.9.3.1

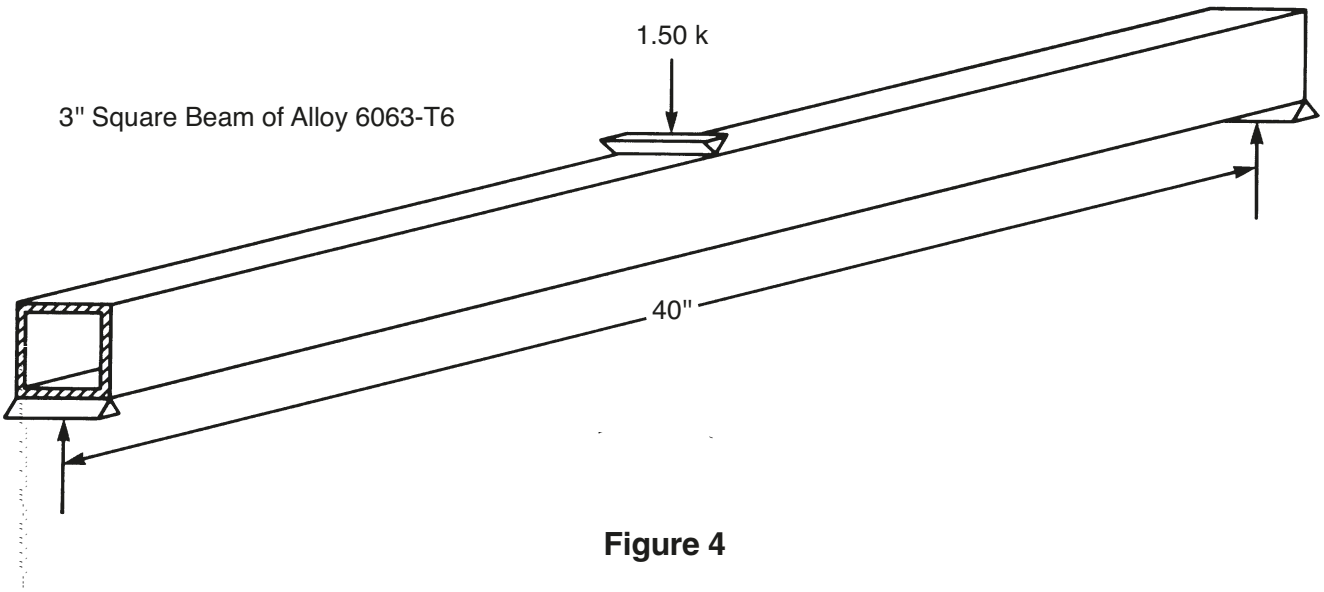

Figure 4

GIVEN:

1. Concentrated load of 1.50 k including dead load, applied at mid span.
2. Span 40 in., simply supported
3. Alloy: 6063-T6
4. Product specification: ASTM B221

FIND:

The thickness of a standard 3 in. square tube that will safely support the load, using ASD.

SOLUTION:

From Part VI Beam Formulas Case 1, a simply supported beam with a concentrated load P at the center, the maximum moment $= M = PL/4 = (1.5\text{ k})(40\text{ in.})/4 = 15.0$ in-k

The available flexural strength of members is the least of the available strengths for the limit states of yielding, rupture, local buckling, and lateral-torsional buckling. Section F.1 gives a safety factor of 1.95 for the rupture limit state and 1.65 for all other limit states.

a) The allowable yield moment given in Section F.2 is $M_{np}/\Omega = ZF_{cy}/\Omega$; using $F_{cy} = 25$ ksi (see Tables A.4.1 and A.4.3), $\Omega = 1.65$, and setting the allowable yield moment equal to the required moment:

$ZF_{cy}/\Omega = Z(25\text{ k/in}^2)/1.65 = 15.0$ in-k

gives $Z = 0.99$ in^3.

b) The allowable moment for the limit state of rupture given in Section F.2 is $M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$; using $F_{tu} = 30$ ksi and $k_t = 1.0$ (see Table A.4.3), $\Omega = 1.95$, and setting the allowable moment equal to the required moment:

$ZF_{tu}/k_t/\Omega = Z(30\text{ k/in}^2)/1.0/1.95 = 15.0$ in-k

gives $Z = 0.98$ in^3. Since the plastic modulus required for the yield limit state exceeds the plastic modulus required for the rupture limit state, use $Z = 0.99$ in^3 to select a trial beam. The smallest square tube shown in Part V, Table 18 for which $Z > 0.99$ in^3 is $3 \times 3 \times 0.095$, for which $Z = 1.20$ in^3, and for which

$M_{np} = ZF_{cy} = (1.20\text{ in}^3)(25\text{ k/in}^2) = 30$ in-k $< 1.5F_{cy}S = 1.5(25\text{ k/in}^2)(1.04\text{ in}^3) = 39$ in-k

c) Now check the beam for local buckling according to Section F.3.

1) The flange is in uniform compression, so its strength is given in Section B.5.4. Section B.5.4.2 addresses flat elements supported on both edges; from Part VI, Table 2-21

$b/t = (3 - 2(0.095))/0.095 = 29.6 > 22.8 = \lambda_1$ and $< \lambda_2 = 39$, so $F_c/\Omega = 19.0 - 0.170(29.6) = 14.0$ ksi

2) The web is in flexure, so its strength is given by Section B.5.5.1, flat elements in flexure supported on both edges. Since the beam is symmetric about the bending axis, $c_c = -c_o$, and $m = 0.65$. Thus λ_1 equals the tabulated value of 34.7.

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$b/t = (3 - 2(0.095))/0.095 = 29.6 < \lambda_1 = 34.7$,
so $F_b/\Omega = 22.7$ ksi

For a 3 × 3 × 0.095 tube, with a section modulus $S = 1.04$ in^3, the stress in the flange is

$f = M/S = (15.0 \text{ in-k})/(1.04 \text{ in}^3) = 14.4$ ksi

Using the weighted average method to determine the allowable moment for the limit state of local buckling (Section F.3.1):

$$M_{nlb} = F_c I_f / c_{cf} + F_b I_w / c_{cw}$$

$I_f = 2[dt^3/12 + dt(d/2 - t/2)^2] = 1.203$ in^4
$I_w = 2t(d - 2t)^3/12 = 0.351$ in^4

The allowable moment for local buckling is

$M_{nlb}/\Omega = (14.0 \text{ k/in}^2)(1.203 \text{ in}^4)/(3/2 - 0.095/2)\text{in.}$
$+ (22.7 \text{ k/in}^2)(0.351 \text{ in}^4)/(3/2 - 0.095)\text{in.} = 17.3$ in-k

d) For lateral-torsional buckling, the slenderness is determined using Section F.4.2.3:

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} = 2.3\sqrt{\frac{(40)(1.04)}{(1)\sqrt{(1.55)(2.33)}}} = 10.8 < 78 = C_c$$

From Section F.4

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 30\left(1 - \frac{10.8}{78}\right) + \frac{\pi^2(10{,}100)10.8(1.04)}{78^3}$$

$= 28.2$ in-k

The available moment is

$M_{nmb}/\Omega = 28.2/1.65 = 17.1$ in-k

The allowable moment is the least of the allowable moments for yielding ($M_{np}/\Omega = ZF_{cy}/\Omega = (1.2)(25)/1.65 = 18.2$), rupture ($M_{nu}/\Omega = ZF_{tu}/\Omega = (1.2)(30)/1.95 = 18.5$), local buckling ($M_{nlb}//\Omega = 17.3$) and lateral-torsional buckling ($M_{nmb}//\Omega = 17.1$), which is 17.1 in-k.

Since the allowable moment (17.1 in-k) is greater than the required moment (15.0 in-k), a 3 × 3 × 0.095 tube is satisfactory for flexure.

For shear in the web, Part VI Beam Formulas Case 1 gives

$V = P/2 = (1.5 \text{ k})/2 = 0.75$ k

Based on Section G.2, the allowable shear stress for the limit state of shear rupture is 9.2 ksi. For shear rupture

Area of webs for rupture is

$A = 2(0.095)(3.00 - 2(0.095)) = 0.534$ in^2

Part VI, Table 2-21 gives the allowable shear stress for the limit state of shear yielding or buckling as

$b/t = 29.6 < 38.7 = \lambda_1$, so $F_s/\Omega = 9.1$ ksi

Area of webs for yielding is

$A = 2(0.095)(3.00) = 0.570$ in^2

Approximate web shear stress

$f_s = V/A = (0.75 \text{ k})/(0.534 \text{ in}^2) = 1.4 \text{ k/in}^2 < 9.1 \text{ k/in}^2$

Use a 3 in. square tube with 0.095 in. thick walls (RT 3 × 3 × 0.095)

NOTES: A lighter tube in 6061-T6 alloy would be satisfactory structurally; however, for architectural uses, 6063-T6 may be preferred because of its superior finishing characteristics.

The supports and load point of Figure 4 are shown as sharp, a condition seldom used in actual practice but used here to define the span length more clearly. In an actual installation, the forces on the beam will be distributed over a distance l_b, which must be large enough to prevent local crippling of the webs.

Section J.9.3.1 addresses web crippling of extruded W-shape members. Although this is a tube, use Section J.9.3.1. From Tables A.4.1 and A.4.3, $E = 10{,}100$ ksi, $F_{cy} = 25$ ksi,

Try $l_b = 0.10$ in.; then $l_b/d = 0.10/3 = 0.033 < 0.2$

The allowable reaction R_n/Ω for concentrated forces applied at a distance from the member end that is less than the member depth divided by 2 is

$$R_n = 0.40t_w^2\left(1 + 3\left(\frac{l_b}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right)\sqrt{\frac{EF_{yw}t_f}{t_w}} =$$

$$0.40(0.095)^2\left(1 + 3\left(\frac{0.10}{3}\right)\left(\frac{0.095}{0.095}\right)^{1.5}\right)\sqrt{\frac{(10{,}100)(25)(0.095)}{0.095}}$$

$= 2.0$ k

So

$R_n/\Omega = 2.0/1.95$

$R_n/\Omega = 1.0$ k allowable, per web

For two webs the end reaction per web is

$V/2 = 0.75/2 = 0.375$ k

0.375 k < 1.0 k; therefore a bearing length of 0.10 in. is satisfactory

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Example 5
WELDED PIPE IN FLEXURE AND SHEAR
Illustrating Sections B.5.5.4, F.2, F.4, and G.4

GIVEN:

1. 42 in. tall pipe, laterally braced at the top
2. Alloy-temper: 6061-T6
3. Product specification: ASTM B429
4. Transversely welded all around its base with 5356 filler
5. 200 lb lateral load applied at top of pipe

FIND:

The size of a standard pipe that will safely resist the load using ASD.

SOLUTION:

Flexure:

The required moment at the base of the pipe is

$M_r = PL$ = (0.2 k)(42 in.) = 8.4 in-k.

Try an NPS 2 1/2 schedule 40 pipe, for which S = 1.06 in^3, Z = 1.45 in^3, J = 3.04 in^4, A = 1.70 in^2 and I_y = 1.53 in^4. From Table A.4.3, the welded tensile yield strength F_{tyw} is 15 ksi and welded tensile ultimate strength F_{tuw} is 24 ksi. For welded 6061, $F_{cyw} = F_{tyw}$ = 15 ksi.

From Section F.2, the moment for the limit state of yielding is the lesser of

$M_{np} = ZF_{cyw}$ = (1.45 in^3)(15 k/in^2) = 21.8 in-k and $1.5SF_{tyw}$ = (1.5)(1.06 in^3)(15 k/in^2) = 23.9 in-k, which is 21.8 in-k.

The available moment at the base of the pipe for the limit state of yielding is

$M_{np}/\Omega = ZF_{cyw}/\Omega$ = (21.8 in-k)/1.65 = 13.2 in-k.

From Section F.2, the available moment at the base of the pipe for the limit state of rupture is

$M_{nu}/\Omega = ZF_{tuw}/k_t/\Omega$ = (1.45 in^3)(24 k/in^2)/1.0/1.95 = 17.8 in-k.

Checking local buckling using Section B.5.5.4 and Table 2-19W,

R_b = (2.875" – 0.203")/2 = 1.336",

$$\sqrt{\frac{R_b}{t}} = \sqrt{\frac{1.336}{0.203}} = 2.57 < 11 = C_{tb}$$

So

F_c/Ω = 17.7 – 0.933(2.57) = 15.3 ksi;

and the available moment at the base of the pipe for the limit state of local buckling is

M_{nLB}/Ω = (15.3 ksi)(1.06 in^3) = 16.2 in-k.

For the limit state of lateral-torsional buckling, in accordance with Section F.4 use welded strengths to determine the buckling constants since the handrail is a cantilever and has a transverse weld. The slenderness from Section F.4.2.3 is

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} = 2.3\sqrt{\frac{(42)(1.06)}{(1)\sqrt{(1.53)(3.04)}}}$$

$$= 10.5 < 133 = C_c, \text{ so}$$

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 21.8\left(1 - \frac{10.4}{133}\right) + \frac{\pi^2(10{,}100)(10.4)(1.06)}{133^3}$$

$$= 20.6 \text{ in-k}$$

The available moment for the limit state of lateral-torsional buckling is

M_{nmb}/Ω = (20.6 in-k)/(1.65) = 12.5 in-k

The allowable moment (12.5 in-k) is the least of these four limit states = (13.2, 17.8, 16.2 and 12.5 in-k) and is greater than the required moment of 8.4 in-k, so an NPS 2 ½ schedule 40 is satisfactory for flexure.

Shear:

The required shear is V_r = 0.2 k. In the weld-affected zone for 6061-T6, according to Tables A.4.1 and A.4.3 the shear ultimate strength is $F_{suw} = 0.6\,F_{tuw}$ = 0.6(24 ksi) = 14.4 ksi and the shear yield strength is 0.6(15 ksi) = 9 ksi. In accordance with Section G.4:

For the limit state of shear rupture, the shear strength is

$V_n = F_{suw}\,A_{wz}/2$ = (14.4 k/in^2)(1.70 in^2)/2 = 12.2 k

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For the limit state of shear rupture, available shear strength is

$V_n / \Omega = (12.2 \text{ k})/1.95 = 6.3 \text{ k}$

For the limit state of shear yielding and shear buckling,

$\lambda_1 = (1.3B_s - F_{sy}) / (1.63D_s)$
$= (1.3(12.0) - 9)) / [1.63(0.051)]$
$= 79.4$

$$\lambda = 2.9\left(\frac{R_b}{t}\right)^{5/8}\left(\frac{L_v}{R_b}\right)^{1/4} = 2.9\left(6.6\right)^{5/8}\left(\frac{42}{1.336}\right)^{1/4}$$

$= 22.3 < 79.4$, so $F_s = F_{sy} = 0.6(15 \text{ ksi}) = 9 \text{ ksi}$

The allowable shear strength for the limit state of shear yielding and shear buckling is

$V_n / \Omega = F_s A_g / 2 / \Omega = (9 \text{ k/in}^2)(1.70 \text{ in}^2) / 2 / 1.65 = 4.6 \text{ k}$

The lesser of the allowable shear strengths (6.3 k and 4.6 k) is 4.6 k > 0.2 k; therefore, an NPS 2 ½ schedule 40 is satisfactory for shear.

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Example 6
PLATE IN FLEXURE
Illustrating Section F.2

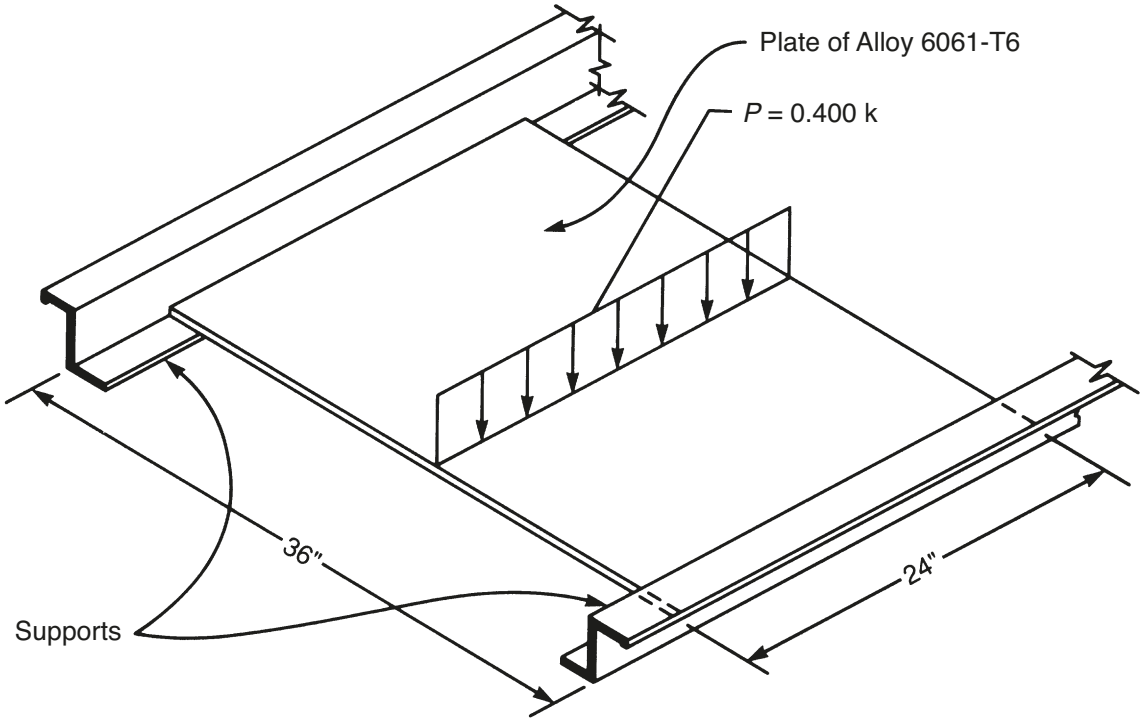

Figure 6

GIVEN:

1. Load 0.400 k, along a line at the center of a plate
2. Plate: 24 in. wide, spanning 36 in.
3. Alloy-temper: 6061-T6
4. Product specification: ASTM B209

FIND:

The minimum standard thickness that will safely support the load using ASD without deflecting more than 3/8 in.

SOLUTION:

From Part VI, Beam Formulas Case 1, simply supported beam, concentrated load P at center

$M = PL/4 = (0.4)(36)/4 = 3.60$ in-k

Section F.1 gives a safety factor of 1.95 for the rupture limit state and 1.65 for all other limit states.

Since $S_t = S_c$ and $F_{cy} = F_{ty}$, the allowable yield moment M_{np}/Ω given in Section F.2 is the lesser of $1.5SF_{ty}/\Omega$ and ZF_{cy}/Ω; using $F_{ty} = 35$ ksi (see Table A.4.3), $\Omega = 1.65$, and setting the allowable yield moment equal to the required moment:

$ZF_{ty}/\Omega = Z(35 \text{ k/in}^2)/1.65 = 3.60$ in-k

gives $Z = 0.170$ in^3.

and

$1.5SF_{ty}/\Omega = 1.5S(35 \text{ k/in}^2)/1.65 = 3.60$ in-k

gives $S = 0.113$ in^3.

The allowable moment for the limit state of rupture given in Section F.2 is $M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$; using $F_{tu} = 42$ ksi and $k_t = 1.0$ (see Table A.4.3), $\Omega = 1.95$, and setting the allowable moment equal to the required moment:

$ZF_{tu}/k_t/\Omega = Z(42 \text{ k/in}^2)/1.0/1.95 = 3.60$ in-k

gives $Z = 0.167$ in^3.

For a rectangle, the section modulus $S = bt^2/6$. Setting the section modulus equal to the required section modulus, and using $b = 24$ in. gives

$24t^2/6 = 0.113$ in^3, for which $t_1 = 0.168$ in.

For a rectangle, the plastic modulus $Z = bt^2/4$. Setting the plastic modulus equal to the required plastic modulus, and

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using b = 24 in. gives

$24t^2/4 = 0.170$ in^3, for which $t_1 = 0.168$ in.

Deflection

From Part VI Beam Formulas Case 1

Deflection = $PL^3/(48EI)$

A correction is required for plates because individual fibers are restricted in the way they can change shape in the direction perpendicular to the stress. They can change in vertical dimension but not in horizontal dimension. An approximate correction is:

$$\text{Deflection} = \Delta = \frac{PL^3(1-\nu^2)}{48EI}$$

where v = Poisson's ratio, given in Table A.4.1 as 0.33.

From Part V Table 23 the moment of inertia for a rectangle is

$I = bt_2^3/12$

Section L.3 requires that bending deflections be determined using the modulus of elasticity from Table A.4.1, in which E = 10,100 ksi

Combining the equations for I and Δ,

$$t_2 = \sqrt[3]{\frac{PL^3(1-\nu^2)}{4bE\Delta}} = \sqrt[3]{\frac{(0.4)36^3(1-0.33^2)}{4(24)(10{,}100)(0.375)}} = 0.36 \text{ in.}$$

based on limiting deflection to 0.375 in..

Since $t_2 > t_1$ deflection controls; use 3/8 in. thick plate.

NOTES: The rails supporting the plate are assumed to have been checked structurally to see that they will safely support the load. They should be fastened to the plate at intervals to prevent spreading.

The loading and deflection limits in this example differ from those for Part VI Table 4-3.

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Example 7
RIVETED CONNECTION
Illustrating Section J.4

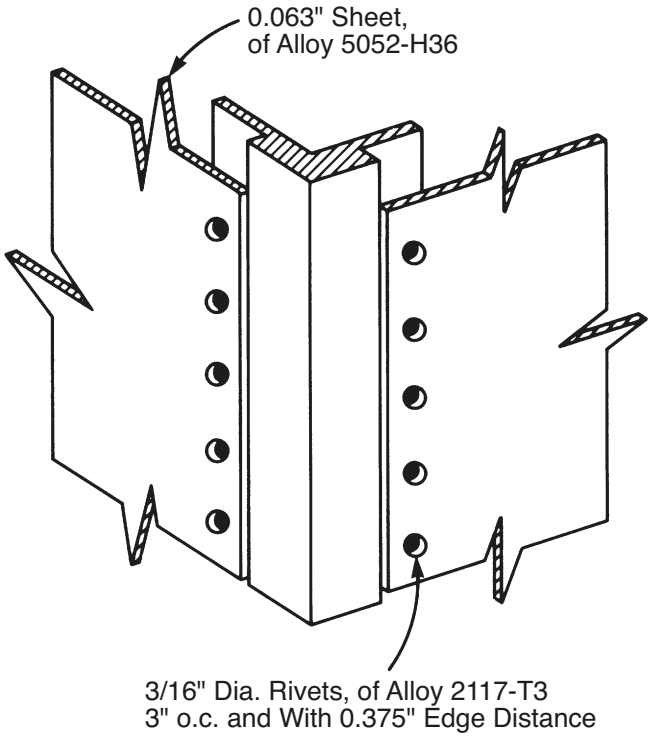

Figure 7

GIVEN:

1. Rivets: 3/16 in. diameter, cold-driven, 2117-T4 before driving, complying with ASTM B316, spaced 3 in. on centers, edge distance 0.375 in., in a 0.191 in. hole
2. Sheet: 0.063 in. thick, 5052-H36
3. Sheet product specification: ASTM B209
4. Corner post extrusion considerably thicker than the sheet and with equivalent unit bearing strength
5. Required ASD shear force: 0.090 k/in.

FIND:

Check the strength of the connection.

SOLUTION:

The rivet spacing meets the requirements of Section J.4.2 because it exceeds 3 times the rivet diameter (3(3/16) = 9/16 < 3).

The hole diameter meets the requirements of Section J.4.1 because it is no more than 4% greater than the rivet diameter (0.191/(3/16) = 1.02)

Table A.4.8 gives the shear ultimate strength of a 2117-T4 rivet as 26 ksi. Section J.4.5 gives the rivet's allowable shear strength as

$$R_n/\Omega = \pi D_h^2 F_{su}/(4\Omega)$$
$$= \pi\,(0.191\text{ in.})^2(26\text{ k/in}^2)/(4(2.34)) = 0.32\text{ k}$$

The allowable shear per inch is
(0.32 k)/(3 in.) = 0.11 k/in. > 0.09 k/in.

Table A.4.3 gives the tensile ultimate strength of 5052-H36 as 37 ksi. Section J.4.6 gives the rivet's allowable bearing as

$$R_n/\Omega = d_e\, t\, F_{tu}/\Omega = (0.375\text{ in.})(0.063\text{ in.})(37\text{ k/in}^2)/1.95$$
$$= 0.448\text{ k but shall not exceed}$$

$$2D_h\, t\, F_{tu}/\Omega = 2(0.191\text{ in.})(0.063\text{ in.})(37\text{ k/in}^2)/1.95$$
$$= 0.46\text{ k}$$

The allowable bearing per inch is
(0.448 k)/(3 in.) = 0.149 k/in. > 0.09 k/in.

Since both bearing and shear are satisfactory, the connection will adequately resist the shear load.

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Example 8
PINNED CONNECTION
Illustrating Section J.6.5

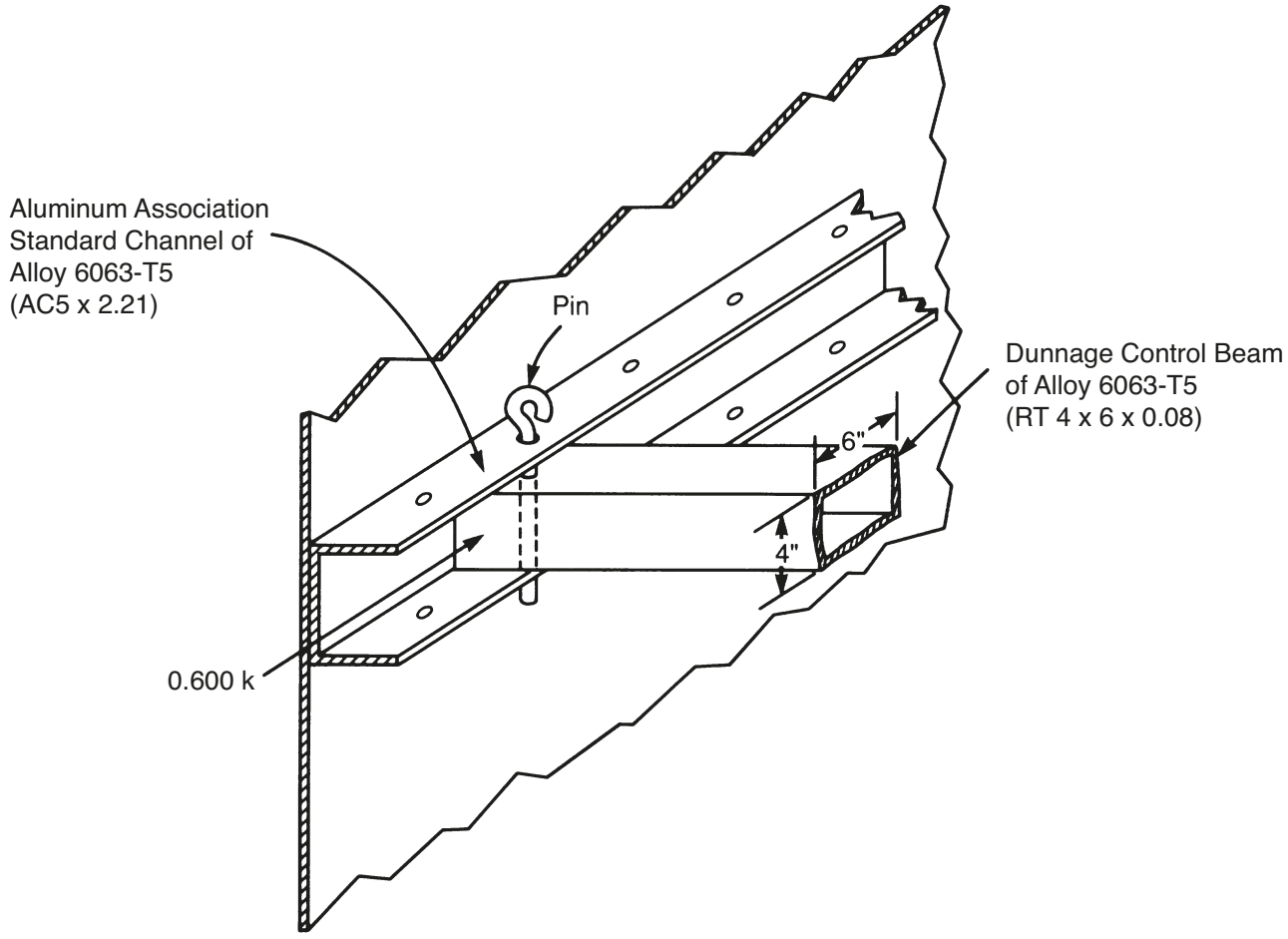

Figure 8

GIVEN:

1. Beam: Hollow rectangular tube 4 in. × 6 in. with wall thickness 0.080 in.
2. End supports: Aluminum Association standard channel AC 5 × 2.21
3. Beam and end support alloy-temper: 6063-T5
4. Beam and end support product specification: ASTM B221
5. Pin alloy-temper: 6061-T6
6. Pin product specification: ASTM B211
7. ASD Beam load: 1.20 k uniformly distributed

FIND:

The minimum pin size for the end connection.

SOLUTION:

From Part VI Table 2-20

Section J.6.5: pin bearing

$F/\Omega = 15$ ksi

From Part VI Beam Formulas Case 6

Simply supported beam, uniformly distributed load,

$R = W/2 = (1.2 \text{ k})/2 = 0.6$ k

$A = (0.6 \text{ k})/(15 \text{ k/in}^2) = 0.04 \text{ in}^2$, required bearing area

The bearing area on the pin is the diameter of the pin times the length in bearing.

$D = A/(2t) = (0.04)/(2(0.080)) = 0.25$ in. = diameter required, based on the bearing stress in the beam wall since the flange of the channel is thicker than the beam wall.

Determine the pin diameter based on bending of the pin.

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From Part V Table 4, the clearance between flanges of the 5 in. channel is:

$C = 5.00 - 2(0.26) = 4.48$ in.

Assuming the beam's bottom rests on the channel's bottom flange, the span for bending is the net clearance plus half the wall thicknesses of the adjacent bearing surfaces.

$L = (4.48 - 4.00) + 0.080/2 + 0.26/2 = 0.65$ in.

A conservative assumption to determine pin bending is that half of the connection load is transferred at the top of the beam.

$M = LR/2 = (0.65)(0.6/2) = 0.195$ in-k

Try a 7/16 in. diameter pin:

For 6061-T6 rod, $F_{sy} = 0.6F_{ty} = 0.6(35 \text{ ksi}) = 21$ ksi, and $F_{su} = 0.6F_{tu} = 0.6(42 \text{ ksi}) = 25.2$ ksi. Per Section J.6.4a), the allowable pin shear is the lesser of

$V_n/\Omega = \pi D^2 F_{sy}/4/\Omega_y = \pi(7/16 \text{ in.})^2(21 \text{ k/in}^2)/4/1.65 = 1.91$ k

$V_n/\Omega = \pi D^2 F_{su}/4/\Omega_u = \pi(7/16 \text{ in.})^2(25.2 \text{ k/in}^2)/4/2.34$
$= 1.62 \text{ k} > 0.3 \text{ k} = (0.6 \text{ k})/2 = V_r =$ required shear (the pin is in double shear)

For 6061-T6 rod, $F_{ty} = 35$ ksi, and $F_{tu} = 42$ ksi. Per Section J.6.4(b), the allowable pin moment is the lesser of

$M_n/\Omega = \pi D^3 F_{ty}/21.3/\Omega_y = \pi(7/16 \text{ in.})^3(35 \text{ k/in}^2)/21.3/1.65$
$= 0.262$ in-k

$M_n/\Omega = \pi D^3 F_{tu}/21.3/\Omega_u = \pi(7/16 \text{ in.})^3(42 \text{ k/in}^2)/21.3/1.0/2.34$
$= 0.222 \text{ in-k} > 0.195 \text{ in-k} = M_r =$ required moment.

Section J.6.4(c) addresses combined shear and flexure:

$$\left(\frac{V_r}{V_c}\right)^3 + \left(\frac{M_r}{M_c}\right) \le 1.0$$

$$\left(\frac{0.3}{1.62}\right)^3 + \left(\frac{0.195}{0.222}\right) = 0.88 \le 1.0$$

The 7/16 in. diameter is greater than the diameter based on bearing, therefore the required diameter is 7/16 in.

NOTES: For cases in which the bearing load on a pin is toward the edge of the member, the effect of edge distance on the allowable bearing should be considered as required in Section J.6.5.

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Example 9
W-SHAPE IN AXIAL COMPRESSION
Illustrating Sections E.1, E.2, E.3, and E.4

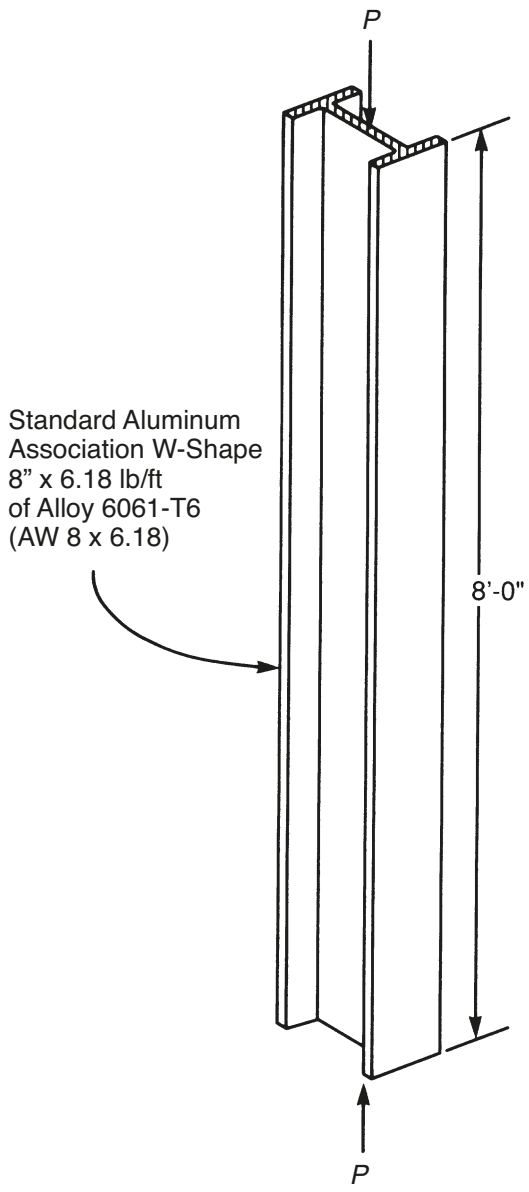

Figure 9

GIVEN:

1. Aluminum Association Standard W-shape AW 8 × 6.18
2. Length: 8 ft
3. End conditions: pinned
4. Laterally supported to resist buckling about the weak axis
5. Alloy-temper: 6061-T6
6. Product specification: ASTM B308

FIND:

The allowable axial compressive strength.

SOLUTION:

From Part V Table 7 the section properties of an AW 8 in. × 6.18 are:

A = 5.26 in^2, r_x = 3.37 in., d = 8.00 in., b_f = 5.00 in., t_f = 0.35 in., t_w = 0.23 in., I_x = 59.7 in^4, I_y = 7.3 in^4, C_w = 107 in^6, J = 0.188 in^4

Chapter E addresses members in compression. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.2. For flexural buckling, using k = 1.0 as required by Section C.3, Section E.2.1 gives the slenderness as

$$kL/r = = (1)(8)(12)/3.37 = 28.5$$

Section E.2.2a) addresses torsional buckling for doubly symmetric members. Assuming the ends are fixed against torsion so that k_z = 0.5:

$$F_e = \left(\frac{\pi^2 EC_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y}$$

$$= \left(\frac{\pi^2 (10{,}100)(107)}{[(0.5)(96)]^2} + (3800)(0.188)\right)\frac{1}{59.7 + 7.3} = 79.8 \text{ ksi}$$

$$\lambda = \pi\sqrt{\frac{E}{F_e}} = \pi\sqrt{\frac{10{,}100}{79.8}} = 35.3$$

The largest slenderness ratio is for torsional buckling with $\lambda = 35.3 < \lambda_2 = 66$, so

$$F_c/\Omega = 0.00047\lambda^2 - 0.232\lambda + 25.2$$

$$F_c/\Omega = 0.00047(35.3)^2 - 0.232(35.3) + 25.2 = 17.6 \text{ ksi}$$

The member buckling stress is F_c = (17.6)(1.65) = 29.0 ksi

The allowable axial compressive strength for member buckling is $P_n = (F_c/\Omega)A_g$ = (17.6)(5.26) = 92.6 k

b) Local buckling is addressed in Section E.3.

Local buckling of the flange (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

$$b/t = (5.00 - 0.23 - 2(0.30))/(2 \text{ x } 0.35) = 6.0$$

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The slenderness is less than $\lambda_1 = 6.7$, so

$F_c/\Omega = 21.2$ ksi

The area of the flanges =
$A_f = 2(5.00 - 0.23)(0.35) = 3.34$ in^2

Local buckling of the web (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

$b/t = (8.00 - 2(0.35) - 2(0.30))/0.23 = 29.1$

The slenderness is between $\lambda_1 = 20.8$ and $\lambda_2 = 33$, so

$F_c/\Omega = 27.3 - 0.291(29.1) = 18.8$ ksi

The area of the web =
$A_w = (8.00 - 2(0.35))(0.23) = 1.68$ in^2

The weighted average allowable local buckling strength is

$P_n/\Omega = (21.1)(3.34) + (18.1)(1.68) + (35/1.65)(2)[5.26 - 3.34 - 1.68] = 107.5$ k

c) The interaction between member buckling and local buckling is addressed in Section E.4. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the flange (a flat element with one edge supported) for the slenderness of 6.0 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0\,b/t)^2} = \frac{\pi^2 (10{,}100)}{(5.0(6.0))^2} = 110.8 \text{ ksi}$$

The elastic buckling stress of the web (a flat element with both edges supported) for the slenderness of 29.1 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6\,b/t)^2} = \frac{\pi^2 (10{,}100)}{(1.6(29.1))^2} = 46.0 \text{ ksi} > 29.0 \text{ ksi} =$$

member buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 92.6 k and 105.8 k, which is 92.6 k.

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Example 10
CORNER ANGLE OF A LATTICED BOX COLUMN
Illustrating Sections E.1, E.2, E.3, and E.4

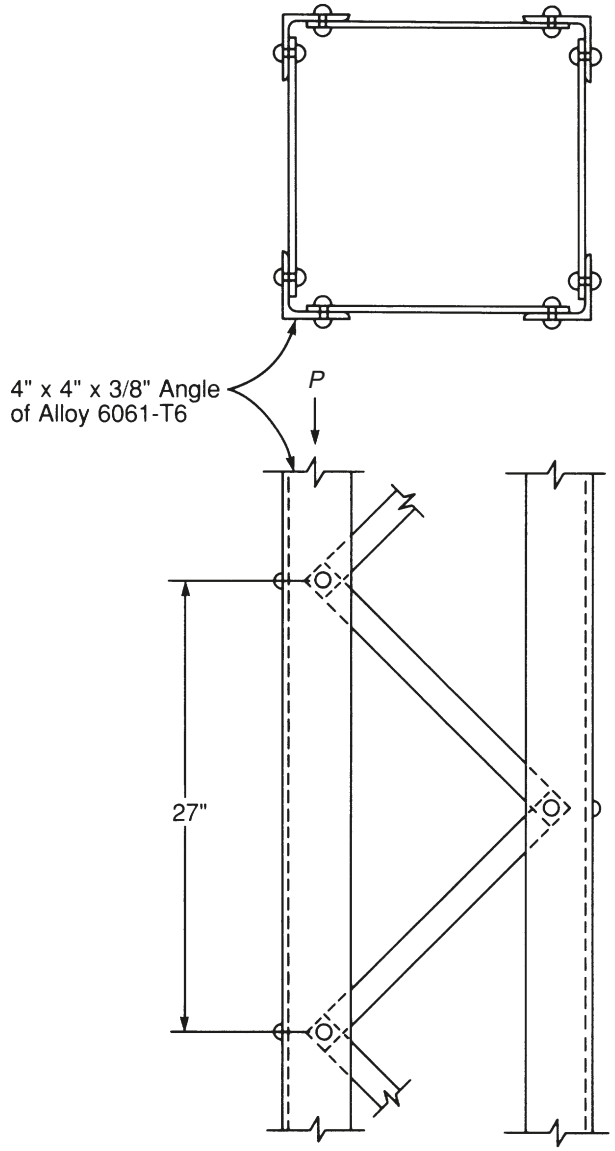

Figure 10

GIVEN:

1. Latticed box section column
2. Corner components: 4 in. × 4 in. × 3/8 in. angle
3. Alloy-temper: 6061-T6
4. Product specification: B221
5. Spacing of lattice points: 27 in. center to center
6. Lattice connection: riveted

FIND:

The allowable axial compressive strength of a corner angle between lattice points.

SOLUTION:

From Part V, Table 10, the section properties of the 4 in. × 4 in. × 3/8 in. angle are

$A = 2.86$ in.^{2}, $R_l = 0.375$ in., $r_x = r_y = 1.22$ in., $r_z = 0.766$ in., $I_x = I_y = 4.26$ in^4

The warping constant C_w is approximately 0 for an angle. The torsional constant is

$$J = (1/3)(0.375)^3(4 + 3.625) = 0.134 \text{ in}^4$$

x_o, y_o = coordinates of the shear center with respect to the centroid

$$x_o = y_o = 1.12 - 0.5(3/8) = 0.9325 \text{ in.}$$

Chapter E addresses columns. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.2. Section E.2.2 addresses flexural-torsional buckling for unsymmetric shapes such as an angle. The elastic buckling stress F_e is the lowest root of the equation

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0$$

where

$$r_o^2 = x_0^2 + y_0^2 + \frac{I_x + I_y}{A_g} = 2(0.9325)^2 + 2(4.26)/2.86 = 4.72 \text{ in}^2$$

$$F_{ex} = F_{ey} = \frac{\pi^2 E}{\left(\frac{k_x L_x}{r_x}\right)^2} = \pi^2(10{,}100)/(27/1.22)^2 = 203.5 \text{ ksi}$$

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) = \frac{(3800)(0.134)}{(2.86)(4.72)} = 37.7 \text{ ksi}$$

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Solving for F_e by trial and error, $F_e = 35.0$ ksi.

$$\lambda = \pi\sqrt{\frac{E}{F_e}} = \pi\sqrt{\frac{10{,}100}{35.0}} = 53.4 < \lambda_2 = 66, \text{ so}$$

$F_c/\Omega = 0.00047\lambda^2 - 0.232\lambda + 25.2$

$F_c/\Omega = 0.00047(53.4)^2 - 0.232(53.4) + 25.2 = 14.2$ ksi

The member buckling stress is $F_c = (14.2)(1.65) = 23.3$ ksi

The allowable axial compressive strength for member buckling is $P_n/\Omega = (F/\Omega)A_g = (14.2)(2.86) = 40.6$ k

b) Local buckling is addressed in Section E.3. Local buckling of the angle leg (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

$b/t = (4.00 - 0.375 - 0.375)/0.375 = 8.7$

The slenderness is between $\lambda_1 = 6.7$ and $\lambda_2 = 12$, so

$F_c/\Omega = 27.3 - 0.91(8.7) = 19.4$ ksi

The allowable axial compressive strength for local buckling is
$P_n/\Omega = (F/\Omega)A_g = (19.4)(2.86) = 55.5$ k

c) The interaction between member buckling and local buckling is addressed in Section E.4. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the leg (a flat element with one edge supported) for the slenderness of 8.7 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0\,b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(8.7))^2} = 52.7 \text{ ksi} > 23.3 \text{ ksi} = \text{member}$$

buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 40.5 k and 55.5 k, which is 40.5 k.

NOTES: The allowable axial compressive strength of the latticed column must also be determined for full length buckling resistance in accordance with Section E.2. The allowable strength is the lesser of this strength and four times the allowable strength of the corner angle computed above, whichever is smaller.

The lattice diagonals brace the corner angles and must have adequate stiffness and strength to meet the requirements of Appendix 6.

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Example 11
WELDED W-SHAPE IN AXIAL COMPRESSION
Illustrating Sections E.1, E.2, E.3, and E.4

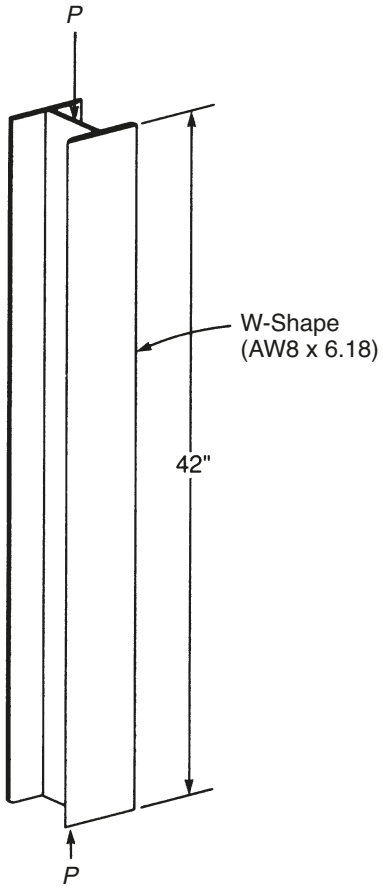

Figure 11

GIVEN:

1. Aluminum Association Standard W-shape AW 8 × 6.18
2. Length: 8 ft
3. End conditions: pinned
4. Laterally supported to resist buckling about the weak axis
5. Alloy-temper: 6061-T6
6. Product specification: ASTM B308
7. Transverse weld at midpoint affecting the full cross section

FIND:

Allowable axial compressive strength.

SOLUTION:

From Part V Table 7 the section properties of an AW 8 × 6.18 are:

A = 5.26 in^2, r_x = 3.37 in., d = 8.00 in., b_f = 5.00 in., t_f = 0.35 in. , t_w = 0.23 in., R = 0.30 in., I_x = 59.7 in^4, I_y = 7.3 in^4, C_w = 107 in^6, J = 0.188 in^4

Chapter E addresses members in compression. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes Ω_c = 1.65. Allowable stresses for 6061-T6 given in Part VI Table 2-19W are used below.

a) Member buckling is addressed in Section E.2. For members with transverse welds farther than 0.05 times the member length from the member ends, the member buckling strength is determined as if the member were fully weld-affected.

For flexural buckling, using k = 1.0 as required by Section C.3, Section E.2.1 gives the slenderness as

$$kL/r = (1)(8)(12)/3.37 = 28.5$$

Section E.2.2a) addresses torsional buckling for doubly symmetric members. Assuming the ends are fixed against torsion so that k_z = 0.5:

$$F_e = \left(\frac{\pi^2 EC_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y}$$

$$= \left(\frac{\pi^2(10{,}100)(107)}{[(0.5)(96)]^2} + (3800)(0.188)\right)\frac{1}{59.7+7.3} = 79.8 \text{ ksi}$$

$$\lambda = \pi\sqrt{\frac{E}{F_e}} = \pi\sqrt{\frac{10{,}100}{79.8}} = 35.3$$

The largest slenderness ratio is for flexural buckling with $\lambda = 35.3 < \lambda_2 = 133$, so

$$F_c/\Omega = 0.00007\lambda^2 - 0.066\lambda\lambda + 10.5$$

$$F_c/\Omega = 0.00007(35.3)^2 - 0.066(35.3) + 10.5 = 8.3 \text{ ksi}$$

The member buckling stress is
F_c = (8.3)(1.65) = 13.7 ksi

The allowable axial compressive strength for member buckling is $P_n/\Omega = (F/\Omega)A_g$ = (8.3)(5.26) = 43.7 k

b) Local buckling is addressed in Section E.3. At the transverse weld, all elements of the section are fully weld-affected.

Local buckling of the flange (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

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b/t = (5.00 – 0.23 – 2(0.30))/(2 x 0.35) = 6.0

The slenderness is less than λ_1 = 9.0, so

F_c /Ω = 9.1 ksi

The area of the flanges =
A_f = 2(5.00 – 0.23)(0.35) = 3.34 in^2

Local buckling of the web (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

b/t = (8.00 – 2(0.35) – 2(0.30))/0.23 = 29.1

The slenderness is between λ_1 = 28.2 and λ_2 = 58, so

F_c / Ω = 12.0 – 0.105(29.1) = 8.9 ksi

The area of the web =
A_w = (8.00 – 2(0.35))(0.23) = 1.68 in^2

The weighted average allowable local buckling strength is

P_n / Ω = (9.1)(3.34) + (8.9)(1.68) + (15/1.65)(5.26 – 3.3.4 – 1.68) = 47.5 k

c) The interaction between member buckling and local buckling is addressed in Section E.4. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the flange (a flat element with one edge supported) for the slenderness of 6.0 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0\, b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(6.0))^2} = 110.8 \text{ ksi}$$

The elastic buckling stress of the web (a flat element with both edges supported) for the slenderness of 29.1 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6\, b/t)^2} = \frac{\pi^2(10{,}100)}{(1.6(29.1))^2} = 46.0 \text{ ksi} > 13.7 \text{ ksi}$$

= member buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 43.7 k and 47.5 k, which is 43.7 k.

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Example 12
SQUARE TUBE COLUMN
Illustrating Sections E.1, E.2, E.3, and E.4

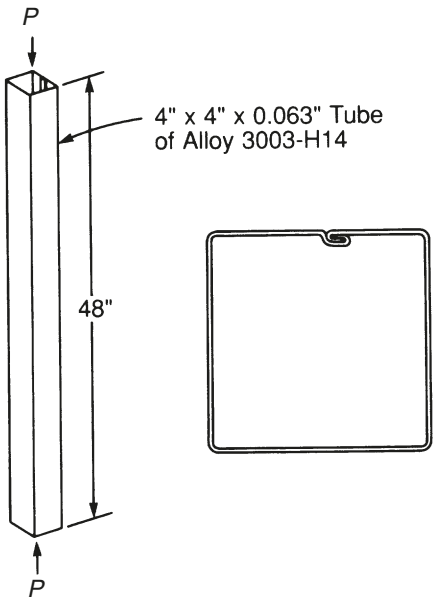

Figure 12

GIVEN:

1. 4 in. square tube column formed with lock-seam from 0.063 in. sheet
2. Length: 48 in.
3. End conditions: pinned
4. Alloy-temper: 3003-H14
5. Product specification: ASTM B209

FIND:

The allowable axial compressive strength.

SOLUTION:

From Part V, Table 23, hollow square section properties are

$A = 4^2 - (4.00 - (0.063)2)^2$

$= 0.992$ in^2

$$r = \sqrt{\frac{d_1^{\,2} + d_2^{\,2}}{12}} = \sqrt{\frac{4^2 + (4 - 0.063(2))^2}{12}} = 1.61 \text{ in.}$$

NOTE: This method assumes sharp corners, whereas the actual corners of roll formed sections are rounded. Where the corner radius is small in comparison with the width of the section, this method is sufficiently accurate for practical purposes.

Chapter E addresses members in compression. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$. Allowable stresses for 3003-H14 given in Part VI Table 2-2 are used below.

a) Member buckling is addressed in Section E.2. For flexural buckling, using $k = 1.0$ as required by Section C.3, Section E.2.1 gives the slenderness as

$kL/r = (1)(48)/1.61 = 29.8 < \lambda_2 = 132$, so

$F_c/\Omega = 0.00007\lambda^2 - 0.068\lambda + 10.7$
$F_c/\Omega = 0.00007(29.8)^2 - 0.068(29.8) + 10.7 = 8.7$ ksi

The member buckling stress is $F_c = (8.7)(1.65) = 14.4$ ksi

The allowable axial compressive strength for member buckling is $P_n/\Omega = (F/\Omega)A_g = (8.7)(0.992) = 8.6$ k

b) Local buckling is addressed in Section E.3.

Local buckling of a side (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

$b/t = (4.00 - 2(0.063))/0.063 = 61.5 > 57 = \lambda_2$, so

$F_c/\Omega = 350/(61.5) = 5.7$ ksi

The weighted average allowable local buckling strength is

$F_c A_g/\Omega = (5.7)(0.992) = 5.6$ k

c) The interaction between member buckling and local buckling is addressed in Section E.4. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of a side (a flat element with both edges supported) for the slenderness of 61.5 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6b/t)^2} = \frac{\pi^2(10{,}100)}{(1.6(61.5))^2} = 10.3 \text{ ksi} < 14.4 \text{ ksi} =$$

member buckling stress; therefore, the allowable strength cannot exceed:

$$P_n/\Omega = \left(\frac{0.85\pi^2 E}{(kL/r)^2}\right)^{1/3} \frac{F_e^{\,2/3} A_g}{\Omega}$$

$$= \left(\frac{0.85\pi^2(10{,}100)}{(29.8)^2}\right)^{1/3} \frac{10.3^{2/3}(0.992)}{1.65} = 13.0 \text{ k}$$

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The allowable axial compressive strength is the least of 8.7 k, 5.6 k, and 13.0 k, which is 5.6 k.

NOTES: The area of the lock seam is generally small and can be neglected. However, the seam must resist longitudinal slippage, otherwise the shape would be classed as an open section and would be subject to flexural torsional buckling. From Part VI, Table 3-1, 0.063 in. thick 3003-H14 is satisfactory for a zero bend radius.

If the corner radii are large, they should be checked using Section B.5.4.5.

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Example 13
COLUMN WITH INTERMEDIATE STIFFENERS
Illustrating Section B.5.4.4

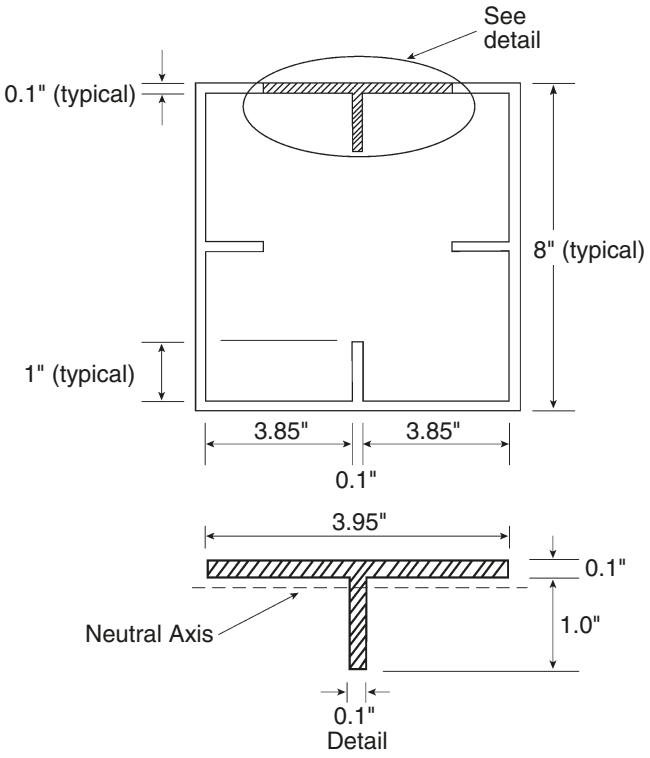

Figure 13

GIVEN:

1. An 8 in. square tube column, with 0.10 in. thick walls and 0.10 in. thick by 1 in. long stiffeners at the middle of each side.
2. Alloy: 6061-T6 extrusion.
3. Product specification: ASTM B221

FIND:

The allowable local buckling compressive stress.

SOLUTION:

Section B.5.4.4 addresses uniform compression of flat elements supported on both edges and with an intermediate stiffener.

The moment of inertia I_o used in Section B.5.4.4 is of the area shown in the detail of Figure 13.

The area width is 3.85 + 0.1 = 3.95 in.

The element width b = 3.85 in.

The element thickness t = 0.1 in.

Properties A_s and I_o are calculated from Part V, Table 23:

$I_n = b_n\, d_n^3/12$, where b_n is the width and d_n is the height

A_n = area of an element

Y_n = vertical distance from bottom fiber to the centroid of the element

n	b_n	d_n	A_n	Y_n	AY_n	AY_n^2	I_n
1	3.95	0.1	0.395	1.05	0.4147	0.4355	0.0003
2	0.1	1.0	0.1	0.5	0.05	0.025	0.0083
	Totals		0.495		0.4647	0.4605	0.0086

$$c = \frac{\Sigma A_n Y_n}{\Sigma A_n} = \frac{0.4647}{0.495} = 0.9389 \text{ in.}$$

$$I_o = \Sigma(A_n Y_n^2) - c^2 \Sigma A_n + \Sigma I_n$$

$$I_o = 0.4605 - (0.9389)^2\,(0.495) + (0.0086) = 0.03275$$

$$\lambda_s = (4.62)\frac{3.85}{0.1}\sqrt{\frac{1+\dfrac{(1.0)(0.1)}{(3.85)(0.1)}}{1+\sqrt{1+\dfrac{10.67(0.03275)}{3.85(0.1)^3}}}}$$

$\lambda_s = 61.4 < 66 = \lambda_2$

$F_1/\Omega = 23.9 - 0.149\,(61.4) = 14.8$ ksi

Check the flat elements on either side of the stiffener:

$$b/t = \frac{3.85}{0.1} = 38.5 > 33 = \lambda_2$$

from Section B.5.4.2

$F_2/\Omega = 580/38.5 = 15.1$ ksi > 14.8 ksi $= F_1$

So $F_c / \Omega = F_1/\Omega = 14.8$ ksi

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Example 14
ROUND TUBE COLUMN
Illustrating Sections E.1, E.2, and E.3

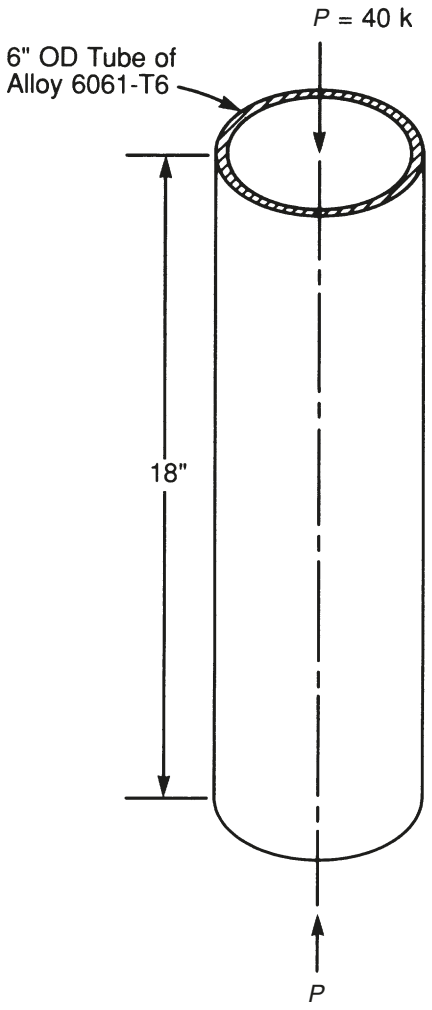

Figure 14

GIVEN:

1. Shape: Round tube, 6 in. OD (outside diameter)
2. Required ASD axial compression force: 40 k, concentric
3. Length: 18 in.
4. Alloy-temper: 6061-T6
5. Product specification: ASTM B429
6. End condition: pinned

FIND:

The wall thickness of a standard tube that has an allowable axial compressive strength of at least 40 k.

SOLUTION:

From Part V, Table 16, round tubes, the radius of gyration r of 6 in. OD tubes ranges from 1.80 in. to 2.08 in.. Select from the table the trial wall thickness of 0.188 in. for which $A = 3.43$ in^2 and $r = 2.06$ in.

Chapter E addresses members in compression. Section E.1 establishes $\Omega_c = 1.65$. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.2. For flexural buckling, Section E.2.1 gives the slenderness as

$kL/r = (1)(18)/2.06 = 8.7 < \lambda_1 = 17.8$, so

$F_c / \Omega = 21.2$ ksi

The allowable axial compressive strength for member buckling is $(F/\Omega)\, A_g = (21.2)(3.43) = 72.7 \text{ k} > 40 \text{ k}$

b) Local buckling is addressed in Section E.3.

Local buckling of round tubes is addressed in Section B.5.4.5. The slenderness is

$$\sqrt{\frac{R_b}{t}} = \sqrt{\frac{(6.0 - 0.188)}{(2)(0.188)}} = 3.93 < 5.3 = \lambda_1, \text{ so}$$

$F_c / \Omega = 21.2$ ksi

The weighted average allowable local buckling strength is

$A_g F_c / \Omega = (21.2)(3.43) = 72.7 \text{ k} > 40 \text{ k}$

The wall thickness $t = 0.188$ in. is satisfactory.

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Example 15
W-SHAPE IN FLEXURE
Illustrating Sections F.2, F.3, F.4, and G.2

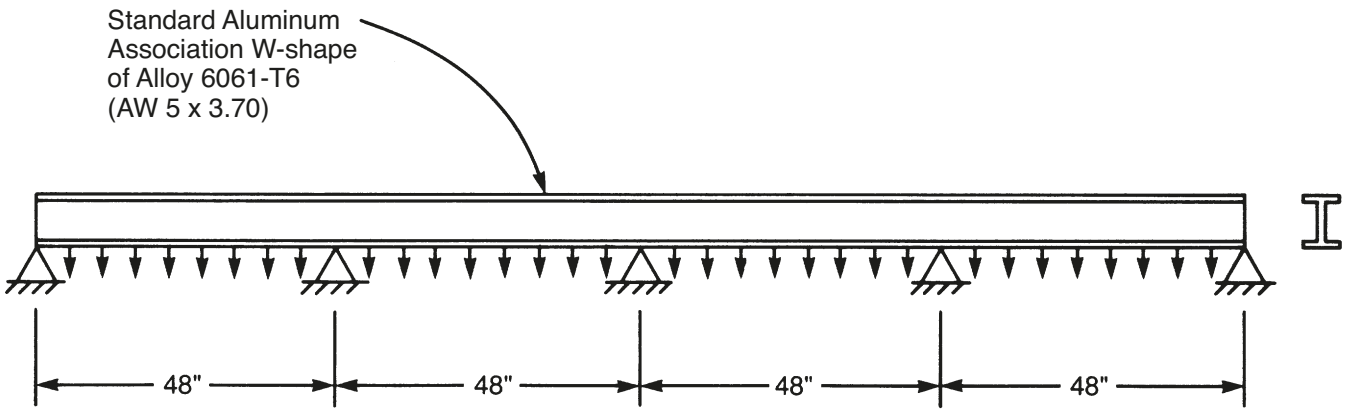

Figure 15

GIVEN:

1. Section: Aluminum Association Standard W-shape AW 5 × 3.70
2. Beam length: 16 ft. with lateral supports at vertical supports only
3. Vertical support spacing 4 ft. o.c. (first support at end of beam)
4. Alloy-temper: 6061-T6
5. Product specification: ASTM B308

FIND:

The allowable uniform load that can be applied to the bottom flange.

SOLUTION:

Part V, Table 7, gives the section properties:

$S_x = 5.58$ in^3, $b = 3.5$ in., $t_w = 0.19$ in., $t_f = 0.32$ in., $r_y = 0.853$ in., $I_y = 2.29$ in^4, $J = 0.0984$ in^4, $C_w = 12.5$ in^6, $Z = 6.31$ in^3, $I_x = 13.9$ in^4

The flange's slenderness ratio is
$b/t = (3.5 – 0.19 – 2(0.30))/2/0.32 = 4.2$

The web's slenderness ratio is
$b/t = (5.0 – 2(0.32 + 0.30))/0.19 = 19.8$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Section G.2 addresses the shear strength of flat webs. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Section F.2 addresses yielding. The allowable moment for the yield limit state is the lesser of

$M_{np}/\Omega = ZF_{cy}/\Omega$
$= (6.31 \text{ in}^3)(35 \text{ k/in}^2)/1.65 = 133.8$ in-k

$M_{np}/\Omega = 1.5S_xF_{ty}/\Omega$
$= 1.5(5.58 \text{ in}^3)(35 \text{ k/in}^2)/1.65 = 177.5$ in-k

which is 133.8 in-k, so $M_{np} = (133.8 \text{ in-k})(1.65) = 220.8$ in-k

b) Section F. 2 addresses rupture. The allowable moment for the rupture limit state is:

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$
$= (6.31 \text{ in}^3)(38 \text{ k/in}^2)/1.0/1.95 = 123.0$ in-k

c) Section F.3 addresses local buckling

Section B.5.4.1 addresses the flange; $b/t = 4.2 < 6.7 = \lambda_1$, so $F_c/\Omega = 21.2$ ksi

Section B.5.5.1 addresses the web; $b/t = 19.8 < 33.1 = \lambda_1$, so $F_b/\Omega = 31.8$ ksi

Using the weighted average method given in Section F.3.1,

$M_{nlb} = F_c I_f/c_{cf} + F_b I_w/c_{cw}$

The moment of inertia of the web is
$I_w = t_w(d – 2t_f)^3/12 = 0.19(5 – 2(0.320))^3/12 = 1.31$ in^4.

The moment of inertia of the flanges is
$I_f = I_x – I_w = 13.9 – 1.31 = 12.6$ in^4.

$M_{nlb}/\Omega = (21.2)(12.6)/(5/2 – 0.32/2) + 31.8(1.31)/(5/2 – 0.32) = 133.3$ in-k

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d) Section F.4 addresses lateral-torsional buckling. Section F.4.2.1 gives the slenderness ratio as $\frac{L_b}{r_{ye}\sqrt{C_b}}$, where r_{ye} may be taken as $1.2r_y$. Section F.4.1.1 allows the bending coefficient C_b to be conservatively taken as 1.

$$\frac{L_b}{1.2r_y} = \frac{48}{1.2(0.853)} = 46.9 < \lambda_2 = C_c = 66, \text{ so}$$

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 220.8\left(1 - \frac{46.9}{66}\right) + \frac{\pi^2(10{,}100)(46.9)(5.58)}{66^3}$$

$$= 154.6 \text{ in-k}$$

$M_{nmb}/\Omega = 154.6/1.65 = 93.7$ in-k

The lateral-torsional buckling stress
$F_b = M_{nmb}/S_x = (154.6 \text{ in-k})/(5.58 \text{ in}^3) = 27.7$ ksi

e) Section F.4.3 addresses interaction between local buckling and lateral-torsional buckling.

The flange's elastic buckling stress given in Section B.5.6 is

$$F_e = \frac{\pi^2 E}{(5.0\, b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(4.2))^2} = 226 \text{ ksi} > 27.7 \text{ ksi}$$

Because the flange's elastic buckling stress is not less than the beam's lateral-torsional buckling stress, the beam's flexural capacity is not limited by the interaction between local buckling and lateral-torsional buckling.

The least of these allowable moments is for lateral-torsional buckling; therefore, $M_n/\Omega = 93.7$ in-k.

From Part VI Beam Formulas Case 43, continuous beam of four equal spans with a uniformly distributed load, the maximum moment is

$$M = \frac{-168wL^2}{1568}$$

Rewriting to solve for w,

$$w = \frac{1568M}{168L^2} = \frac{1568(93.7)}{168(48)^2} = 0.380 \text{ k/in.}$$

= allowable distributed load for flexure

The section is symmetric about its X axis; therefore, the allowable positive moment is equal to the allowable negative moment. Thus, the minus sign for w may be removed.

f) Section G.2 addresses the limit state of web shear yielding or buckling, where b is the clear height between flanges:

$b/t = (5.0 - 2(0.32))/0.19 = 22.9 < \lambda_1 = 35.3$, so $F_s/\Omega = F_{sy}/\Omega = 12.7$ ksi

For the limit state of shear rupture, $F_s/\Omega = F_{su}/\Omega = 11.7$ ksi

$A = dt_w = (5.00)(0.19) = 0.95$ in^2 = area of web
$V = AF_s/\Omega = 0.95(11.7) = 11.1$ k, allowable shear

From Part VI Beam Formulas Case 43, the maximum shear is

$$V = \frac{17wL}{28}, \text{ which can be written}$$

$$w = \frac{28V}{17L}$$

$$w = \frac{28(11.1)}{17(48)} = 0.381 \text{ k/in.} = \text{allowable distributed load for shear}$$

Using the smaller of the loads for flexure and shear, the allowable uniform load is 0.380 k/in.

NOTES: Example 3 notes also apply to this example.

A more accurate flexural strength can be determined by using Section F.4.2 to compute r_{ye}. For shapes symmetric about the bending axis and where the load acts downward on the bottom flange (away from the beam's shear center), Section F.4.2.1b) gives:

$$r_{ye} = \sqrt{\frac{I_y}{S_x}\left[\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{C_w}{I_y} + \frac{0.038JL_b^2}{I_y}}\right]}$$

$$= \sqrt{\frac{2.29}{5.58}\left[\frac{5}{4} + \sqrt{\frac{5^2}{16} + \frac{12.5}{2.29} + \frac{0.038(0.0984)(48)^2}{2.29}}\right]}$$

$$= 1.36 \text{ in.}$$

r_{ye} may be used in place of $1.2r_y = 1.024$ in. to compute the lateral-torsional buckling strength.

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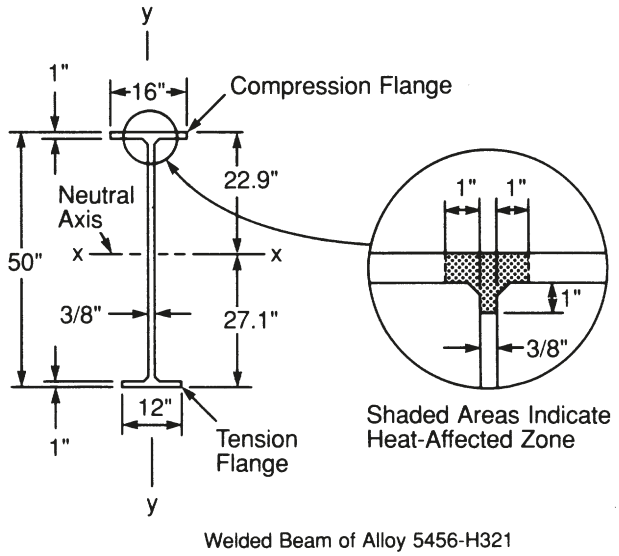
Example 16
WELDED GIRDER IN FLEXURE
Illustrating Sections F.2, F.3, and F.4



Welded Beam of Alloy 5456-H321

Figure 16

GIVEN:

1. Welded girder; see Figure 16
2. Lateral support spacing: compression flange, 10 ft o.c.
3. Alloy-temper: 5456-H321
4. Product specification: ASTM B928
5. Load applied downward on the compression flange

FIND:

The allowable moment with the top flange in compression.

SOLUTION:

To compute section properties, see Part V, Table 23.

The moment of inertia of a rectangle about its centroid is

$I_n = b_n d_n^{\,3}/12$

where b_n is the width and d_n, is the height.

A_n = area of an element

Y_n = vertical distance from bottom fiber to centroid of element

n	b_n	d_n	A_n	Y_n	AY_n	AY_n^2	I_n
1	16.0	1.00	16.0	49.5	792	39204	1
2	0.375	48.0	18.0	25.0	450	11250	3456
3	12.0	1.00	12.0	0.5	6	3	1
	Totals		46.0		1248	50457	3458

The height of the centroid of the section

$$c_t = \frac{\Sigma A_n Y_n}{\Sigma A_n} = \frac{1248}{46.0} = 27.13 \text{ in.}$$

$$I_x = \sum(A_n Y^2{}_n) - c_t^2 \sum A_n + \sum I_n = 20{,}057 \text{ in}^4$$

For the compression flange,

$c_c = 50.0 - 27.13 = 22.87$ in.

The section modulus for compression is

$S_c = I_x/c_c = 20{,}057/22.87 = 877 \text{ in}^3$

The section modulus for tension is

$S_t = I_x/c_t = 20{,}057/27.13 = 739 \text{ in}^3$

$I_y = [(1)(16)^3 + (1)(12)^3 + (48)(0.375)^3]/12 = 485.5 \text{ in}^4$

$I_{yc} = (1)(16)^3/12 = 341.3 \text{ in}^4$

$I_{yt} = (1)(12)^3/12 = 144.0 \text{ in}^4$

$\alpha = 1/(I_{yc}/I_{yt} + 1)$

$\alpha = 1/(341.3/144 + 1) = 0.297$

$J = [(16)(1)^3 + (12)(1)^3 + (48)(0.375)^3]/3 = 10.2 \text{ in}^4$

$C_w = d_f^2 I_{yc} \alpha = (49)^2(341.3)\,(0.297) = 243{,}400 \text{ in}^6$

The distance from the centroid to the shear center is y_o

$y_o = -(c_c - t_{tf}/2) + \alpha d_f = -(22.9 - \tfrac{1}{2}) + 0.297(49) = -7.85$ in. (above the centroid)

$$\beta_x = 0.9 d_f \left(\frac{2I_{yc}}{I_y} - 1\right)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right]$$

$$= 0.9(49)\,(2(341.3/485.5) - 1)(1 - (485.5/20{,}057)^2)$$

$$= 17.9 \text{ in.}$$

For the portion of the cross section outside the weld-affected zone, Table A.4.3 gives mechanical properties for 5456-H321 plate. The web is 3/8 in. thick plate (with $F_{tu} = 46$ ksi) and the flange is 1 in. thick plate (with $F_{tu} = 44$ ksi). For design, conservatively use the mechanical properties of the flange throughout the section:

$E = 10{,}100$ ksi , $F_{tu} = 44$ ksi,
$F_{ty} = 31$ ksi, $F_{cy} = 0.9(31) = 27.9$ ksi

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From Part VI, Table 1-1, the buckling constants for the unwelded material are

$B_c = 32.6$	$B_p = 39.0$	$B_{br} = 52.0$
$D_c = 0.226$	$D_p = 0.297$	$D_{br} = 0.457$
$C_c = 95.9$	$C_p = 87.6$	$C_{br} = 75.8$

From Table B.4.3, $k_1 = 0.50$, $k_2 = 2.04$

For the portion of the cross section in the weld-affected zone, Table A.4.3 gives mechanical properties for 5456-H321 plate:

$E = 10{,}100$ ksi , $F_{tu} = 42$ ksi , $F_{ty} = 19$ ksi, $F_{cy} = 19$ ksi

From Part VI, Table 1-2, the buckling constants for the weld affected material are

$B_c = 21.6$	$B_p = 25.7$	$B_{br} = 34.1$
$D_c = 0.123$	$D_p = 0.158$	$D_{br} = 0.243$
$C_c = 117.7$	$C_p = 108$	$C_{br} = 93.6$

From Table B.4.3, $k_1 = 0.50$, $k_2 = 2.04$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure.

a) Section F.2 addresses the yield and rupture limit states. The plastic neutral axis is located by equating the compressive yield force on the compression side of the plastic neutral axis and the tensile yield force on the tensile side of the plastic neutral axis. Conservatively use the compressive yield stress F_{cy} for both the compressive and tensile yield stresses.

Designating the distance from the bottom of the section to the plastic neutral axis as y, the compressive yield force (kips) is the sum of:

compressive yield force in unwelded part of flange

$27.9(16 – 2.375)(1) = 380.1$

compressive yield force in welded part of flange

$19(2.375)(1) = 45.1$

compressive yield force in welded part of web

$19(0.375)(1) = 7.1$

compressive yield force in unwelded part of web

$27.9(50 – 2 – y)(0.375) = 502.2 – 10.46y$

The sum of the above is $934.5 – 10.46y$.

The tensile yield force (kips) is the sum of:

tensile yield force in unwelded part of flange

$27.9(12 – 2.375)(1) = 268.5$

tensile yield force in welded part of flange

$19(2.375)(1) = 45.1$

tensile yield force in welded part of web

$19(0.375)(1) = 7.1$

tensile yield force in unwelded part of web

$27.9(y – 2)(0.375) = –20.9 + 10.46y$

The sum is $299.8 + 10.46y$.

Setting the compressive yield force equal to the tensile yield force,

$934.5 – 10.46y = 299.8 + 10.46y$,
$y = 634.7/20.92 = 30.33$”

The yield strength moment M_{np} is determined by summing the moments in each zone about the plastic neutral axis as tabulated below.

flange F or web W	C or T	welded W or unwelded U	F_y k/in^2	w in.	t in.	$A = wt$ in^2	$F_y A$ k	ybar in.	ybar - y in.	$F_y A$(ybar - y) in-k
F	C	U	27.9	13.625	1	13.63	380.1	49.5	19.16	7283
F	C	W	19	2.375	1	2.38	45.1	49.5	19.16	865
W	C	W	19	1	0.375	0.38	7.1	48.5	18.16	129
W	C	U	27.9	17.66	0.375	6.62	184.8	39.17	8.83	1631
							617.2			
F	T	U	27.9	9.625	1	9.63	268.5	0.5	29.84	8013
F	T	W	19	2.375	1	2.38	45.1	0.5	29.84	1347
W	T	W	19	1	0.375	0.38	7.1	1.5	28.84	205
W	T	U	27.9	28.34	0.375	10.63	296.5	16.17	14.17	4202
							617.3			

$M_{nu} = 23{,}676$

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The allowable moment for the yield limit state is $M_{np}/\Omega = 23{,}676/1.65 = 14{,}350$ in-k.

Since the weld affected area on the compression side of the plastic axis is the same as on the tension side of the neutral axis, the location of the plastic neutral axis is the same if no part of the beam were weld-affected, all of the beam were weld-affected, or part of the beam is weld affected. Thus the plastic section modulus can be calculated as

$$Z = (16")(1")(49.5" - 30.33") + (0.375")(49" - 30.33")^2/2 + (12")(1")(30.33" - 0.5") + (0.375")(30.33" - 1")^2/2$$

$$Z = 891 \text{ in}^3$$

The yield limit state moment if no part of the section were weld-affected is

$$M_{npo} = ZF_{cy} = (891 \text{ in}^3)(27.9 \text{ k/in}^2) = 24{,}870 \text{ in-k};$$

$$M_{npo}/\Omega = 24{,}870/1.65 = 15{,}070 \text{ in-k}$$

The yield limit state moment if all of the section were weld-affected is

$$M_{npw} = ZF_{cyw} = (891 \text{ in}^3)(19 \text{ k/in}^2) = 16{,}930 \text{ in-k};$$

$$M_{npw}/\Omega = 16{,}930/1.65 = 10{,}260 \text{ in-k}$$

The rupture limit state moment is determined using the welded tensile strength of 42 ksi:

$$M_{nuw} = ZF_{tu} = (891 \text{ in}^3)(42 \text{ k/in}^2) = 37{,}420 \text{ in-k};$$

$$M_{nuw}/\Omega = 37{,}420/1.95 = 19{,}190 \text{ in-k}$$

b) Section F.3 addresses local buckling.

Section B.5.4.1 addresses the flange. The slenderness ratio of the compression flange is

$$b/t = (16 - 3/8)/2/1 = 7.8$$

For the unwelded portion of the flange

$$\lambda_1 = (B_p - F_{cy})/(5.0D_p) = (39.0 - 27.9)/(5.0(0.297)) = 7.5$$

$$\lambda_2 = \frac{k_1 B_p}{5.0 D_p} = \frac{0.50(39.0)}{5.0(0.297)} = 13.1$$

$\lambda_1 = 7.5 < b/t = 7.8 < 13.1 = \lambda_1$, so
$F_{co} = B_p - 5.0D_p \; b/t = 39.0 - 5.0(0.297)(7.8) = 27.4$ ksi

$$F_{co}/\Omega = (27.4 \text{ ksi})/1.65 = 16.6 \text{ ksi}$$

For the welded portion of the flange

$$\lambda_1 = (B_p - F_{cy})/(5.0D_p) = (25.7 - 19)/(5.0(0.158)) = 8.5$$

$b/t = 7.8 < 8.5 = \lambda_1$, so
$F_{cw}/\Omega = F_{cyw}/\Omega = (19 \text{ ksi})/1.65 = 11.5$ ksi

Section B.5.4 provides the strength of the compression flange as

$$F_{cf} = F_{co}(1 - A_{wz}/A_g) + F_{cw} A_{wz}/A_g$$

The gross area of the compression flange is

$$A_g = 16(1) = 16 \text{ in}^2$$

The weld-affected area of the compression flange is

$$A_{wz} = 2.375 \text{ in}^2$$

$$F_{cf}/\Omega = [F_{co}(1 - A_{wz}/A_g) + F_{cw} A_{wz}/A_g]/\Omega$$

$$F_{cf}/\Omega = [16.6(1 - 2.375/16) + 11.5(2.375)/16] = 15.8 \text{ ksi}$$

Section B.5.5.1 addresses the web.

The slenderness ratio of the web is

$$b/t = (50 - 2)/0.375 = 128$$

$$c_c = -22.9 + 1 = -21.9$$

$$c_o = 27.1 - 1 = 26.1$$

$$c_o/c_c = 26.9/-21.9 = -1.19$$

$$m = 1.3/(1 - c_o/c_c) = 1.3/(1 - (-1.19)) = 0.592$$

For the unwelded portion of the web

$$\lambda_2 = \frac{k_1 B_{br}}{m D_{br}} = \frac{0.5(52.0)}{(0.59)(0.457)} = 96$$

$b/t = 128 > 96 = \lambda_2$, so

$$F_{bo} = \frac{k_2\sqrt{B_{br}E}}{mb/t} = \frac{2.04\sqrt{(52.0)(10{,}100)}}{(0.592)(128)} = 19.5 \text{ ksi}$$

$$F_{bo}/\Omega = 19.5/1.65 = 11.8 \text{ ksi}$$

For the welded portion of the web

$$\lambda_2 = \frac{k_1 B_{br}}{m D_{br}} = \frac{0.5(34.1)}{(0.592)(0.243)} = 118.5$$

$b/t = 128 > 121 = \lambda_2$, so

$$F_{bw} = \frac{k_2\sqrt{B_{br}E}}{mb/t} = \frac{2.04\sqrt{(34.1)(10{,}100)}}{(0.592)(128)} = 15.8 \text{ ksi}$$

$$F_{bw}/\Omega = 15.8/1.65 = 9.6 \text{ ksi}$$

Section B.5.5 provides the strength of the web in compression as

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}$$

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The gross area of the web in compression is

$A_g = 0.375(22.9 - 1) = 8.21$ in^2

The weld-affected area of the web in compression is

$A_{wz} = (1)(0.375) = 0.375$ in^2

$F_b/\Omega = [F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}]/\Omega$

$F_b/\Omega = [11.8(1 - 0.375/8.21) + 9.6(0.375)/8.21]$
$= 11.7$ ksi

Section F.3.1 provides the weighted average strength of the elements.

The moment of inertia of the flanges is

$I_f = (12)(1)^3/12 + (16)(1)^3/12 + (16)(1)(22.9 - 0.5)^2$
$+ (12)(1)(27.1 - 0.5)^2 = 16{,}521$ in^4

The moment of inertia of the web is

$I_w = (0.375)(48)^3/12 + (0.375)(48)(27.1 - 25)^2 = 3535$ in^4

$M_{nlb} = F_{cf} I_f/c_{cf} + F_{cw} I_w/c_{cw}$

$M_{nc}/\Omega = (15.8)(16{,}521)/(22.9 - 0.5) +$
$(11.7)(3535)/(22.9 - 1) = 13{,}540$ in-k

c) Section F.4 addresses lateral-torsional buckling. Section F.4.1.1 allows the bending coefficient C_b to be conservatively taken as 1.

Since the compression flange is larger than the tension flange, Section F.4.2.2 does not apply. Section F.4.2.5 applies to any beam, so using it:

$$M_e = \frac{\pi^2 E I_y}{L_b^2}\left[U + \sqrt{U^2 + \frac{0.038 J L_b^2}{I_y} + \frac{C_w}{I_y}}\right]$$

$U = C_1 g_0 + C_2 \beta_x/2$. Section F.4.2.5 permits C_1 and C_2 to be taken as 0.5, so

$U = 0.5(-22.9 + 7.85) + 0.5(17.9)/2 = -3.05$ in.

$$M_e = \frac{(1)\pi^2(10{,}100)(485.5)}{(120)^2} \times \left[-3.05 + \sqrt{(-3.05)^2 + \frac{0.038(10.2)(120)^2}{485.5} + \frac{243{,}400}{485.5}}\right.$$

$= 66{,}470$ in-k

$$\lambda = \pi\sqrt{\frac{ES_{xc}}{M_e}} = \pi\sqrt{\frac{(10100)(879)}{66{,}470}} = 36.3$$

For a beam with no portion weld-affected:

$\lambda = 36.3 < 95.9 = C_c$, so

$$M_{nmob} = M_{npo}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 24{,}870\left(1 - \frac{36.3}{95.9}\right) + \frac{\pi^2(10{,}100)(36.3)(877)}{95.9^3}$$

$= 19{,}050$ in-k

$F_b = M_{nmbo}/S_x = (19{,}050 \text{ in-k})/(877 \text{ in}^3) = 21.7$ k/in^2

For a beam entirely weld-affected:

$\lambda = 36.3 < 117.7 = C_c$, so

$$M_{nmwb} = M_{npw}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 16{,}930\left(1 - \frac{36.3}{117.7}\right) + \frac{\pi^2(10{,}100)(36.3)(879)}{117.7^3}$$

$= 13{,}650$ in-k

$F_b = M_{nmbw}/S_x = (13{,}650 \text{ in-k})/(877 \text{ in}^3) = 15.6$ k/in^2

Section F.4 provides the lateral-torsional buckling strength of longitudinally welded beams as

$M_n = M_{no}(1 - A_{wz}/A_f) + M_{nw}(A_{wz}/A_f)$

where

$A_{wz} = (1 + 0.375 + 1)(1) + (1)(0.375) = 2.75$ in^2

$A_f = (16)(1) + (22.9/3 - 1)(0.375) = 18.5$ in^2

$M_{nmb} = 19{,}050(1 - 2.75/18.5) + 13{,}650(2.75/18.5)$
$= 18{,}250$ in-k

$M_{nmb}/\Omega = 18{,}250/1.65 = 11{,}060$ in-k

The lateral-torsional buckling stress $F_b = M_{nmb}/S_c$

$F_b = (18{,}250 \text{ in-k})/877 \text{ in}^3 = 20.8$ k/in^2

d) Section F.4.3 addresses interaction between local |buckling and lateral-torsional buckling.

The flange's slenderness ratio is

$b/t = (16 - 0.375)/2/1 = 7.8$

The flange's elastic buckling stress given in Section B.5.6 is

$$F_e = \frac{\pi^2 E}{(5.0\, b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(7.8))^2} = 65.5 \text{ ksi} > 20.8 \text{ ksi}$$

Because the flange's elastic buckling stress is not less than the beam's lateral-torsional buckling stress, the beam's flexural capacity is not limited by the interaction between local buckling and lateral-torsional buckling.

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The allowable moments are:

For yielding: M_{np} / Ω =14,350 in-k
For rupture: M_{nu} / Ω =19,190 in-k
For local buckling: M_n / Ω =13,540 in-k
For lateral-torsional buckling: M_n / Ω = 11,060 in-k

The least of these is 11,060 in-k from lateral-torsional buckling.

NOTES: If the shape of the moment diagram is known the lateral-torsional buckling strength can be determined more precisely by using the bending coefficient C_b computed according to Section F.4.1.1.

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Example 17
WELDED BEAM SUBJECT TO FATIGUE
Illustrating Sections 3.1 and 3.2

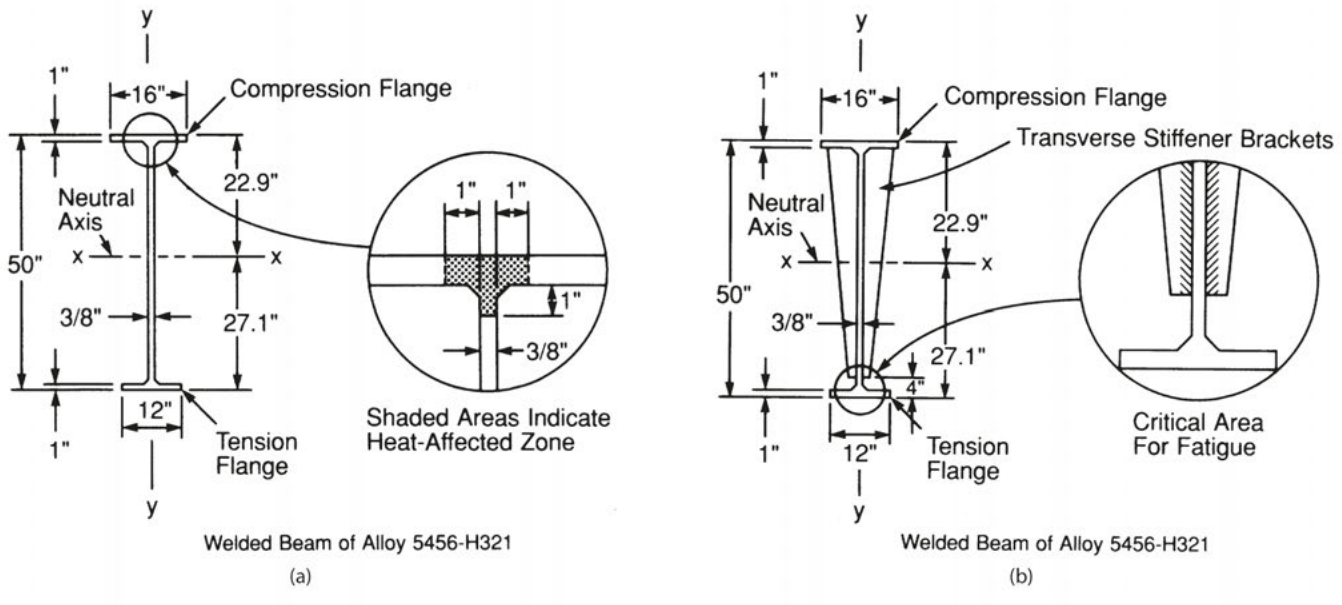

Figure 17

GIVEN:

1. Welded girder; see Figure 17
2. Lateral support spacing: compression flange, 10 ft o.c.
3. Alloy-temper: 5456-H321
4. Product specification: ASTM B928
5. Number of load cycles: 500,000
6. Load applied downward on the compression flange

FIND:

The allowable moment range for fatigue loading of the beams shown in Figure 17.

SOLUTION:

a) Beam with no transverse brackets

Specification Figure 3.1 (Detail 4) is a girder with continuous welds attaching web and flange, similar to that shown in Figure 17a. The stress category is selected from Table 3.1. The category for a built-up member (see general condition in left column) with continuous weld parallel to the direction of stress for detail numbers 3, 4, and 5 (right column) is B.

Section 3.2 requires for constant amplitude loading that the applied stress range S_{ra} shall not exceed the allowable stress range S_{rd}

$$S_{rd} = C_f N^{-1/m}$$

Where, for Stress Category B,

C_f = 130 ksi and m = 4.84

for the number of cycles, N = 500,000,

$$S_{rd} = (130)(500{,}000)^{-1/4.84} = 8.6 \text{ ksi}$$

The section modulus, S_w corresponding to the weld location on the tension flange is:

$$S_w = 20{,}057/(27.1 - 1.0) = 768 \text{ in}^3$$

The allowable moment range for fatigue ΔM is calculated for a tensile stress range at the web's bottom.

$$\Delta M = S_{rd}\, S_w = 8.6\ (768) = 6630 \text{ in-k}$$

If variable amplitude loading occurred, an equivalent stress range would be calculated and compared to the allowable stress range. For example, if the loading were

100,000 cycles	9.5 ksi stress range
50,000 cycles	10.0 ksi stress range
350,000 cycles	7.1 ksi stress range
500,000 cycles	at various stress ranges

Section 3.3 requires that the equivalent stress range S_{re} shall not exceed the allowable stress range S_{rd}

$$S_{re} = [(100/500)9.5^{4.84} + (50/500)10^{4.84} + (350/500)7.1^{4.84}]^{1/4.84}$$

$$S_{re} = 8.2 \text{ ksi} < 8.6 \text{ ksi} = S_{rd}$$

So this variable amplitude loading does not exceed the allowable stress range.

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b) Beam with transverse brackets

Specification Figure 3.1 Detail 6 is a girder with a similar detail at the bottom of the stiffener to that shown in Figure 17b. The category corresponding to Detail 6 is C.

Section 3.2 requires for constant amplitude loading that the applied stress range S_{ra} shall not exceed the allowable stress range S_{rd}

$$S_{rd} = C_f \ N^{-1/m}$$

Where, for stress category C,

C_f = 278 ksi and m = 3.64

for the number of cycles, N = 500,000,

$$S_{rd} = (278)\ (500{,}000)^{-1/3.64} = 7.6 \text{ ksi}$$

The section modulus at the bottom end of the stiffener is:

$$S_w = (20{,}057)/(27.13 - 4.0) = 867 \text{ in}^3$$

The allowable moment range for fatigue ΔM is calculated for a tensile stress range at the end of the stiffener.

$$\Delta M = (7.6 \text{ k/in}^2)\ (867 \text{ in}^3) = 6{,}550 \text{ in-k}$$

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Example 18
PIPE IN FLEXURE
Illustrating Sections F.2, F.3, and F.4

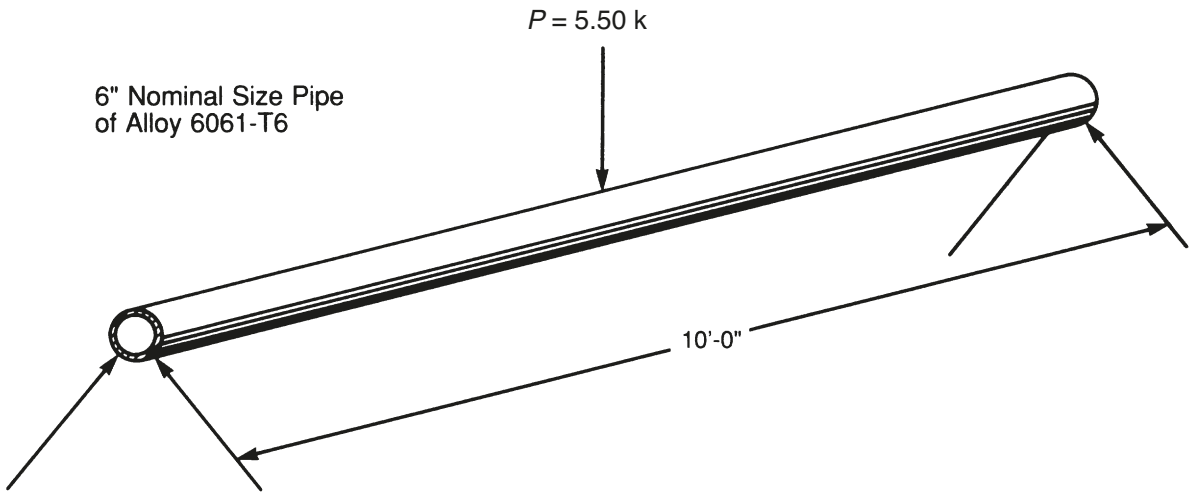

Figure 18

GIVEN:

1. ASD concentrated load of 5.5 k at mid-span
2. Span: 10 ft, simply supported
3. Alloy-temper: 6061-T6
4. Product specification: ASTM B429

FIND:

Is a 6 in. schedule 40 pipe adequate in flexure for the required load?

SOLUTION:

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.2 addresses the limit states of yielding and rupture. Part V Table 17 shows, for a 6 in. schedule 40 pipe:

D = 6.625 in, t = 0.280 in., S = 8.50 in^3, Z = 11.3 in^3, I_y = 28.1 in^4, J = 56.2 in^4

For the limit state of yielding, the allowable moment is the lesser of

$M_{np}/\Omega = 1.5SF_{ty}/\Omega = 1.5(8.50\text{ in}^3)(35\text{ k/in}^2)/1.65$
$= 270.4$ in-k

$M_{np}/\Omega = ZF_{ty}/\Omega = (11.3\text{ in}^3)(35\text{ k/in}^2)/1.65 = 239.7$ in-k

The lesser of these is $M_{np}/\Omega = 239.7$ in-k, and
$M_{np} = (239.7\text{ in-k})(1.65) = 395.5$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/\ k_t\ /\ \Omega$
$= (11.3\text{ in}^3)(38\text{ k/in}^2)/1/1.95$
$= 220.2$ in-k.

The allowable moment for local buckling determined using Section F.3.3 is based on Section B.5.5.4.

$$\sqrt{\frac{R_b}{t}} = \sqrt{\frac{(6.625 - 0.280)}{(2)(0.280)}} = 3.37 < 7.4 = \lambda_1, \text{ and}$$

$F_b/\Omega = 39.3 - 2.7(3.37) = 30.2$ ksi

The allowable moment for local buckling is

$M_{nlb}/\Omega = SF_b/\Omega = (8.50\text{ in}^3)(30.2\text{ k/in}^2) = 256.7$ in-k

For closed shapes, the slenderness for lateral-torsional buckling using Section F.4.2.3 is

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} = 2.3\sqrt{\frac{(120)(8.50)}{(1)\sqrt{(28.1)(56.2)}}} =$$

$= 11.7 < 66 = C_c$, so

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 395.5\left(1 - \frac{11.7}{66}\right) + \frac{\pi^2(10{,}100)(11.7)(8.50)}{66^3}$$

$= 359.9$ in-k

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The allowable moment for lateral-torsional buckling is $M_{nmb}/\Omega = 359.9/1.65 = 218.1$ in-k

The allowable moment is the least of the allowable moments for yielding (239.7), rupture (220.2), local buckling (256.7), and lateral-torsional buckling (218.1), which is 218.1 in-k

From Part VI Beam Formulas Case 1, a simply supported beam with a concentrated load P at center, the maximum moment is

$M = PL/4 = (5.5)(10)(12)/4 = 165$ in-k < 218.1 in-k

The 6 in. schedule 40 pipe is therefore satisfactory for flexure.

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Example 19
RECTANGULAR BAR IN FLEXURE
Illustrating Sections F.2 and F.4

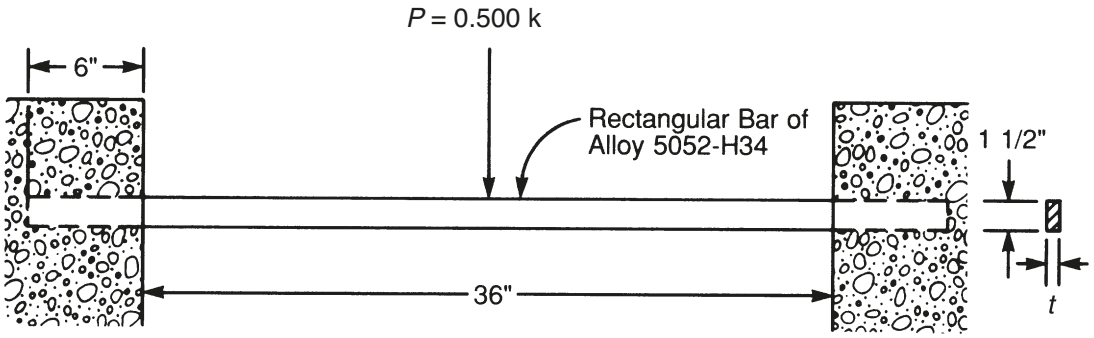

Figure 19

GIVEN:

1. Beam section: 1.50 in. deep rectangular bar
2. Load: 0.500 k at mid-span
3. Span: 36 in.
4. Ends of beam restrained against rotation and translation, lateral support at ends only
5. Alloy-temper: 5052-H34
6. Product specification: ASTM B209

FIND:

The thinnest standard bar based on flexural strength with an allowable load that exceeds the applied load.

SOLUTION:

From Part V Table 23 provides section properties for a rectangle.

Try a 1/4 in. thick bar

$A = td = 0.25\ (1.50) = 0.375\ \text{in}^2$

$I_x = td^3/12 = (0.25)(1.5)^3/12 = 0.070\ \text{in}^4$

$S_x = td^2/6 = (0.25)(1.5)^2/6 = 0.094\ \text{in}^3$

$Z = td^2/4 = (0.25)(1.5)^2/4 = 0.141\ \text{in}^3$

From Part VI, Beam Formulas Case 26, concentrated load P at center, the maximum moment is

$M_{max} = PL/8 = (0.5)(36)/8 = 2.25$ in-k

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Part VI Table 2-10 gives allowable stresses for 5052-H34.

Section F.2 addresses the limit states of yielding and rupture.

For the limit state of yielding, the allowable moment is the lesser of

$1.5F_{cy}S/\Omega = 1.5(0.9)(26)(0.094)/1.65 = 2.0$ in-k

and $ZF_{cy}/\Omega = (0.141)(0.9)(26)//1.65 = 2.0$ in-k,
so $M_{np}/\Omega = 2.0$ in-k, and
$M_{np} = (2.0)(1.65) = 3.3$ in-k.

For the limit state of tensile rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$
$= (0.141\ \text{in}^3)(34\ \text{k/in}^2)/1/1.95 = 2.46$ in-k.

Since the least of these is 2.0 in-k < 2.25 in-k, a thicker bar is needed.

Try a 1/2 in. thick bar

$A = 0.75\ \text{in}^2$

$I_x = 0.141\ \text{in}^4$

$S_x = (0.5)(1.5)^2/6 = 0.188\ \text{in}^3$

$Z = (0.5)(1.5)^2/4 = 0.281\ \text{in}^3$

For the limit state of yielding, the allowable moment is the lesser of

$1.5F_{cy}S/\Omega = 1.5(0.9)(26)(0.188)/1.65 = 4.0$ in-k

and $ZF_{cy}/\Omega = (0.281)(0.9)(26)/1.65 = 4.0$ in-k,
so $M_{np}/\Omega = 4.0$ in-k, and
$M_{np} = (4.0)(1.65) = 6.6$ in-k.

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For the limit state of tensile rupture, the allowable moment is

$$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$$
$$= (0.281\ \text{in}^3)(34\ \text{k/in}^2)/1/1.95$$
$$= 4.9\ \text{in-k}.$$

Now check the limit state of lateral-torsional buckling addressed in Sections F.4, F.4.1.1, and F.4.2.4. Since I_{yc}/I_y = 0.5, use equation F.4-2 for C_b. Since the maximum moment occurs at the midspan and the moment is zero at the ¼ and ¾ points on the span,

$$C_b = \frac{4M_{max}}{\sqrt{4M_{max}^2 + 4M_A^2 + 7M_B^2 + 4M_C^2}} R_m$$
$$= \frac{4(2.25)}{\sqrt{(2.25)^2 + 4(0) + 7(2.25) + 4(0)}}(1.0) = 1.41 \le 3.0$$

$$\lambda = \frac{2.3}{t}\sqrt{\frac{L_b d}{C_b}} = \frac{2.3}{0.5}\sqrt{\frac{36(1.5)}{1.41}} = 28.5 < \lambda_2 = 105$$

As given in Section F.4:

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$
$$= 6.6\left(1 - \frac{28.5}{105}\right) + \frac{\pi^2(10{,}100)(28.5)(0.188)}{105^3} = 5.27\ \text{in-k}$$

The allowable moment for lateral-torsional buckling is M_{nmb}/Ω = 5.27/1.65 = 3.19 in-k

The allowable moment is the least of the allowable moments for yielding (4.0), rupture (4.9), and lateral-torsional buckling (3.19), which is 3.19 in-k > 2.25 in-k.

Use a 1/2 in. thick bar.

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Example 20
RECTANGULAR TUBE IN FLEXURE
Illustrating Sections F.2, F.3, F.4, and G.2

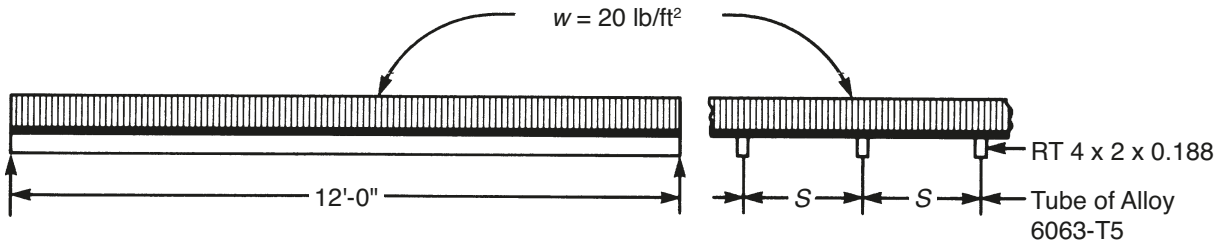

Figure 20

GIVEN:

1. 4 in. × 2 in rectangular tube with 0.188 in. wall (RT 4 × 2 × 0.188)
2. Load: 20 lb/ft² total of live and dead loads
3. 12 ft simple span, laterally unsupported
4. Alloy-temper: 6063-T5
5. Product specification: ASTM B221

FIND:

The maximum allowable spacing of the beams using ASD.

SOLUTION:

Part I Table A.4.3 provides mechanical properties for 6063-T5:

$F_{cy} = F_{ty} = 16$ k/in², $F_{tu} = 22$ k/in²

Part V Table 19 provides section properties for rectangular tubes:

$I_x = 4.23$ in⁴, $S_x = 2.11$ in³, $I_y = 1.37$ in⁴, $J = 3.19$ in⁴, and $Z = 2.67$ in³

The slenderness ratio of the flange is
$b/t = (2 - 2\ (0.188))/0.188 = 8.6$

The slenderness ratio of the web is
$b/t = (4 - 2(0.188))/0.188 = 19.3$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Part VI Table 2-20 gives allowable stresses for 6063-T5.

From Section F.2, for the limit state of yielding, the allowable moment is the lesser of:

$1.5F_{cy}S/\Omega = 1.5(16)(2.11)/1.65 = 30.7$ in-k

and $ZF_{cy}/\ \Omega = (2.67)(16)/1.65 = 25.9$ in-k, so
$M_{np}/\Omega = 25.9$ in-k, and
$M_{np} = (25.9)(1.65) = 42.7$ in-k.

For the limit state of tensile rupture, the allowable moment is:

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (2.67\ \text{in}^3)(22\ \text{k/in}^2)/1/1.95 = 30.1$ in-k.

From Section F.3, the local buckling strength is determined using Part VI Table 2-20:

Section B.5.4.2 addresses the flange; $b/t = 8.6 < 25.6 = \lambda_1$, so $F_b/\Omega = 9.7$ ksi

Section B.5.5.1 addresses the web; $b/t = 19.3 < 36.1 = \lambda_1$, so $F_b/\Omega = 14.5$ ksi

Conservatively use the lesser of these in lieu of the weighted average compressive strength given in Section F.3.1; then the allowable moment for local buckling is:

$M_{nlb}/\Omega = SF_b/\Omega = (2.11)(9.7) = 20.5$ in-k

Section F.4.2.3 addresses lateral-torsional buckling of closed shapes. Conservatively using $C_b = 1.0$,

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} = 2.3\sqrt{\frac{(144)(2.11)}{(1)\sqrt{(1.37)(3.19)}}} = 27.7 < 99 = C_c,$$

so

$$M_{nmb} = M_{np}\left(1 - \frac{\lambda}{C_c}\right) + \frac{\pi^2 E \lambda S_{xc}}{C_c^3}$$

$$= 42.7\left(1 - \frac{27.7}{99}\right) + \frac{\pi^2(10{,}100)(27.7)(2.11)}{99^3}$$

$$= 36.8 \text{ in-k}$$

The allowable moment for lateral-torsional buckling is $M_{nmb}/\Omega = 36.8/1.65 = 22.3$ in-k

The allowable moment is the least of the allowable moments for yielding (25.9), rupture (30.1), local buckling (20.5), and lateral-torsional buckling (22.3), which is 20.5 in-k.

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Part V Beam Formulas Case 6, simply supported beam with uniform load, has a maximum moment of

$M = WL/8$, which can be written as

$W = 8M/L$

$W_1 = 8(20.5)/144 = 1.14$ k
= allowable total load for flexure

Section G.2 addresses the limit state of shear rupture. The allowable stress on the net area is:

$F_{su}/k_t/\Omega = 0.6(22)\ /1\ /1.65 = 8.0$ ksi

Section G.2 also addresses the limit state of web shear yielding or buckling:

$b/t = (4 - 2(0.188))/0.188 = 19.3 < \lambda_1 = 43.6$

$F_s/\Omega = 5.8$ ksi, which governs. (See also Part VI Table 2-20)

Web area

$A = 2(0.188)(4) = 1.5$ in^2

$V = (F_s/\Omega)\ A = 5.8(1.5) = 8.7$ k

$W_2 = 2V = 2(8.7) = 17.4$ k = allowable load for shear.

Since $W_1 < W_2$, flexure controls

$W = W_1 = 1.14$ k, total allowable load per beam.

The allowable spacing can now be determined from the given unit load of 20 lb/ft^2 or 0.020 k/ft^2

Spacing = (1.14 k)/[0.020 k/ft^2)(12 ft)]
= 4.75 ft o.c. = 57 in.

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Example 21
W-SHAPE IN FLEXURE
Illustrating Sections F.2 and F.3

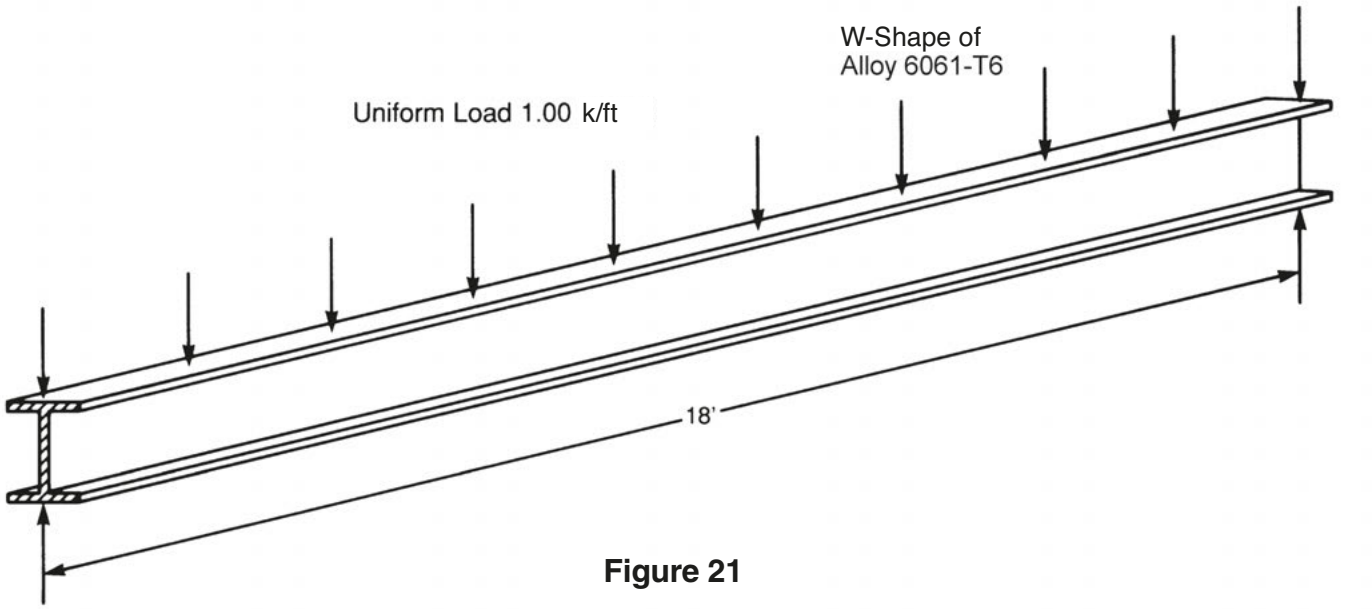

Figure 21

GIVEN:

1. Uniform load: 1.0 k/ft including dead load
2. Span: 18 ft, simply supported
3. Compression flange is adequately supported laterally
4. Alloy-temper: 6061-T6
5. Product specification: ASTM B308

FIND:

Size of lightest Aluminum Association standard W-Shape with an allowable load that exceeds 1.0 k/ft.

SOLUTION:

Part VI Beam Formulas Case 6 gives the total load W as

$$W = wL = 1.0(18.0) = 18.0 \text{ k}$$

Part VI Table 4-2 indicates that an AW 10 × 8.65 will support 22.05 k at a 17 ft span; therefore, it may be the desired beam. The allowable load for an 18 ft span is not tabulated, but it can be determined as follows:

Maximum moment,

$$M = WL/8 = (18 \text{ k})(18 \text{ ft})(12 \text{ in/ft})/8 = 486 \text{ in-k}$$

Part V, Table 7, gives the section properties:

$S_x = 26.4$ in^3, $Z = 29.5$ in^3, $b = 6$ in., $t_w = 0.25$ in., $t_f = 0.41$ in., $R = 0.40$ in.

The flange's slenderness ratio is
$b/t = (6 – 0.25 – 2(0.40))/2/0.41 = 6.0$

The web's slenderness ratio is
$b/t = (10.0 – 2(0.41 + 0.40))/0.25 = 33.5$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.2 addresses yielding and rupture:

For the limit state of yielding, the allowable moment is the lesser of

$$1.5F_{cy}S/\Omega = 1.5(35)(26.4)/1.65 = 840 \text{ in-k}$$

and $ZF_{cy}S/\Omega = (29.5)(35)/1.65 = 626$ in-k,
so $M_{np}/\Omega = 626$ in-k.

For the limit state of rupture, the allowable moment is

$$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (29.5)(38)/1/1.95 = 575 \text{ in-k.}$$

Section F.3 addresses local buckling:

Section B.5.4.1 addresses the flange; $b/t = 6.0 < 6.7 = \lambda_1$, so $F_b/\Omega = 21.2$ ksi

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Section B.5.5.1 addresses the web;
$b/t = 33.5 > 33.1 = \lambda_1$,
so $F_b/\Omega = 40.5 - 0.262(33.5) = 31.7$ ksi

Conservatively using the lesser of these, the allowable moment for local buckling is

$$M_{nlb}/\Omega = SF_b/\Omega = (26.4)(21.2) = 560 \text{ in-k}$$

The least of these allowable moments (840, 626, 575 and 560 in-k) is 560 in-k > 486 in-k.

Since the required moment (486 in-k) is less than the available moment (560 in-k), the trial beam is satisfactory.

NOTE: Section G.2 (shear in webs supported on both edges) should be also be checked. It will be more likely to govern for deep, heavily loaded beams.

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Example 22
UNSYMMETRIC BEAM IN FLEXURE
Illustrating Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, F.2, and F.3

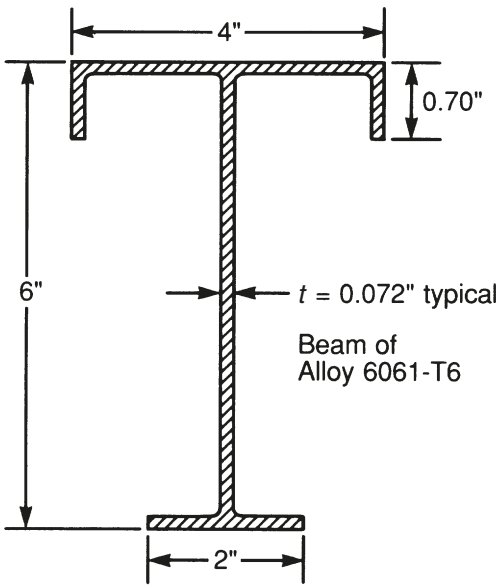

Figure 22

GIVEN:

1. Beam of cross section shown in Figure 22
2. Continuous lateral support of compression (top) flange
3. Alloy-temper: 6061-T6
4. Product specification: ASTM B221

FIND:

Allowable moment.

SOLUTION:

The section properties are computed as shown in example 16 with the following results:

$c_t = 3.70$ in. $\qquad I_x = 5.15$ in^4

The section modulus for the compression flange is
$S_c = I/c_c = 5.15/(6 - 3.70) = 2.24$ in^3.

The section modulus for the tension flange is
$S_t = I/c_t = 5.15/(3.70) = 1.39$ in^3.

In a similar fashion, the plastic neutral axis is determined to be located at 4.63 in. from the bottom of the section, and the plastic section modulus Z is determined as 1.943 in^3.

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.2 addresses yielding and rupture:

For the limit state of yielding, the allowable moment is the least of

$1.5F_{cy}S_c/\Omega = 1.5(35)(2.24)/1.65 = 71.3$ in-k

$1.5F_{ty}S_t/\Omega = 1.5(35)(1.39)/1.65 = 44.2$ in-k

and $ZF_{cy}/\Omega = (1.943)(35)/1.65 = 41.2$ in-k,
so $M_{np}/\Omega = 41.2$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (1.943)(38)/1/1.95 = 37.9$ in-k.

Section F.3 addresses local buckling.

Section B.5.5.1 addresses local buckling of elements in flexure (the web). The web slenderness is

$b/t = (6 - 2(0.072))/0.072 = 81.3$

$c_c = -(6 - 3.7) = -2.3$; $c_o = 3.7$

$c_o/c_c = 3.7/(-2.3) = -1.6 < -1$, so
$m = 1.3/(1 - c_o/c_c) = 1.3/(1 - (3.7/-2.3)) = 0.50$

$\lambda_1 = (B_{br} - 1.5F_{cy})/(mD_{br})$
$= (66.8 - 1.5(35))/(0.5(0.665)) = 43.0$

$\lambda_2 = k_1B_{br}/(mD_{br}) = 0.5(66.8)/[(0.5)(0.665)] = 100.5$

Since $\lambda_1 = 43.0 < 81.3 < 100.5 = \lambda_2$,

$F_b/\Omega = [B_{br} - mD_{br}(b/t)]/\Omega$
$= (66.8 - 0.5(0.665)(81.3))/1.65 = 24.1$ ksi

The allowable moment based on web compression is

$M_{wlb} = (24.1)(5.15)/(6 - 3.70 - 0.072) = 55.7$ in-k

The distance from the neutral axis to the centroid of the flange stiffener is

$c = 6 - 3.70 - 0.072 - 0.5(0.7 - 0.072) = 1.91$ in.

The stiffener can be treated as an element in uniform compression if the distance from the neutral axis to the centroid of the stiffener is greater than 75% of the distance from the neutral axis to the extreme fiber.

The distance from the neutral axis to the extreme fiber $c = 6 - 3.70 = 2.3$ in.; $0.75(2.3) = 1.72$ in. < 1.91 in., so treat

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the stiffener as an element in uniform compression.

Section B.5.4.1 addresses local buckling of elements in uniform compression supported on one edge. The stiffener's slenderness is

$b/t = (0.70 - 0.072)/0.072 = 8.7$, which is between $6.7 = \lambda_1$ and $10.5 = \lambda_2$, so

$F_b / \Omega = 27.3 - 0.91(8.7) = 19.4$ ksi

The allowable moment based on stiffener local buckling is $M_{slb} = (19.4)(5.15)/(6 - 3.70 - 0.072) = 44.8$ in-k

Section B.5.4.3 addresses local buckling of elements supported on one edge and with a stiffener at the other edge.

The flange element width is $b = (4 - 3(0.072))/2 = 1.89$ in.

The depth of the stiffener is $D_s = 0.70 - 0.072 = 0.628$ in.

$D_s/b = 0.628/1.89 = 0.33 < 0.8$, so Section B.5.4.3 applies.

$$\lambda_e = 1.28\sqrt{\frac{E}{F_{cy}}} = 1.28\sqrt{\frac{10{,}100}{35}} = 21.7$$

$b/t = 1.89/0.072 = 26.25$

The stiffener's radius of gyration about the flange's mid-thickness is conservatively approximated by the following equation:

$$r_s = \frac{d_s \sin\theta}{\sqrt{3}} = \frac{0.7 - 0.072}{\sqrt{3}} = 0.363$$

$2\lambda_e = 43.5 > 26.25 = b/t > 21.7 = \lambda_e$, so

$$\rho_{st} = \frac{r_s}{1.5t\left(\frac{b/t}{\lambda_e} + 3\right)} = \frac{0.363}{1.5(0.072)\left(\frac{26.25}{21.7} + 3\right)} = 0.797 \le 1.0$$

F_{UT}/Ω = allowable stress for flange as if supported on one edge per B.5.4.1

$b/t = 26.25 > 10.5 = \lambda_2$, so

$F_{UT}/\Omega = 186/26.25 = 7.1$ ksi

F_{ST}/Ω = allowable stress for flange as supported on both edges per B.5.4.2

$\lambda_1 = 20.8 < b/t = 26.25 < 33 = \lambda_2$

$F_{ST}/\Omega = 27.3 - 0.291\ (b/t) = 27.3 - 0.291(26.25)$

$F_{ST}/\Omega = 19.7$ ksi

$F_c/\Omega = F_{UT}/\Omega + (F_{ST}/\Omega - F_{UT}/\Omega)\rho_{ST} \le F_{ST}$

$F_c/\Omega = 7.1 + (19.7 - 7.1)\ (0.797) = 17.1$ ksi

$M_{flb} = (17.1)(5.15)/(6 - 3.70 - (0.072/2)) = 38.9$ in-k

The allowable moments for yield and rupture, and buckling (of web, stiffener and flange), are 41.2, 37.9, 55.7, 44.8 and 38.9 in-k, respectively. The smallest of these is for the limit state of rupture, so the allowable moment is

$M = 37.9$ in-k

NOTE: Shear stress should be checked using Section G.2.

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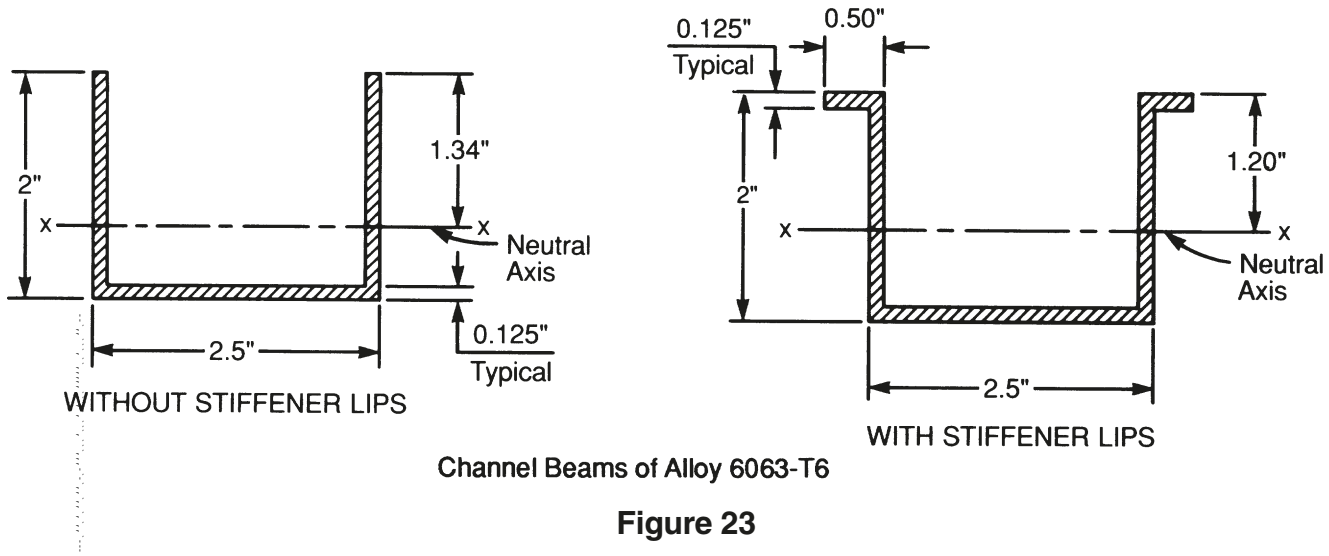
Example 23
CHANNEL IN FLEXURE
Illustrating Sections B.5.4.1, B.5.5.1, B.5.5.2, F.2, and F.3



Channel Beams of Alloy 6063-T6

Figure 23

GIVEN:

1. 2.5 in. × 2 in. × 0.125 in. channels as shown in Figure 23
2. Alloy-temper: 6063-T6
3. Product specification: ASTM B221
4. Channel has continuous lateral brace

FIND:

The allowable positive moment about the X axis for each channel shown in Figure 23

SOLUTION:

Part I, channel without stiffener lips:

The section properties are computed using the method shown in example 16 with the following results

c_c = 1.34 in. to the top fiber

I = 0.325 in^4,

$S_c = I/c_c$ = 0.325/1.34 = 0.243 in^3,
$S_t = I/c_t$ = 0.325/(2 – 1.34) = 0.492 in^3,
Z = 0.435 in^3

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Allowable stresses for 6063-T6 given in Part VI Table 2-21 are used below.

Section F.2 addresses yielding and rupture.

For the limit state of yielding, the allowable moment is the least of

$1.5F_{cy}S_c/\Omega$ = 1.5(25)(0.243)/1.65 = 5.52 in-k

$1.5F_{ty}S_t/\Omega$= 1.5(25)(0.492)/1.65 = 11.2 in-k

and ZF_{cy}/Ω = (0.435)(25)/1.65 = 6.59 in-k,
so M_{np}/Ω = 5.52 in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$ = (0.435)(30)/1/1.95 = 6.69 in-k.

Section F.3 addresses local buckling.

Section B.5.5.2 addresses elements in flexure (the web) with the tension edge supported and the compression edge free. The web slenderness is

b/t = (2 – 0.125)/0.125 = 15,
which is between λ_1 = 6.5 and λ_2 = 23 so
F_b/Ω = 27.9 – 0.81(b/t) = 15.7 ksi

The allowable moment for local buckling is
M_{nlb} = (15.7)(0.325)/1.34 = 3.81 in-k

The least of the allowable moments is M_{nlb} = 3.81 in-k, so 3.81 in-k is the allowable moment.

Part II, channel with stiffener lips:

The section properties are computed using the method shown in example 16 with the following results:

c = 1.20 in. to the top fiber

I = 0.461 in^4,

$S_c = I/c_c$ = 0.461/1.20 = 0.384 in^3,
$S_t = I/c_t$ = 0.461/(2 – 1.20) = 0.576 in^3,
Z = 0.566 in^3

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Section F.2 addresses yielding and rupture.

For the limit state of yielding, the allowable moment is the least of

$1.5F_{cy}S_c/\Omega = 1.5(25)(0.384)/1.65 = 8.73$ in-k

$1.5F_{ty}S_t/\Omega = 1.5(25)(0.576)/1.65 = 13.1$ in-k

and $ZF_{cy}/\Omega = (0.566)(25)/1.65 = 8.58$ in-k,
so $M_{np}/\Omega = 8.58$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (0.566)(30)/1/1.95 = 8.71$ in-k.

Section F.3 addresses local buckling.

Section B.5.4.1 addresses local buckling of elements in uniform compression supported on one edge (the lip). The lip slenderness is

$b/t = (0.50 - 0.125)/0.125 = 3 < \lambda_1 = 7.3$,
so $F_b/\Omega = 15.2$ ksi

The allowable moment based on lip local buckling is $M_{nflb}/\Omega = (15.2)(0.461)/1.20 = 5.84$ in-k

Section B.5.5.1 addresses elements in flexure (the web) supported on both edges. The web slenderness is

$b/t = (2 - 2(0.125))/0.125 = 14$

$c_c = -1.20$

$c_o = 2 - 1.20 = 0.8$

$c_o/c_c = 0.8/(-1.2) = -0.67$

$m = 1.15 + c_o/(2c_c) = 1.15 + 0.5(-0.67) = 0.82$

$\lambda_1 = [B_{br} - 1.5F_{cy}]/(mD_{br})$
$= [46.1 - 1.5(25)]/[(0.82)(0.382)] = 27.5$

Since $b/t = 14 < \lambda_1 = 27.5$, $F_b/\Omega = 22.7$ ksi

The allowable moment based on web local buckling is $M_{nwlf}/\Omega = (22.7)(0.461)/(1.20 - 0.125) = 9.73$ in-k.

The least of the allowable moments (8.58, 8.71, 5.84 and 9.73 in-k) is for the limit state of flange (lip) local buckling, so 5.84 in-k is the allowable moment.

NOTES: The use of Section B.5.5.1 assumes that the lip provides lateral support at the top of the web. Section B.5.5.5 may be used to determine the local buckling strength more precisely and check this assumption.

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Example 24
ALLOWABLE WEB STRESS IN A WELDED BEAM
Illustrating Section B.5.5.1

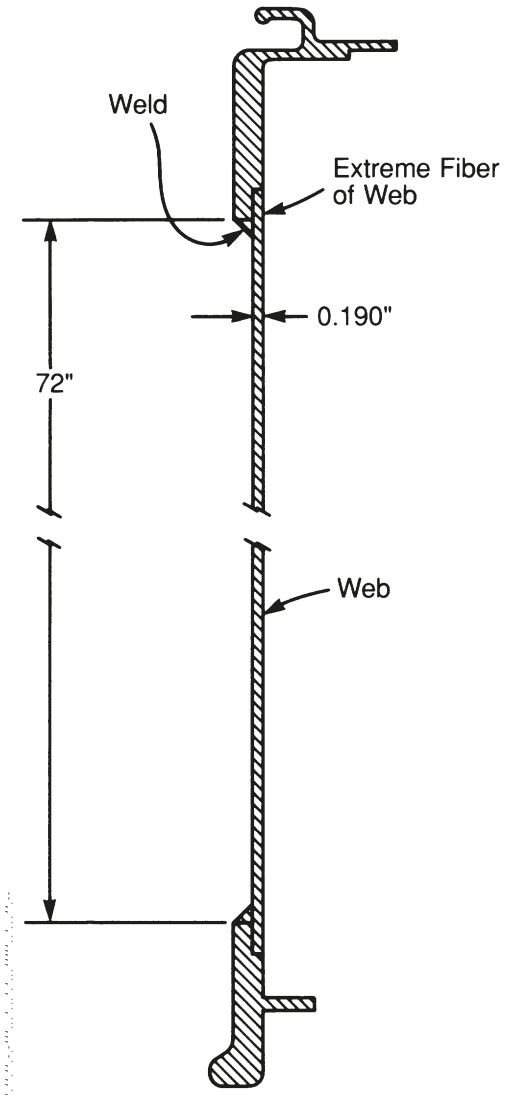

Figure 24

GIVEN:

1. Beam cross section as shown in Figure 24
2. Alloy-temper of web: 6061-T6
3. Product specification: ASTM B209

FIND:

The allowable compressive flexural stress at the extreme fiber of web.

SOLUTION:

Assume that the neutral axis is approximately at the mid-height of the web. For the web,

$b/t = 72/0.190 = 379$

Section B.5.5 states that for welded elements in flexure, the stress corresponding to the flexural compression strength is

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}$$

where

F_{bo} = stress corresponding to the flexural compression strength calculated using Section B.5.5.1 for an element if no part of the cross section were weld-affected. Using Part VI Table 2-18 for unwelded allowable stresses, since $b/t = 379 > 77 = \lambda_2$:

$F_{bo}/\Omega = 1563/(b/t) = 1563/379 = 4.1$ ksi

F_{bw} = stress corresponding to the flexural compression strength calculated using Section B.5.5.1 for an element if the entire cross section were weld-affected. Use Part VI Table 2-18W for the welded allowable stresses. Since $b/t = 379 > 123 = \lambda_2$:

$F_{bw}/\Omega = 982/(b/t) = 982/379 = 2.6$ ksi

A_{wzc} = cross sectional area of the weld-affected zone in compression

$A_{wzc} = (1 \text{ in.})(0.190 \text{ in.}) = 0.19 \text{ in}^2$

A_{gc} = gross cross sectional area of the element in compression.

$A_{gc} = (72 \text{ in.})(0.190 \text{ in.})/2 = 6.84 \text{ in}^2$

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}$$

$$F_b/\Omega = (4.1)(1 - 0.19/6.84) + (2.6)(0.19)/6.84 = 4.1 \text{ ksi}$$

NOTES: Lateral-torsional buckling must also be checked using Section F.4.

Filler metal for welds should be selected from Table M.9.1

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Example 25
ALLOWABLE WEB STRESS IN A WELDED BEAM WITH STIFFENED WEB
Illustrating Section B.5.5.3

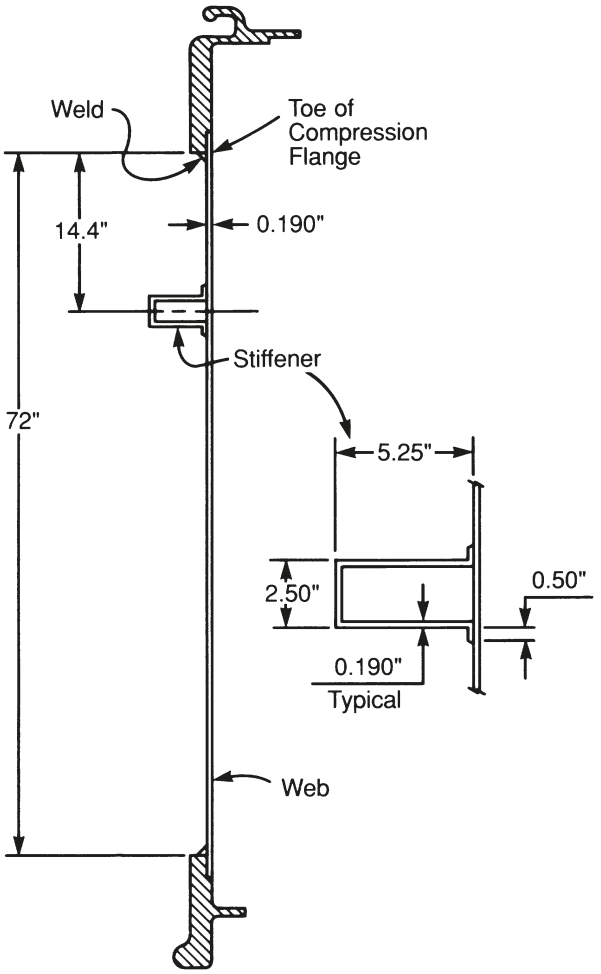

Figure 25

GIVEN:

1. Beam cross section as shown in Figure 25
2. Neutral axis of beam is at mid-height of web
3. Transverse stiffener spacing 10 ft o.c.
4. Alloy-temper of web: 6061-T6
5. Product specification: ASTM B209

FIND:

1. The allowable web stress at the toe of the compression flange.
2. Confirm the adequacy of the longitudinal stiffener

SOLUTION:

For the web, $b/t = 72/0.190 = 379$

Section B.5.5 states that for welded elements in flexure, the stress corresponding to the flexural compression strength is

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}$$

where

F_{bo} = stress corresponding to the flexural compression strength calculated using Section B.5.5.3 for an element if no part of the cross section were weld-affected. Using Part VI Table 2-18 for unwelded allowable stresses, since $b/t = 379 > 173 = \lambda_2$:

$$F_{bo}/\Omega = 3502/(b/t) = 3502/379 = 9.2 \text{ ksi}$$

F_{bw} = stress corresponding to the flexural compression strength calculated using Section B.5.5.3 for an element if the entire cross section were weld-affected. Use Part VI Table 2-18W for the welded allowable stresses. Since $b/t = 379 > 275 = \lambda_2$:

$$F_{bw}/\Omega = 2201/(b/t) = 2201/379 = 5.8 \text{ ksi}$$

A_{wzc} = cross sectional area of the weld-affected zone in compression

$$A_{wzc} = (1 \text{ in.})(0.190 \text{ in.}) = 0.19 \text{ in}^2$$

A_{gc} = gross cross sectional area of the element in compression.

$$A_{gc} = (72 \text{ in.})(0.190 \text{ in.})/2 = 6.84 \text{ in}^2$$

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc}$$

$$F_b/\Omega = (9.2)(1 - 0.19/6.84) + (5.8)(0.19)/6.84 = 9.1 \text{ ksi}$$

Section B.5.5.3 provides requirements for the longitudinal stiffener

$\alpha_s = 3.5$, $b = 72$ in., $t = 0.190$ in., $f = 9.1$ ksi, $s = 10$ ft $= 120$ in.

$$A_L = 5.25(2.50) - 5.06(2.12) + 0.19(1.00) = 2.59 \text{ in}^2$$

$$I_L = \frac{0.02\alpha_S f t b^3}{E}\left[\left(1+\frac{6A_L}{bt}\right)\left(\frac{s}{b}\right)^2 + 0.4\right]$$

$$= \frac{0.02(3.5)(9.1)(0.19)(72)^3}{10{,}100}\left[\left(1+\frac{6(2.59)}{72(0.19)}\right)\left(\frac{120}{72}\right)^2 + 0.4\right]$$

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I_L = 28.3 in^4

= the required moment of inertia of the longitudinal stiffener.

Actual moment of inertia

= (5.25^3(2.50) – 5.06^3(2.12) + 0.19^3(1.00))/3 = 29.0 in^4

The stiffener is therefore satisfactory.

The required distance from the toe of the compression flange to the centroid of the stiffener is

0.4(72)/2 = 14.4 in.

NOTES: The notes of example 24 also apply to this example. Stresses in the longitudinal stiffener should also be checked.

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Example 26
W-SHAPE WITH WEB SHEAR CONTROLLING
Illustrating Sections F.2, F.3, and G.2

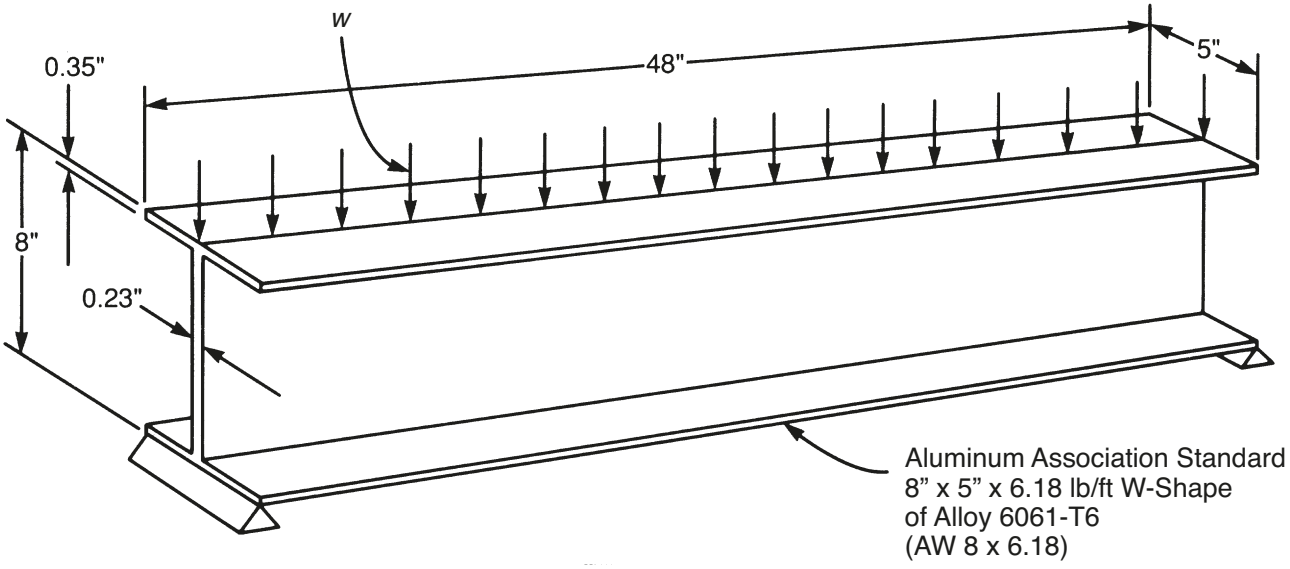

Figure 26

GIVEN:

1. Aluminum Association standard W-shape AW 8 × 6.18
2. Span: 4 ft, simply supported at ends
3. Compression flange continuously laterally supported
4. Alloy-temper: 6061-T6
5. Product specification: ASTM B308

FIND:

The allowable uniform load

SOLUTION:

From Part V, Table 7, Aluminum Association standard W-shapes

d = 8.00 in., b = 5.00 in., A = 5.26 in^2, t_f = 0.35 in., t_w = 0.23 in., R = 0.30 in., I_x = 59.7 in^4, S_x = 14.9 in^3, Z = 16.7 in^3

For the flange, b/t = (5.00 – 0.23 – 2(0.30))/2/0.35 = 6.0

For the web, b/t = (8.00 – 2(0.35 + 0.30))/0.23 = 29.1

Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling.

Section F.2 addresses yielding and rupture:

For the limit state of yielding, the allowable moment is the lesser of

$1.5F_{cy}S/\Omega$ = 1.5(35)(14.9)/1.65 = 474 in-k

and ZF_{cy}/Ω = (16.7)(35)/1.65 = 354 in-k,
so M_{np}/Ω = 354 in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega$ = (16.7)(38)/1/1.95 = 325 in-k.

Section F.3 addresses local buckling.

Section B.5.4.1 addresses the flange; $b/t = 6.0 < 6.7 = \lambda_1$, so F_b/Ω = 21.2 ksi

Section B.5.5.1 addresses the web; $b/t = 29.1 < 33.1 = \lambda_1$, so F_b/Ω = 31.8 ksi

The least of these is 21.1 ksi so the allowable moment for local buckling is

$M_{nlb}/\Omega = SF/\Omega$ = 21.2(14.9) = 316 in-k

The allowable moment is the least of the allowable moments for yielding (354 in-k), rupture (325 in-k), and local buckling (316 in-k), which is 316 in-k.

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For the limit state of shear rupture, Part VI Table 2-19 gives an allowable stress of 11.7 ksi. For the limit state of shear yielding or buckling, Section G.2 addresses shear in flat webs supported on both edges

For $b/t = (8.00 - 2(0.35))/0.23 = 31.7 < \lambda_1 = 35.3$,
$F_s/\Omega = 12.7$ ksi, allowable web shear stress.

Allowable shear =
$(F_s/\Omega)A_w = (11.7 \text{ k/in}^2)(8)(0.23 \text{ in}^2) = 21.5$ k

From Part VI, Beam Formulas Case 6, for a simply supported beam with a uniform load,

$M = wL^2/8$, which can be written as $w_1 = 8M/L^2$

$V = wL/2$, shear at end of beam. Rearranging, $w_2 = 2V/L$

$w_1 = 8M/L^2 = 8(314/12)/4^2 = 13.1$ k/ft for flexure.

$w_2 = 2V/L = 2(21.5)/4 = 10.7$ k/ft for shear

Since w_1, the allowable load for flexure, is greater than w_2, the allowable load for shear, the allowable load is $w_2 = 10.7$ k/ft.

NOTES: Section F.3.1, the weighted average flexural strength, could be used to determine a more precise and less conservative flexural strength. Since shear controlled, however, using Section F.3.1 would not result in a greater allowable distributed load on the beam.

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Example 27
WELDED CONNECTION
Illustrating Section J.2

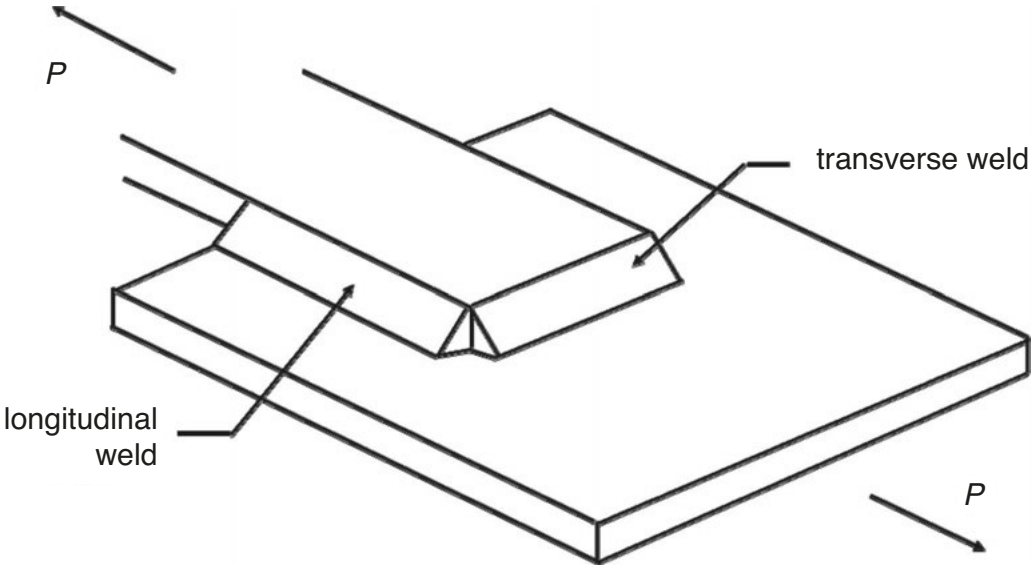

Figure 27

GIVEN:

1. Welded connection as shown in Figure 27
2. Longitudinal weld length 6 in. (each side), transverse weld length 4 in.
3. Weld size: S_w = 3/8 in. equal leg fillet
4. Base metal: 6061-T6, 0.500 in. thick
5. Product specification: ASTM B221
6. Filler alloy: 4043

FIND:

The allowable force P on the connection.

SOLUTION:

Section J.2 establishes the allowable strength of welded connections as R_n/Ω, where $\Omega = 1.95$.

Section J.2.2.1 defines the effective throat of a fillet weld; the effective throat for an equal leg fillet is

$S_{we} = 0.707S_w$

$S_{we} = 0.707(0.375 \text{ in.}) = 0.265 \text{ in.}$

Section J.2.2.2 defines the effective length $L_{we.}$ If longitudinal and transverse welds are not continuous at the corners:

$L_{we} = 4 \text{ in.} > 4S_w = 4(0.375 \text{ in.}) = 1.5 \text{ in.}$, so the full length of the weld is effective.

The length of the end-loaded fillet weld is
6 in. < 100(0.375 in.) = 37.5 in.,
which does not exceed the maximum effective length prescribed in Section J.2.2.2.

Section J.2.5 establishes the nominal strength of a fillet weld R_n as the lesser of the base material strength for the limit states of tensile rupture and shear rupture and the weld metal strength for the limit state of rupture as follows:

(a) For the base metal

$R_n = F_{nBM} A_{BM}$

where

F_{nBM} = nominal stress of the base metal corresponding to its welded ultimate strength from Table A.4.3

For base metal in tension,
$F_{nBM} = F_{tuw} = 24$ ksi

For base metal in shear,
$F_{nBM} = 0.6F_{tuw} = 0.6(24 \text{ ksi}) = 14.4$ ksi

A_{BMT} = cross-sectional area of the base metal in tension = (0.5 in.)(4 in.) = 2.0 in^2

A_{BMV} = cross-sectional area of the base metal in shear = (0.5 in.)2(6 in.) = 6.0 in^2

$R_n = (2.0 \text{ in}^2)(24 \text{ k/in}^2) + (6.0 \text{ in}^2)(14.4 \text{ k/in}^2) = 134.4 \text{ k}$

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(b) For the weld metal

$R_n = F_{nw} A_{we}$

where

F_{nw} = nominal stress of the weld metal corresponding to its ultimate strength from Table A.4.6

$F_{nw} = 0.6(0.85F_{tuw}) = (0.6)(0.85)(24\ k/in^2) = 12.2\ k/in^2$

A_{we} = effective area of the weld =
$S_{we}L_{we} = (0.265\ in.)(16\ in.) = 4.24\ in^2$

$R_n = F_{nw} A_{we} = (12.2\ k/in^2)(4.24\ in^2) = 51.7\ k$

Because the strength of the 4043 filler (F_{tuw} = 24 ksi) matches the welded strength of the 6061 base metal (F_{tuw} = 24 ksi), it is not necessary to check the strength of the fusion zone of the filler metal to the base metal, as the fillet weld throat is smaller than the fillet weld leg size, which is the width of the fusion zone. If the base metal's welded strength were less than the filler's strength, then the fusion zone's strength would need to be checked.

The lesser of the R_n values is 51.7 k, so

$P = R_n / \Omega = (51.7\ k)/1.95 = 26.5\ k$

NOTES: The strength of aluminum fillet welds is usually governed by the strength of the filler alloy, as in this example. Therefore, the joint strength can be increased by using a stronger filler, such as 5356. Table M.9.1 shows which fillers may be used.

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Example 28
OPEN SHAPE IN FLEXURE
Illustrating Sections F.2, F.3, and F.4

GIVEN:

1. Twin span curtainwall shape as shown in Figure 28d
2. Beam cross section and properties as given in Figure 28e
3. Uniform wind load of 26.3 lb/ft^2. Load must be applied as both a pressure (positive inward) and suction (negative) loading. Beams are spaced 5 ft o.c.
4. Lateral bracing provided at anchors and at horizontals
5. Alloy-temper: 6063-T5
6. Product specification: ASTM B221

FIND:

Check the given shape's ability to carry the wind load safely using ASD.

SOLUTION:

From Part VI, Beam Formulas Case 36, continuous beam of two equal spans-uniformly distributed load:

Load, w = (26.3 lb/ft^2) (5 ft) (1 ft/12 in.) = 11.0 lb/in. (positive and negative)

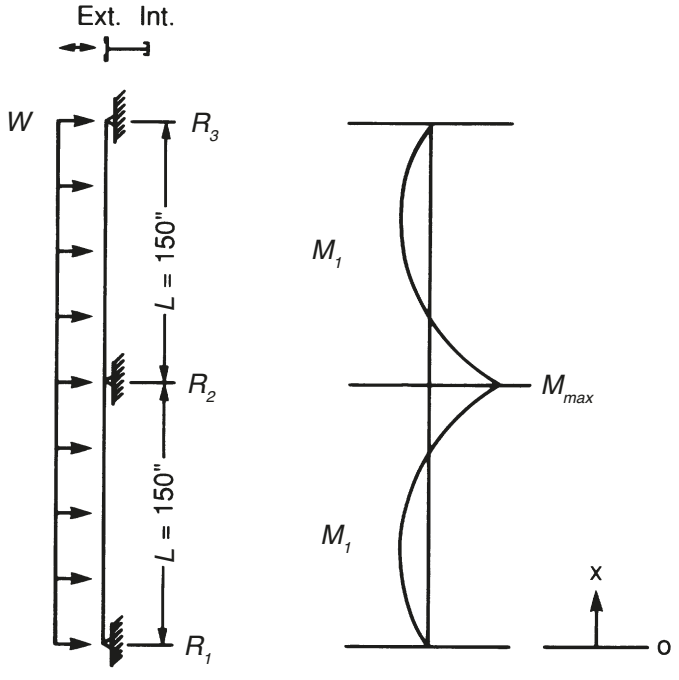

Figure 28a

At any point x between supports 1 and 2,

$$M(x) = R_1 x - \frac{wx^2}{2} = \left(\frac{3}{8}\right) wLx - \frac{wx^2}{2}$$

$$M_{max} = \frac{wL^2}{8} = \frac{(11.0)(150)^2}{8} = 30.9 \text{ in-k}$$

$$M_1 = \frac{9}{128} wL^2 = \frac{9(11.0)(150)^2}{128} = 17.4 \text{ in-k}$$

Per Section F.1, the available flexural strength of members is the least of the available strengths for the limit states of yielding, rupture, local buckling, and lateral-torsional buckling. These available strengths are tabulated below.

For local buckling:

For the interior flange, Section B.5.4.3, flat elements with one edge supported and one edge with stiffener, applies if $D_s/b < 0.8$; however,

D_s/b = (0.625 – 0.125)/[(1.75 – 2(0.375) – 0.125)/2]
= 0.5/0.4375 = 1.14 > 0.8,

so Section B.5.4.3 cannot be applied. Using instead Section B.5.4.1, flat elements supported on one edge,

b/t = (1.75 – 0.125)/2/0.125 = 6.5 < 8.2 = λ_1,
so F_b/Ω = 9.7 ksi

For the web (Section B.5.5.1, flat element with both edges supported):

h/t = (6 – 0.125 – 0.125 – 0.125)/0.125 = 45;
since λ_1 = 36.1 < 45 < 119 = λ_2

F_b/Ω = 17.2 – 0.072(45) = 14.0 ksi

For the exterior flange, b/t = (1.5 – 0.125/2)/0.125 = 11.5;
since λ_1 = 8.2 < 11.5 < 15.9 = λ_2,

F_b/Ω = 11.8 – 0.26(11.5) = 8.8 ksi

For lateral-torsional buckling, Section F.4 allows the slenderness to be determined by any applicable Section in F.4.2. Since this is an open shape unsymmetric about the bending axis and the minor axis moment of inertia of the compression flange is not always less than or equal to the minor axis moment of inertia of the tension flange, use Section F.4.2.5 to determine the slenderness ratio, since F.4.2.5 applies to any shape.

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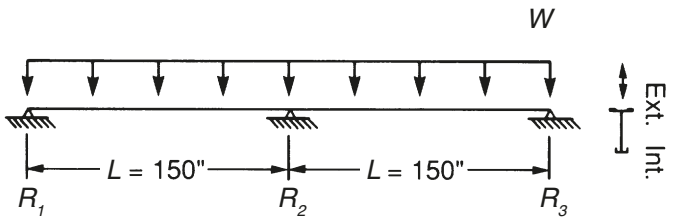

Figure 28b

For the inward pressure load:

	symbol	units	span			
			0' to 2'	2' to 10'-6	10'-6 to 12'-6	
compression flange at M_{max}			exterior	exterior	interior	
unbraced length	L_b	in.	24	102	24	
major axis moment of inertia	I_x	in^4	11.28	11.28	11.28	
distance from bottom to n.a.	c_x	in.	3.05	3.05	3.05	
depth of section	d	in.	6.00	6.00	6.00	
distance between flange centerlines	d_f	in.	5.75	5.75	5.75	= 6 – 0.125(2)
compressive section modulus	S_c	in^3	3.82	3.82	3.70	$= I/c^{-}$
tensile section modulus	S_t	in^3	3.70	3.70	3.82	$= I/c$
flange moment of inertia	I_{xf}	in^4	9.42	9.42	9.42	
web moment of inertia	I_{xw}	in^4	1.86	1.86	1.86	
y axis moment of inertia top flange	I_{ytop}	in^4	0.677	0.677	0.677	
y axis moment of inertia bottom flange	I_{ybot}	in^4	0.238	0.238	0.238	
y axis moment of inertia compression flange	I_{yc}	in^4	0.677	0.677	0.238	
coefficient of monosymmetry	β_x	in.	2.43	2.43	–2.48	$= 0.9d_f\left(\frac{2I_{yc}}{I_y}-1\right)\left[1-\left(\frac{I_y}{I_x}\right)^2\right]$
distributed load	w	k/in	0.011	0.011	0.011	
span	L	in.	150.0	150.0	150.0	
distance to 1/4 point	x	in.	6.0	49.5	132.0	
moment at 1/4 point	M_A	in-k	3.51	17.15	–14.16	
distance to 1/2 point	x	in.	12.0	75.0	138.0	
moment at 1/2 point	M_B	in-k	6.63	15.47	–19.35	
distance to 3/4 point	x	in.	18.0	100.5	144.0	
moment at 3/4 point	M_C	in-k	9.36	6.63	–24.95	
bending coefficient	C_b	-	1.61	1.21	1.49	$= \frac{4M_{\max}}{\sqrt{4M_{max}^2+4M_A^2+7M_B^2+4M_C^2}}$
distance from load to shear center	g_o	in.	–1.69	–1.69	–1.69	

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	symbol	units	span			
			0' to 2'	2' to 10'-6	10'-6 to 12'-6	
	U	in.	–0.239	–0.239	–1.465	$= C_1 g_0 + C_2 \beta_x/2$, where $C_1 = C_2 = 0.5$
torsion constant	J	in^4	0.0293	0.0293	0.0293	
warping constant	C_w	in^6	6.11	6.11	6.11	
minor axis moment of inertia	I_y	in^4	0.92	0.92	0.92	
plastic section modulus	Z	in^3	4.374	4.374	4.374	
modulus of elasticity	E	k/in^2	10,100	10,100	10,100	
elastic LTB buckling moment	M_e	in-k	395.0	36.6	257.1	$= \frac{\pi^2 E I_y}{L_b^2}\left[U + \sqrt{U^2 + \frac{0.038 J L_b^2}{I_y} + \frac{C_w}{I_y}}\right]$
LTB slenderness ratio	λ	-	24.5	92.9	31.0	$= \pi\sqrt{\frac{E S_{xc}}{C_b M_e}}$
slenderness limit	C_c	-	99	99	99	from Part VI Table 1-1
LTB moment	M_{nLTB}	in-k	62.3	40.8	59.9	see Section F.4
available LTB moment	M_{nLTB}/Ω	in-k	37.8	24.7	36.3	
compressive yield strength	F_{cy}	k/in^2	16	16	16	
tensile yield strength	F_{ty}	k/in^2	16	16	16	
tensile ultimate strength	F_{tu}	k/in^2	22	22	22	
safety factor (except for rupture)	Ω_y	-	1.65	1.65	1.65	
safety factor for rupture	Ω_u	-	1.95	1.95	1.95	
limit state moment for yielding	M_{np}	in-k	70.0	70.0	70.0	$= Z F_{cy}$
available moment for yielding	M_{np}/Ω	in-k	42.4	42.4	42.4	
available moment for rupture	M_{nu}/Ω	in-k	49.3	49.3	49.3	$= Z F_{tu}/k_t/\Omega$
available stress web local buckling	F_{nbLB}/Ω	k/in^2	14.0	14.0	14.0	
available stress flange local buckling	F_{ncLB}/Ω	k/in^2	8.8	8.8	9.7	
distance n.a. to flange centerline	c_{cf}	in.	2.76	2.76	2.987	
distance n.a. to web extreme fiber	c_{cw}	in.	2.70	2.70	2.925	
available moment for local buckling	M_{nLB}/Ω	in-k	39.7	39.7	39.5	$= (F_{ncLB}/\Omega) I_f/c_{cf} + (F_{nbLB}/\Omega) I_w/c_{cw}$
available moment	M_n/Ω	in-k	37.8	24.7	36.3	$= \min(M_{np}/\Omega, M_{nu}/\Omega, M_{nLB}/\Omega, M_{nLBT}/\Omega)$
maximum moment	M_{max}	in-k	11.7	17.4	30.9	
is $M_n/\Omega > M_{max}$?			OK	OK	OK	

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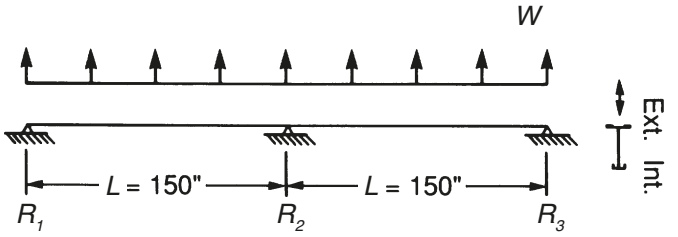

Figure 28c

For the outward pressure load:

	symbol	units	span			
			0' to 2'	2' to 10'-6	10'-6 to 12'-6	
compression flange at M_{max}			interior	interior	exterior	
unbraced length	L_b	in.	24	102	24	
major axis moment of inertia	I_x	in^4	11.28	11.28	11.28	
distance from bottom to n.a.	c_x	in.	3.05	3.05	3.05	
depth of section	d	in.	6.00	6.00	6.00	
distance between flange centerlines	d_f	in.	5.75	5.75	5.75	= 6 – 0.125(2)
compressive section modulus	S_c	in^3	3.70	3.70	3.82	$= I/c$
tensile section modulus	S_t	in^3	3.82	3.82	3.70	$= I/c$
flange moment of inertia	I_{xf}	in^4	9.42	9.42	9.42	
web moment of inertia	I_{xw}	in^4	1.86	1.86	1.86	
y axis moment of inertia top flange	I_{ytop}	in^4	0.677	0.677	0.677	
y axis moment of inertia bottom flange	I_{ybot}	in^4	0.238	0.238	0.238	
y axis moment of inertia compression flange	I_{yc}	in^4	0.238	0.238	0.677	
coefficient of monosymmetry	β_x	in.	–2.48	–2.48	2.43	$= 0.9 d_f \left(\frac{2I_{yc}}{I_y} - 1 \right) \left[1 - \left(\frac{I_y}{I_x} \right)^2 \right]$
distributed load	w	k/in	0.011	0.011	0.011	
span	L	in.	150.0	150.0	150.0	
distance to 1/4 point	x	in.	6.0	49.5	132.0	
moment at 1/4 point	M_A	in-k	3.51	17.15	–14.16	
distance to 1/2 point	x	in.	12.0	75.0	138.0	
moment at 1/2 point	M_B	in-k	6.63	15.47	–19.35	
distance to 3/4 point	x	in.	18.0	100.5	144.0	
moment at 3/4 point	M_C	in-k	9.36	6.63	–24.95	
bending coefficient	C_b	-	1.61	1.21	1.49	$= \frac{4M_{max}}{\sqrt{4M_{max}^2 + 4M_A^2 + 7M_B^2 + 4M_C^2}} R_m$

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	symbol	units	span			
			0' to 2'	2' to 10'-6	10'-6 to 12'-6	
distance from load to shear center	g_o	in.	1.69	1.69	1.69	
	U	in.	0.225	0.225	1.451	$= C_1 g_0 + C_2 \beta_x / 2$, where $C_1 = C_2 = 0.5$
torsion constant	J	in^4	0.0293	0.0293	0.0293	
warping constant	C_w	in^6	6.11	6.11	6.11	
minor axis moment of inertia	I_y	in^4	0.92	0.92	0.92	
plastic section modulus	Z	in^3	4.374	4.374	4.374	
modulus of elasticity	E	k/in^2	10,100	10,100	10,100	
elastic LTB buckling moment	M_e	in-k	468.6	40.7	720.4	$= \frac{\pi^2 E I_y}{L_b^2}\left[U + \sqrt{U^2 + \frac{0.038 J L_b^2}{I_y} + \frac{C_w}{I_y}}\right]$
LTB slenderness ratio	λ	-	22.1	86.7	18.8	$= \pi\sqrt{\frac{E S_{xc}}{C_b M_e}}$
slenderness limit	C_c	-	99	99	99	from Part VI Table 1-1
LTB moment	M_{nLTB}	in-k	62.8	41.6	64.1	see Section F.4
available LTB moment	M_{nLTB}/Ω	in-k	38.0	25.2	38.8	
compressive yield strength	F_{cy}	k/in^2	16	16	16	
tensile yield strength	F_{ty}	k/in^2	16	16	16	
tensile ultimate strength	F_{tu}	k/in^2	22	22	22	
safety factor (except for rupture)	Ω_y	-	1.65	1.65	1.65	
safety factor for rupture	Ω_u	-	1.95	1.95	1.95	
limit state moment for yielding	M_{np}	in-k	70.0	70.0	70.0	$= Z F_{cy}$
available moment for yielding	M_{np}/Ω	in-k	42.4	42.4	42.4	
available moment for rupture	M_{nu}/Ω	in-k	49.3	49.3	49.3	$= Z F_{tu} / k_t / \Omega$
available stress web local buckling	F_{nbLB}/Ω	k/in^2	14.0	14.0	14.0	
available stress flange local buckling	F_{ncLB}/Ω	k/in^2	9.7	9.7	8.8	
distance n.a. to flange centerline	c_{cf}	in.	2.987	2.987	2.76	
distance n.a. to web extreme fiber	c_{cw}	in.	2.925	2.925	2.70	
available moment for local buckling	M_{nLB}/Ω	in-k	39.5	39.5	39.7	$= (F_{ncLB}/\Omega) I_f / c_{cf} + (F_{nbLB}/\Omega) I_w / c_{cw}$
available moment	M_n/Ω	in-k	38.0	25.2	38.8	$= \min(M_{np}/\Omega, M_{nu}/\Omega, M_{nLB}/\Omega, M_{nLBT}/\Omega)$
maximum moment	M_{max}	in-k	11.7	17.4	30.9	
is $M_n/\Omega > M_{max}$?			OK	OK	OK	

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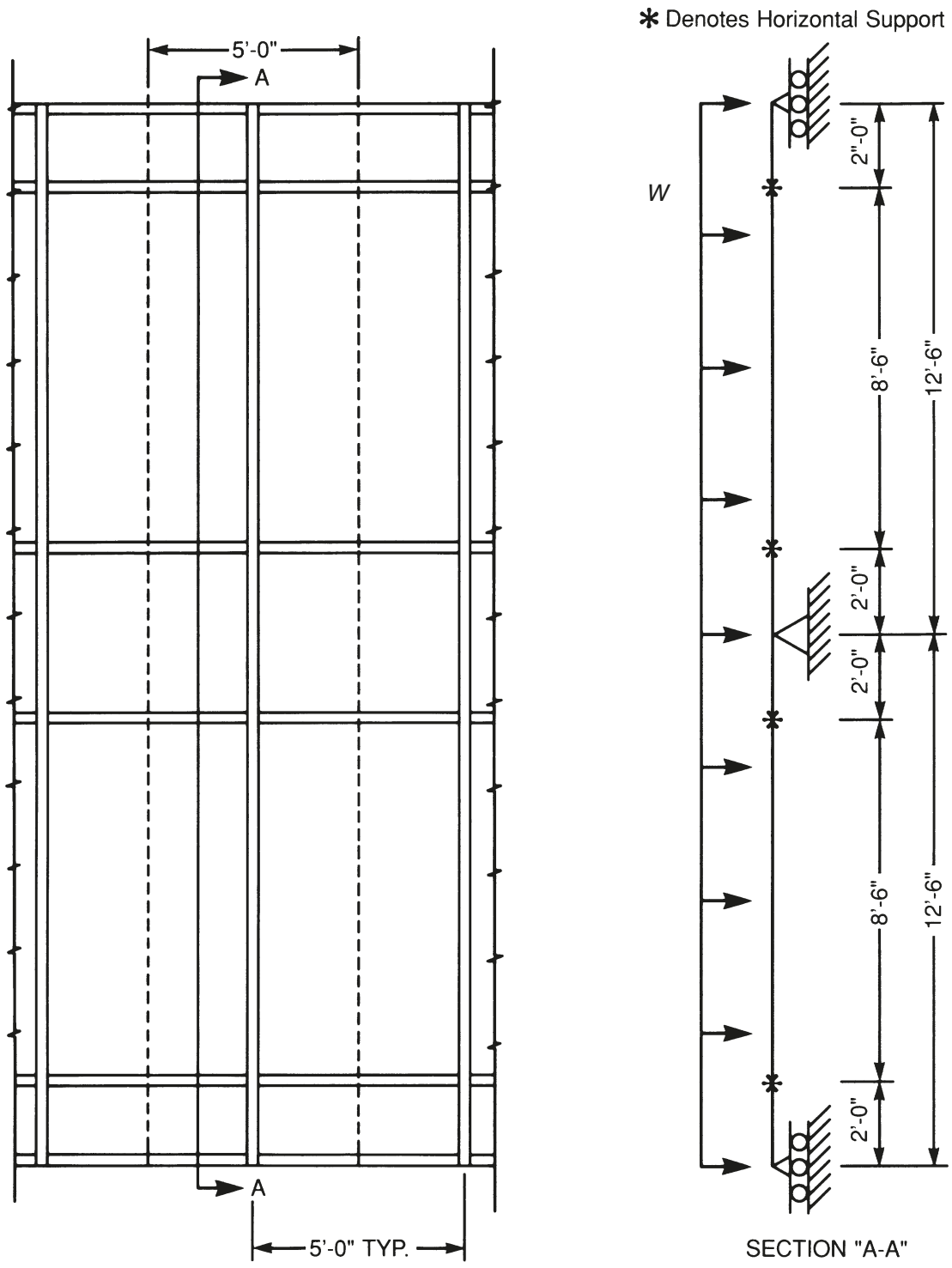

Figure 28d

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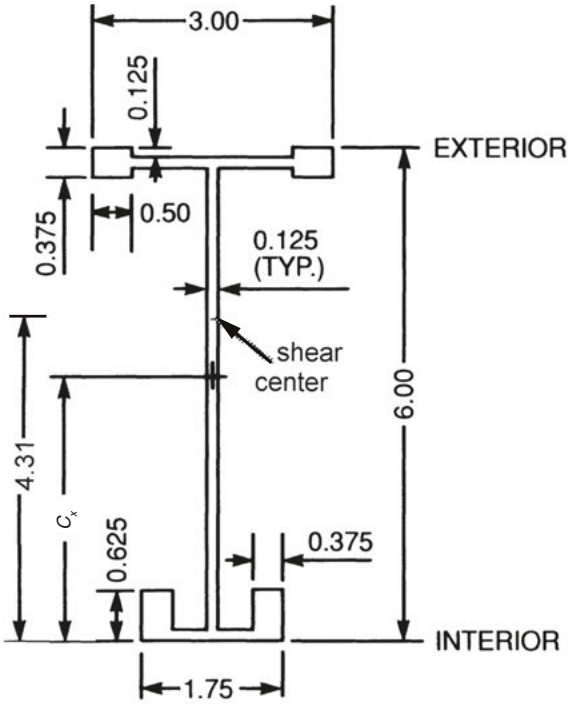

	Properties
A	1.92 in^2
I_x	11.28 in^4
c_x	3.05 in.
r_x	2.42 in.
I_y	0.92 in^4
r_y	0.69 in.
J	0.0293 in^4
C_w	6.11 in^6
Z	4.374 in^3
S_{top}	3.82 in^3
S_{bot}	3.70 in^3
I_{xf}	9.42 in^4
I_{xw}	1.86 in^4
I_{ytop}	0.677 in^4
I_{ybot}	0.238 in^4

Figure 28e

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Example 29
FORMED SHEET IN FLEXURE
Illustrating Sections B.5.4.2, B.5.5.1, F.2, F.3, J.9.3.2, L.3, and 1.4

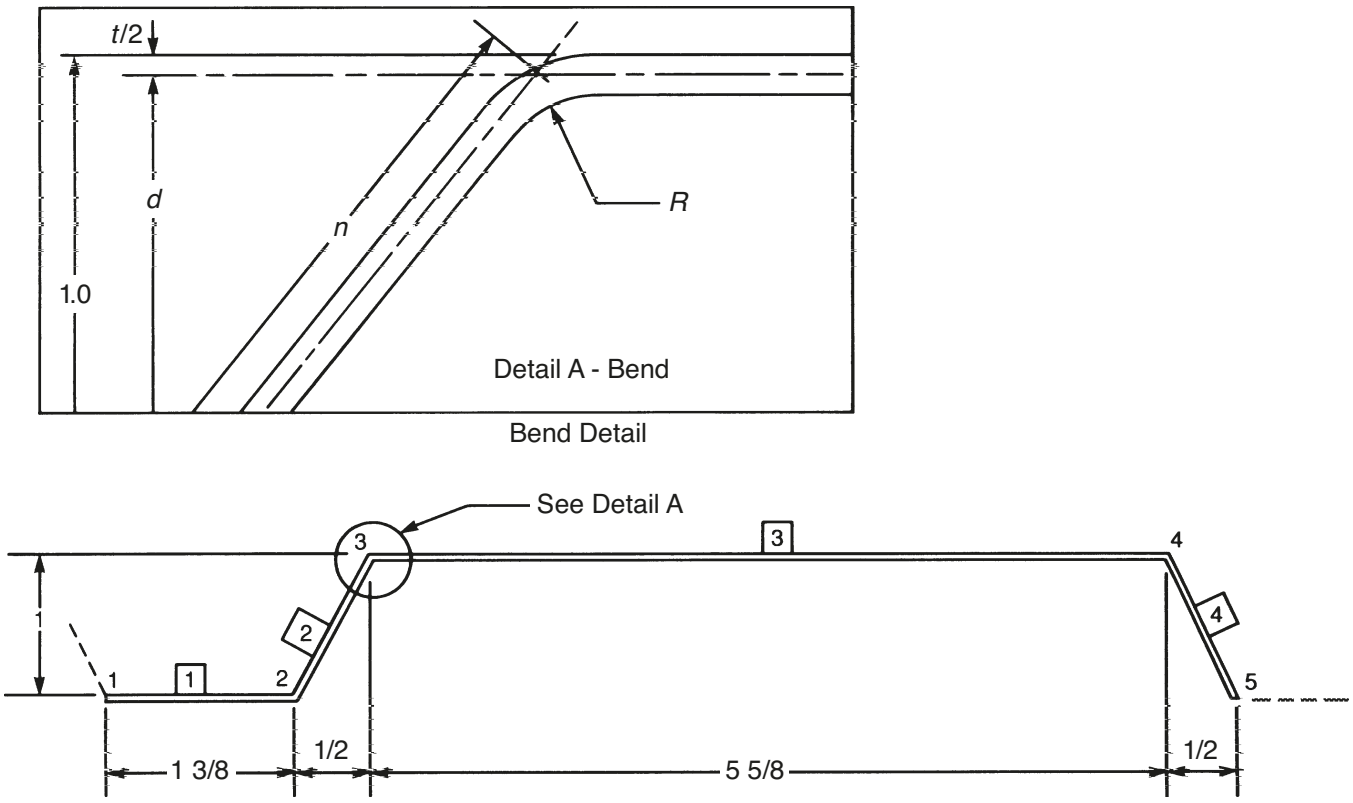

Figure 29

GIVEN:

1. 8 in. rib panel, repeating pattern
2. Thickness = 0.032 in.
3. Material: Alclad 3004-H151 (F_{tu} = 34 ksi, F_{ty} = 30 ksi)
4. Bend radii are 0.0625 in. at inner surface of each bend

FIND:

1. Allowable moments for:
   a. top in compression
   b. bottom in compression
2. Moment of inertia for deflection calculations
3. Allowable reactions:
   a. interior
   b. exterior
4. Check the applicability of calculations for the above against the criteria of Section 1.4.

SOLUTION:

1. Allowable moments for:
   a. top in compression
   b. bottom in compression

This siding is the 8" ribbed siding shown in Part V Table 20 with section properties given in Part V Table 21.

Calculations of Section Properties

The small radii are ignored. Nodal geometry is based on points of intersection of centerlines of elements.

Nodal geometry

Node	*x*	*y*
1	0.000	0.016
2	1.375	0.016
3	1.875	0.984
4	7.500	0.984
5	8.000	0.016

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Element Properties

Element	y	L	yL	y^2L	I
1	0.016	1.375	0.022	0.000	0.000
2	0.500	1.090	0.545	0.272	0.085
3	0.984	5.625	5.535	5.446	0.000
4	0.500	1.090	0.545	0.272	0.085
Totals		9.179	6.647	5.992	0.170

$c_t = \Sigma yL/\Sigma L = 6.647/9.179 = 0.724$ in., height of neutral axis

$I_x = [\Sigma(y^2L) - c_t^2\Sigma L + \Sigma I]t = [5.992 - (0.724)^2(9.179) + 0.170](0.032) = (1.349 \text{ in}^3)(0.032 \text{ in.})$

$I_x = 0.0432 \text{ in}^4$

$S_{bot} = I_x/c_t = 0.0432/0.724 = 0.0596 \text{ in}^3$

$S_{top} = I_x/(\text{height} - c_t) = 0.0432/(1 - 0.724) = 0.1565 \text{ in}^3$

The moment of inertia of the flanges (elements 1 and 3) is

$I_f = [(1.375)(0.724-0.016)^2+(5.625)(0.984-0.724)^2](0.032) = 0.0342 \text{ in}^4$

The moment of inertia of the webs (elements 2 and 4) is

$I_w = [2(1.090)(0.724 - 0.5)^2 + 2(0.085)] (0.032) = 0.0089 \text{ in}^4$

The plastic section modulus computed by finding the plastic neutral axis such that the area above this axis equals the area below is $Z = 0.0781 \text{ in}^3$.

Section F.1 states that the allowable moment is the least of the allowable moments for yielding, rupture, local buckling, and lateral-torsional buckling. Lateral-torsional buckling is unlikely to govern for this shape. Section F.1 also establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure.

By Section F.2, the allowable moment for yielding is the least of

$1.5F_{cy}S_c/\Omega$

$1.5F_{ty}S_t/\Omega$

and ZF_{cy}/Ω

For the top flange in compression,

$1.5F_{cy}S_c/\Omega = 1.5(27)(0.1565)/1.65 = 3.84$ in-k

$1.5F_{ty}S_t/\Omega = 1.5(30)(0.0596)/1.65 = 1.63$ in-k

and $ZF_{cy}/\Omega = (0.0781)(27)/1.65 = 1.28$ in-k,
so $M_{np}/\Omega = 1.28$ in-k.

For the bottom flange in compression,

$1.5F_{cy}S_c/\Omega = 1.5(27)(0.0596)/1.65 = 1.46$ in-k

$1.5F_{ty}S_t/\Omega = 1.5(30)(0.1565)/1.65 = 4.27$ in-k

and $ZF_{cy}/\Omega = (0.0781)(27)/1.65 = 1.28$ in-k,
so $M_{np}/\Omega = 1.28$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (0.0781)(34)/1/1.95 = 1.36$ in-k.

The allowable moment for the limit state of local buckling is determined using Section F.3.1.

For the top flange in compression,

a) Element 3 is in uniform compression;
$b/t = \lambda = 5.625/0.032 = 175.8$.

By Section B.5.4.2, $\lambda_2 = 41.8$, so

$$F_c/\Omega = \frac{k_2\sqrt{B_p E}}{(1.6\,b/t)\Omega} = \frac{2.04\sqrt{(37.6)(10{,}100)}}{1.6(175.8)(1.65)} = 2.7 \text{ ksi}$$

b) Elements 2 and 4 are in flexural compression;
$b/t = \lambda = 1.09/0.032 = 34.1$.

By Section B.5.5.1:

$c_c = 0.724 - 1 = -0.276$ in., $c_o = 0.724$ in.;
since $c_o/c_c = 0.724/(-0.276) = -2.62 < -1$,

$m = 1.3/(1 - c_o/c_c) = 1.3/(1 - (-2.62)) = 0.359$ and

$\lambda_1 = (B_{br} - 1.5F_{cy})/(mD_{br}) = (50.2 - 1.5(27))/0.359/0.433 = 62.4 > 34.1$,

so $F_b/\Omega = 1.5\,F_{cy} = 1.5(27)/1.65 = 24.5$ ksi

$M_{nLB}/\Omega = (F_c/\Omega)\,I_f/c_{cf} + (F_b/\Omega)\,I_w/c_{cw}$

$M_{nLB}/\Omega = (2.7)\,(0.0342)/(1 - 0.724 - 0.032/2) + 24.5(0.0089)/(0.276 - 0.032) = 1.25$ in-k

For the bottom flange in compression,

a) Element 1 is in uniform compression;
$b/t = \lambda = 1.375/0.032 = 43.0$.

By Section B.5.4.2, $\lambda_2 = 41.8$, so

$$F_c/\Omega = \frac{k_2\sqrt{B_p E}}{(1.6\,b/t)\Omega} = \frac{2.04\sqrt{(37.6)(10{,}100)}}{1.6(43.0)(1.65)} = 11.1 \text{ ksi}$$

b) Elements 2 and 4 are in flexural compression;
$b/t = \lambda = 1.09/0.032 = 34.1$.

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By Section B.5.5.1:

$c_c = -0.724$ in., $c_o = 0.276$ in.;
since $c_o/c_c = 0.276/(-0.724) = -0.381$, and
$-1 < -0.381 < 1$,

$m = 1.15 + c_o/2c_c = 1.15 + (-0.381/2) = 0.959$ and

$\lambda_1 = (B_{br} - 1.5F_{cy})/(mD_{br}) = (50.2 - 1.5(27))/0.959/0.433$
$= 23.4 < 34.1$,

$\lambda_2 = k_1 B_{br}/(mD_{br}) = 0.5(50.2)/0.959/0.433 = 60.4$

so $F_b/\Omega = (B_{br} - mD_{br}\lambda)/\Omega$
$= (50.2 - 0.959(0.433)(34.1))/1.65 = 21.8$ ksi

$M_{nLB}/\Omega = (F_c/\Omega) I_f/c_{cf} + (F_b/\Omega) I_w/c_{cw}$

$M_{nLB}/\Omega = (11.1)(0.0342)/(0.724 - 0.032/2) +$
$21.8(0.0089)/(0.724 - 0.032) = 0.82$ in-k

For the top flange in compression, the least of the allowable moments for yielding (1.28 in-k), rupture (1.36 in-k), and local buckling (1.25 in-k) is 1.25 in-k.

For the bottom flange in compression, the least of the allowable moments for yielding (1.28 in-k), rupture (1.36 in-k), and local buckling (0.82 in-k) is 0.82 in-k.

The above results can be converted to allowable moments per foot of width as follows:

M_{atc} = (1.25)(12 in./ft.)/(8 in./cycle)

= 1.87 k-in./ft-width (top in compression)

M_{abc} = (0.82)(12in./ft)/(8 in./cycle)

= 1.23 k-in./ft-width (bottom in compression)

2. Moment of inertia for deflection calculations

Refer to Section L.3

For element 1: $F_e = \dfrac{\pi^2 E}{(1.6b/t)^2} = \dfrac{\pi^2(10{,}100)}{(1.6(43))^2}$

$= 21.1$ ksi > 11.1 ksi $= f_a$

so the width of element 1 is not reduced for deflection calculations.

For element 3: $F_e = \dfrac{\pi^2 E}{(1.6b/t)^2} = \dfrac{\pi^2(10{,}100)}{(1.6(175.8))^2}$

$= 1.3$ ksi < 2.7 ksi $= f_a$

so the effective width of element 3 is

$b_e = b\,(F_e/f_a)^{1/2}$
$= 5.625\,(1.3/2.7)^{1/2}$
$= 3.90$ in.

Similarly, it can be seen that elements 2 and 4 are not reduced. A recalculation of the moment of inertia follows:

Element Properties

Element	y	L	L_{eff}	yL_{eff}	y^2L_{eff}	I_{eff}
1	0.016	1.375	1.375	0.022	0.000	0.000
2	0.500	1.090	1.090	0.545	0.272	0.085
3	0.984	5.625	3.90	3.838	3.78	0.000
4	0.500	1.090	1.090	0.545	0.272	0.085
Totals			7.455	4.95	4.32	0.170

$c_t = \sum (yL_{eff})/\sum L = 4.95/7.455$

$= 0.664$ in., height of neutral axis

$I_x = [\sum(y^2L_{eff}) - c_t^2 \sum L_{eff} + \sum I_{eff}]t$
$= [(4.32 - (0.664)^2(7.455) + 0.170)](0.032)$
$= (1.203\ \text{in}^3)(0.032\ \text{in.})$

$= 0.0385\ \text{in}^4$, for deflection calculations when element 3 is at its allowable compressive stress.

3. Allowable reactions:

a. allowable interior reaction

Reference: Section J.9.3.2

Let the bearing length, N, be 2.0 in.

Consider element 2 (a web).

$$P_c/\Omega = \frac{C_{wa}(N + C_{w1})}{\Omega C_{wb}}$$

where $C_{wa} = t^2 \sin\theta\,(0.46F_{cy} + 0.02\sqrt{EF_{cy}}\,)$

where $t = 0.032$ in.

$\theta = 63.4°$

$F_{cy} = (0.9)(30) = 27$ ksi

$E = 10{,}100$ ksi

so $C_{wa} = (0.032)^2 \sin 63.4°\,(0.46(27) + 0.02\sqrt{(10{,}100)(27)}$

$C_{wa} = 0.0209$ k

$C_{w1} = 5.4$ in.

$C_{wb} = C_{w3} + R_i\,(1 - \cos\theta)$

where

$C_{w3} = 0.4$ in.

$R_i = 0.0625$ in.

so

$C_{wb} = 0.4 + 0.0625\,(1 - \cos 63.4°)$

$C_{wb} = 0.435$ in.

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so $P_c/\Omega = \dfrac{(0.0209)(2.0+5.4)}{(1.95)(0.435)} = 0.182$ k per web

The allowable interior reaction, F_{int} is

$F_{int} = (P_c/\Omega)$(2 webs/cycle)(12 in./ft.)(1 cycle/8 in.) (1000 lb/k) = 546 lb/ft-width.

Section J.9.3.3, combined web crippling and flexure, should also be considered.

b. Allowable end reaction

Let the bearing length, l_b, be 2.0 in.

Again, consider element 2.

$$P_c/\Omega = \frac{1.2C_{wa}(l_b + C_{w2})}{\Omega C_{wb}}$$

where $C_{wa} = 0.0209$ k [see (a) above]

$C_{w2} = 1.3$ in.

$C_{wb} = 0.435$ in. [see (a) above]

$P_c/\Omega = \dfrac{1.2(0.0209)(2.0+1.3)}{(1.95)(0.435)} = 0.098$ k per web.

The allowable end reaction, P_{end}, is:

$P_{end} = (P_c/\Omega)$(2 webs/cycle)(12 in./ft)(1 cycle/8 in.) (1000 lb/k) = 293 lb/ft-width

4. Check the applicability of calculations for the above against the criteria of Section 1.4.

Cases (a), (b), and (e) do not apply. Cases (c), (f), and (g) vary with each installation.

Case (d) is checked as follows:

maximum $b = 5.625 + 2(0.25)$

$= 6.125$ in.

$b/t = 6.125/0.032$

$= 191$

Condition (1) is stated then algebraically rearranged.

(1) $b/t < \dfrac{1230}{\sqrt[3]{q}}$ otherwise tests are required.

$q < (1230/(b/t))^3$

$q < 265$ psf

Condition (2) is treated likewise

(2) $b/t < 435\sqrt{F_{ty}/q}$ otherwise tests are required.

$q < [435/(b/t)]^2 F_{ty}$

$q < [435/191]^2(30)$

$q < 155$ psf

Subcase (2) governs. Tests must be run to establish the load carrying capacity of the panel when:

a. $q > 155$ psf

b. Cases (c), (f), or (g) are not satisfied.

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Example 30
SCREW CONNECTION
Illustrating Section J.5

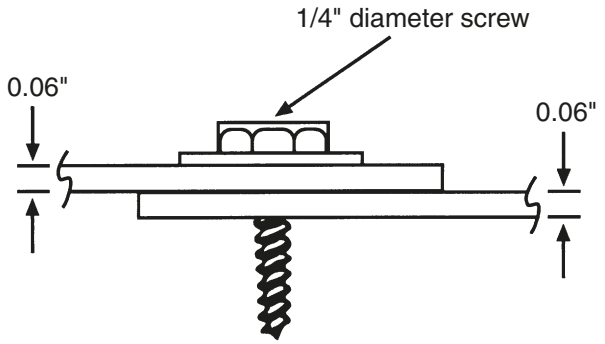

Figure 30

GIVEN:

1. Tapping screw of 7075-T73 aluminum, 1/4” diameter, UNC thread joining 0.06 in. thick 3003-H16 sheet on top of 0.06 in. thick 5052-H32 sheet
2. Sheet product specification: ASTM B209
3. 5/8” outside diameter flat washer under the screw head
4. The hole diameter in the top sheet is 9/32 in.
5. Distance from center of screw to edge of sheet is 1 in.

FIND:

The allowable shear and tension forces for the connection.

SOLUTION:

1. Allowable shear force

The allowable connection shear is determined according to Section J.5.5, which specifies a safety factor $\Omega = 3.0$ for screw connection shear.

a) Section J.5.5.1 addresses bearing. Since the edge distance is 1 in. > 0.5 in. = 2(1/4 in.) = 2D, the allowable bearing force is $2F_{tu}Dt/\Omega$. Using F_{tu} from Table A.4.3, the allowable shear for bearing is

Sheet	Alloy	Thickness (in.)	F_{tu} (ksi)	$2F_{tu}Dt/\Omega$ (k)
1	3003-H16	0.06	24	0.24
2	5052-H32	0.06	31	0.31

b) Section J.5.5.2 addresses screw tilting. Since $t_2 = 0.06 \leq 0.06 = t_1$, the allowable screw tilting shear is

$$R_n/\Omega = 4.2\,(t_2^3 D)^{1/2} F_{tu2}/\Omega$$
$$= 4.2\,(0.06^3\,(0.25))^{1/2}(31)/3 = 0.32 \text{ k}$$

c) Section J.5.5.3 addresses screw shear. The single shear strength of a 1/4” 7075-T73 machine screw is given in Part VI, Table 5-1 as 1170 lb.

$$R_n/(1.25\Omega) = (1170 \text{ lb})/(1.25(3)) = 0.31 \text{ k}$$

The allowable shear is the least of 0.24, 0.31, 0.32, and 0.31 k, so the allowable shear is 0.24 k based on bearing on the top sheet.

2. Allowable tensile force

The allowable connection tension is determined according to Section J.5.4, which specifies a safety factor $\Omega = 3.0$ for screw connection tension.

Section J.5.4 requires that the washer outside diameter D_w equal or exceed 5/16 in.:

D_w = 5/8 in. > 5/16 in.

a) Section J.5.4.1 addresses pull-out. The allowable pull-out force is

$$R_n/\Omega = K_s D L_e F_{ty2}/\Omega$$
$$= (1.01)(0.25)(0.06)(23)/3 = 0.12 \text{ k}$$

b) Section J.5.4.2 addresses pull-over. The allowable pull-over force is:

$$R_n/\Omega = C_{pov}\, t_1 F_{tu1}(D_{ws} - D_h)/\Omega$$
$$= (1.0)(0.06)(24)(0.625 - 9/32)/3$$
$$= 0.16 \text{ k}$$

c) Section J.5.4.3 addresses screw tension. The tensile strength of a 1/4” diameter 7075-T73 machine screw is given in Part VI, Table 5-1 as 1940 lb.

$$R_n/(1.25\Omega) = (1940 \text{ lb})/(1.25(3)) = 0.52 \text{ k}$$

The allowable tension is the least of 0.12, 0.16, and 0.52 k, so the allowable tension is 0.12 k based on pull-out.

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Example 31
FLEXURAL STRENGTH
Illustrating Sections F.2 and F.3

GIVEN:

1. Symmetric Shape: Aluminum Association standard W-shape AW 12 x 14.3

d	12”
b_f	7”
t_f	0.62”
t_w	0.31”
S_x	52.9 in^3
Z	59.1 in^3
web height h	10.76” = 12” – 2(0.62”)
flange area	7(0.62) = 4.34 in^2
web area	10.76(0.31) = 3.34 in^2

Unsymmetric Shape: Modified AW 12 x 14.3 (top flange 1” wide instead of 7” wide)

d	12”
b_f (bottom)	7”
b_f (top)	1”
t_f	0.62”
t_w	0.31”
web height h	10.76”= 12” – 2(0.62”)
bottom flange area	7(0.62) = 4.34 in^2
top flange area	1(0.62) = 0.62 in^2
web area	10.76(0.31) = 3.34 in^2

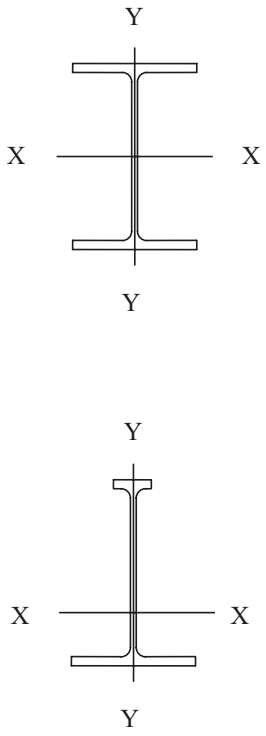

Figure 31

2. Alloy: 6061-T6

3. Product specification: ASTM B308

4. Continuous minor axis lateral bracing

FIND:

The allowable moment about the major axis for each shape for loading causing compression in the top flange

SOLUTION:

Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Symmetric Shape: Aluminum Association standard W-shape AW 12 x 14.3:

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure. Because the beam is continuously laterally supported, the beam is not subject to lateral-torsional buckling.

Section F.2 addresses yielding and rupture:

For the limit state of yielding, the allowable moment is the lesser of

$1.5F_{cy}S_c/\Omega = 1.5(35)(52.9)/1.65 = 1683$ in-k

and $ZF_{cy}/\Omega = (59.1)(35)/1.65 = 1254$ in-k, so
$M_{np}/\Omega = 1254$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (59.1)(38)/1/1.95 = 1152$ in-k.

Section F.3 addresses local buckling:

Section B.5.4.1: Flange:
$b/t = (7” – 0.31” – 2(0.40))/2/(0.62”) = 4.8 < 6.7 = \lambda_1$, so
$F_c/\Omega = 21.2$ ksi

Section B.5.5.1: Web:
$b/t = (10.76”)/(0.31”) = 34.7 > 33.1 = \lambda_1$, so
$F_b/\Omega = 40.5 – 0.262(34.7) = 31.4$ ksi

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$I_f = 2[(7")(0.62")^3/12 + (7")(0.62")(6" - 0.62"/2)^2]$
$= 281.3 \text{ in}^4$

$c_{cf} = 12"/2 - (0.62"/2) = 5.69"$

$c_{tf} = 12"/2 = 6"$

$I_w = (0.31")(10.76")^3/12 = 32.2 \text{ in}^4$

$c_{cw} = c_{tw} = 10.76"/2 = 5.38"$

From Section F.3.1, the weighted average method allowable moment is:

$$\frac{M_{nlb}}{\Omega} = \frac{(F_c/\Omega)I_f}{c_{cf}} + \frac{(F_b/\Omega)I_w}{c_{cw}}$$
$$= \frac{(21.2)(281.3)}{5.69} + \frac{(31.4)(32.2)}{5.38} = 1236 \text{ in-k}$$

The allowable moment is the least of the allowable moments for yielding, rupture, and local buckling, which is 1152 in-k.

Unsymmetric Shape: Modified AW 12 × 14.3 (top flange 1" wide):

Determine moment of inertia: (Table below)

The neutral axis is located $(70.96 \text{ in}^3)/(8.3 \text{ in}^2) = 8.55"$ below the top of the section.

The section modulus on the top (compression) side is $S_c = I/c_c = 139/8.55 = 16.24 \text{ in}^3$.

The section modulus on the bottom (tension) side is $S_t = I/c_t = 139/3.45 = 40.29 \text{ in}^3$.

The plastic neutral axis is determined to be located 0.593 in. above the bottom of the shape, and the plastic modulus $Z = 26.15 \text{ in}^3$.

Section F.2 addresses yielding and rupture:

For the limit state of yielding, the allowable moment is the least of

$1.5F_{cy}S_c/\Omega = 1.5(35)(16.24)/1.65 = 517$ in-k

$1.5F_{ty}S_t/\Omega = 1.5(35)(40.28)/1.65 = 1282$ in-k

and $ZF_{cy}/\Omega = (26.15)(35)/1.65 = 555$ in-k, so
$M_{np}/\Omega = 517$ in-k.

For the limit state of rupture, the allowable moment is

$M_{nu}/\Omega = ZF_{tu}/k_t/\Omega = (26.15)(38)/1/1.95 = 510$ in-k.

Section F.3 addresses local buckling:

Section B.5.4.1: Flange: |
$b/t = (1" - 0.31")/2/(0.62") = 0.6 < 6.7 = \lambda_1$, so
$F_c/\Omega = 21.2$ ksi

Section B.5.5.1: Web: $b/t = (10.76")/(0.31") = 34.7$

The neutral axis is located 8.55" – 0.62" = 7.93" below top end of web and 10.76" – 7.93" = 2.83" above bottom of web.

$c_o/c_c = 2.83/(-7.93) = -0.36$, so

$m = 1.15 + (-0.36)/2 = 0.97$.

$\lambda_1 = (B_{br} - 1.5F_{cy})/(mD_{br})$
$= (66.8 - 1.5(35))/[(0.97)(0.665)] = 22.2 < 34.7 = b/t$,

$\lambda_2 = k_1B_{br}/(mD_{br}) = (0.5)(66.8)/0.97/0.665 = 51.8$

so $F_b/\Omega = B_{br}/\Omega - mD_{br}(b/t)/\Omega$
$= 66.8/1.65 - 0.97(0.665)(34.7)/1.65 = 26.9$ ksi

$I_f = 42.93 + 42.12 = 85.05 \text{ in}^4$
$c_{cf} = 8.55" - 0.62"/2 = 8.24"$
$c_{tf} = 12" - 8.55" = 3.45"$
$I_w = 53.9 \text{ in}^4$
$c_{cw} = 7.93"$
$c_{tw} = 2.83"$

From Section F.3.1, the allowable moment is:

$$\frac{M_{nlb}}{\Omega} = \frac{(F_c/\Omega)I_f}{c_{cf}} + \frac{(F_b/\Omega)I_w}{c_{cw}}$$
$$= \frac{(21.2)(85.05)}{8.24} + \frac{(26.9)(53.9)}{7.93} = 402 \text{ in-k}$$

The allowable moment is the least of the allowable moments for yielding, rupture, and local buckling, which is 402 in-k.

	A in^2	y in	Ay in^3	d in	Ad^2 in^4	I in^4	$Ad^2 + I$ in^4
bottom flange	4.34	11.69	50.73	3.14	42.79	0.14	42.93
web	3.34	6	20.04	2.55	21.72	32.18	53.9
top flange	0.62	0.31	0.19	8.24	42.10	0.02	42.12
total	8.3		70.96		106.61	32.34	139

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PART VIII

GUIDELINES FOR ALUMINUM SHEET METAL WORK IN BUILDING CONSTRUCTION

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

PART VIII

Guidelines for Aluminum Sheet Metal Work In Building Construction

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Guidelines for Aluminum Sheet Metal Work in Building Construction

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1. SCOPE

These guidelines apply to the use of aluminum in roofing, flashing and other sheet metal work in building construction. They do not apply to proprietary or pre-formed sheet metal systems or products such as horizontal siding, fascia and soffit systems, curtain wall systems, or corrugated or ribbed roofing and siding.

2. MATERIALS

2.1 ALUMINUM SHEET

2.1.1 Alloy and Temper

Sheet shall be 1100, 3003, Alclad 3003, 3004, Alclad 3004, 3105, 5005, 5050, or 5052 alloy and H14 or H34 temper. Properties shall conform to *Aluminum Standards and Data*.

Table 1 Minimum Nominal Sheet Thickness

	Residential		Non-Residential	
	(in.)	(mm)	(in.)	(mm)
Roofing				
Standing Seam	0.024	0.60	0.032	0.80
Batten Seam	0.024	0.60	0.032	0.80
Shingles	0.019	0.50	0.019	0.50
Proprietary Systems	0.019	0.50	0.024	0.60
Flashings				
Base	0.019	0.50	0.032	0.80
Cap	0.019	0.50	0.032	0.80
Ridge, Hip	0.024	0.60	0.032	0.80
Coping Covers	0.024	0.60	0.032	0.80
Scuppers	0.024	0.60	0.032	0.80
Splash Pans	0.032	0.80	0.040	1.0
Chimney	0.019	0.50	0.032	0.80
Apron	0.024	0.60	0.032	0.80
Head	0.019	0.50	0.032	0.80
Sill	0.019	0.50	0.032	0.80
Curbs	0.024	0.60	0.032	0.80
Through-Wall				
Lintel	0.024	0.60	0.032	0.80
Spandrel	0.024	0.60	0.032	0.80
Sill	0.024	0.60	0.032	0.80
Parapets	0.024	0.60	0.032	0.80
Gravel Stops and Fascia	0.024	0.60	0.032	0.80
Edge Strips	0.024	0.60	0.032	0.80
Gutters				
Gutters	0.027	0.70	0.032	0.80
Continuous Cleats	0.024	0.60	0.032	0.80
Hangers	0.064	1.6	0.080	2.0
Rainwater Goods				
Downspouts (Leaders)	0.019	0.50	0.024	0.60
Elbows	0.019	0.50	0.024	0.60
Leader Heads	0.024	0.60	0.032	0.80
Clips	0.040	1.0	0.064	1.6
Straps	0.040	1.0	0.064	1.6
Valley	0.019	0.50	0.032	0.80
Snow, Eave	0.024	0.60	0.032	0.80
Expansion Joint, Building			0.032	0.80

2.1.2 Thickness

Sheet thickness shall be sufficient for the intended use, but not less than the minimum nominal thickness listed in Table 1. The thickness of shingles and proprietary roofing systems shall be determined for specific applications on the basis of load tests.

2.1.3 Dimensional Tolerances

Tolerances on sheet dimensions shall conform to *Aluminum Standards and Data.*

2.1.4 Finish

Sheet shall be mill finish unless otherwise specified. Embossed, anodized, or painted sheet shall be acceptable provided it has the necessary strength and formability for the intended purpose.

2.2 BUILDING PAPER AND ROOFING FELT

Building paper or roofing felt used where condensation occurs such as over poorly vented spaces shall be vapor barriers conforming to Federal Specifications UU-B-790A, Type I, Grade A; HH-R-590A, Type II, Class C; or polyethylene not less than 4 mils (0.1 mm) thick conforming to Federal Specifications L-P-378B or L-P-512A.

Building paper or roofing felt over well ventilated spaces need not be water proof but shall be water repellant and conform to Federal Specifications UU-B-790A, Type I, Grade C or D; HH-R-590A, Type II; or HH-R-595B, Type I or II.

Building paper and roofing felt that contains additives of heavy metals or chemicals corrosive to aluminum shall not be used.

Building paper or roofing felt shall have a minimum weight of 15 lb (6.8 kg) and shall be overlapped at least 2 in. (50 mm) so as to shed water and shall be secured along the laps with large flat headed aluminum nails spaced no farther than 6 in. (150 mm) on centers.

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2.3 SEALANTS

2.3.1 One Part

One part synthetic or rubber base sealants shall conform to Federal Specification TT-S-230A(1). Use shall conform to manufacturers' specifications.

2.3.2 Two Part

Two part synthetic or rubber base sealants shall conform to Federal Specification TT-S-00227E(1) or ANSI A116.1. Use shall conform to manufacturers' specifications.

2.4 ELASTIC CEMENT

Elastic cement shall conform to Federal Specification SS-C-153.

2.5 FASTENERS

2.5.1 Cleats

Cleats shall be aluminum of the same alloy, temper, and nominal thickness as the sheet unless otherwise specified. Cleats shall be at least 2 in. (50 mm) wide and long enough to be fully incorporated into the seam with the other end folded back over the nail heads. They shall be fastened securely with two aluminum nails placed parallel to the seam.

2.5.2 Nails

Nails shall be 5056 or 6061 aluminum and conform to ASTM F 1667.

2.5.3 Screws, Bolts, and Nuts

Screws and bolts shall be 6061-T6 or 2024-T4 aluminum except that 2024-T4 fasteners shall not be used in marine or corrosive industrial environments. Nuts shall be 6061-T6 or 6262-T9 aluminum. Alternately, screws, bolts and nuts shall be 300 series stainless steel. Washers shall be used under bolt and screw heads.

2.5.4 Washers

Washers shall be 1100-H18 aluminum or of the same material as the sheet or fasteners used. The minimum nominal thickness of washers shall be 0.040 in.(1 mm). Where water tightness is required an elastomeric washer shall be used with the metal washer.

2.5.5 Miscellaneous Hardware

Expansion inserts, plugs, anchors, and shields shall be wood, fiber, plastic, lead, or aluminum and shall be chosen to suit the environment of each application.

2.5.6 Rivets

Rivets shall be 1100-H14 aluminum unless otherwise specified. Rivets shall have a shank diameter of at least 0.187 in. (4.75 mm) and sufficiently long to form a proper head. Blind rivets shall be used only where maximum water tightness, strength, or corrosion resistance is not required. Blind rivets shall be 1100 sleeve, 5056 mandrel; 5050 sleeve, 5056 mandrel; 5052 sleeve, 5056 mandrel; 5052 sleeve, 7178 mandrel; 5056 sleeve, 1020 steel mandrel; stainless steel; or monel.

2.6 PAINT

Paint for back painting aluminum shall be bituminous paint of the cut-back type conforming to specification MIL-C-450 B (1) or TT-C-494 or methacrylate type lacquers conforming to MIL-L-19537C (2).

3. SURFACE PREPARATION

3.1 GENERAL

All surfaces upon which aluminum sheet is to be placed shall be smooth, even and free of projections and hollows. The surface shall be dry before and during the placing of the aluminum. For wood surfaces the lumber shall be of good quality, well seasoned, straight, and free of knotholes and splits. It shall be laid with joints true, even, and firmly attached with all fastener heads flush with the top surface. On masonry surfaces adequate provision shall be made for receiving fasteners in accordance with the plans for sheet metal work.

3.2 DISSIMILAR METALS

Galvanic corrosion of aluminum caused by contact with dissimilar metals shall be prevented by proper design considerations and installation procedures. Water that has come in contact with copper, brass, or bronze shall be directed away from aluminum.

3.3 WOOD

Wood sheathing or wood surfaces to be covered with aluminum shall be covered with building paper or roofing felt (Section 2.2) or the wood shall be painted with two coats of good quality exterior type paint or the aluminum shall be back painted (Section 2.6).

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3.4 CONCRETE AND MASONRY

Concrete and masonry surfaces to be covered with aluminum shall be covered with building paper or roofing felt (Section 2.2) or the aluminum shall be back painted (Section 2.6). Where aluminum is to be caulked into slots or reglets in masonry, brickwork, or concrete, the slot or reglet shall be filled with sealant (Section 2.3) so that the sealant covers both surfaces of that part of the aluminum in the slot or reglet.

4. JOINING

4.1 MECHANICAL JOINTS

Mechanical seams and joints for aluminum shall be the same as those used for other sheet metals. Lap and lock seams shall not be riveted or otherwise fastened together to restrict relative movement unless such seams are designed to transfer movement to a different location.

End joints of formed sheet members such as ridge, hip, valley, gable or rake strips, battens, aprons, gravel stops, coping and cap flashing shall not be riveted or fastened together to restrict movement. Simple laps shall not be used unless the slope is sufficient to provide drainage and flat widths are less than 8 in. (200 mm). For flashing with flat widths over 8 in. (200 mm) or surfaces with slopes less than 3 in 12 (1:4), sealant filled controlled slip joints shall be used. Joints shall allow for thermal movement of 0.125 in. (3 mm) or that determined for the application allowing for the temperature of the metal at the time of installation, whichever is greater.

The installer shall account for the metal temperature at the time of installation and leave adequate allowance for expansion and contraction.

4.2 SOLDERING

Aluminum shall not be soldered.

4.3 BRAZING

Brazing shall be done in the shop and flux residue shall be completely removed.

4.4 WELDING

Welding shall comply with AWS D1.2.

5. STANDING SEAM ROOFING

5.1 ROOF SLOPES

These specifications do not apply to roofs with slopes less than 3 in 12 (1:4).

5.2 DIMENSIONS

Roof sheets shall not exceed 10 ft (3 m) and no straight run of roofing shall exceed 30 ft (10 m). Nominal sheet thickness shall be 0.024 in. (0.6 mm) where the distance between standing seams does not exceed 20 in. (500 mm) and 0.032 in. (0.8 mm) where the distance between standing seams is from 20 in. (500 mm) to 27 in. (700 mm). To allow for expansion, sheet width shall be 0.125 in. (3 mm) less than the center to center spacing of the standing seams.

5.3 TRANSVERSE SEAMS

5.3.1 (See Figures 1 and 2). For roofs with slopes 6 in 12 (1:2) or greater, the lower end of each sheet shall be folded under 0.75 in. (20 mm). The fold shall be slit 1 in. (25 mm) away from the corner to form a tab where the sheet turns up to make a standing seam. The upper end of each sheet shall be folded over 2 in. (50 mm). The 0.75 in. (20 mm) fold on the lower end of the upper sheet shall be hooked into the 2 in. (50 mm) fold on the upper end of the underlying sheet. Transverse seams shall be staggered a distance of one half the sheet length in adjacent roof sheets.

5.3.2 (See Figures 1 and 2). For roofs with slopes at least 3 in 12 (1:4) but less than 6 in 12 (1:2), the lower end of each sheet shall be folded under 0.75 in. (20 mm). The fold shall be slit 1 in. (25 mm) away from the corner to form a tab where the sheet turns up to make a standing seam. The upper end of each sheet shall be folded over 0.5 in. (12 mm). A 1.5 in. (38 mm) wide locking strip the full width of the sheet shall be secured at least 4 in. (100 mm) below the top folded edge by rivets spaced no more than 6 in. (150 mm) apart. The 0.75 in. (20 mm) fold on the lower end of the upper sheet shall hook into the locking strip on the upper end of the underlying sheet. Alternately, transverse seams shall be made as specified in Section 5.3.1 and filling the seams with sealant. Transverse seams shall be staggered a distance of one half the sheet length in adjacent roof sheets.

5.4 DIMENSIONS

(See Figure 1). Standing seams shall finish 1 in. (25 mm) high except on curved surfaces where they shall finish a minimum of 0.75 in. (20 mm) high. One side edge of roof sheets shall be 1.5 in. (38 mm) high and the other

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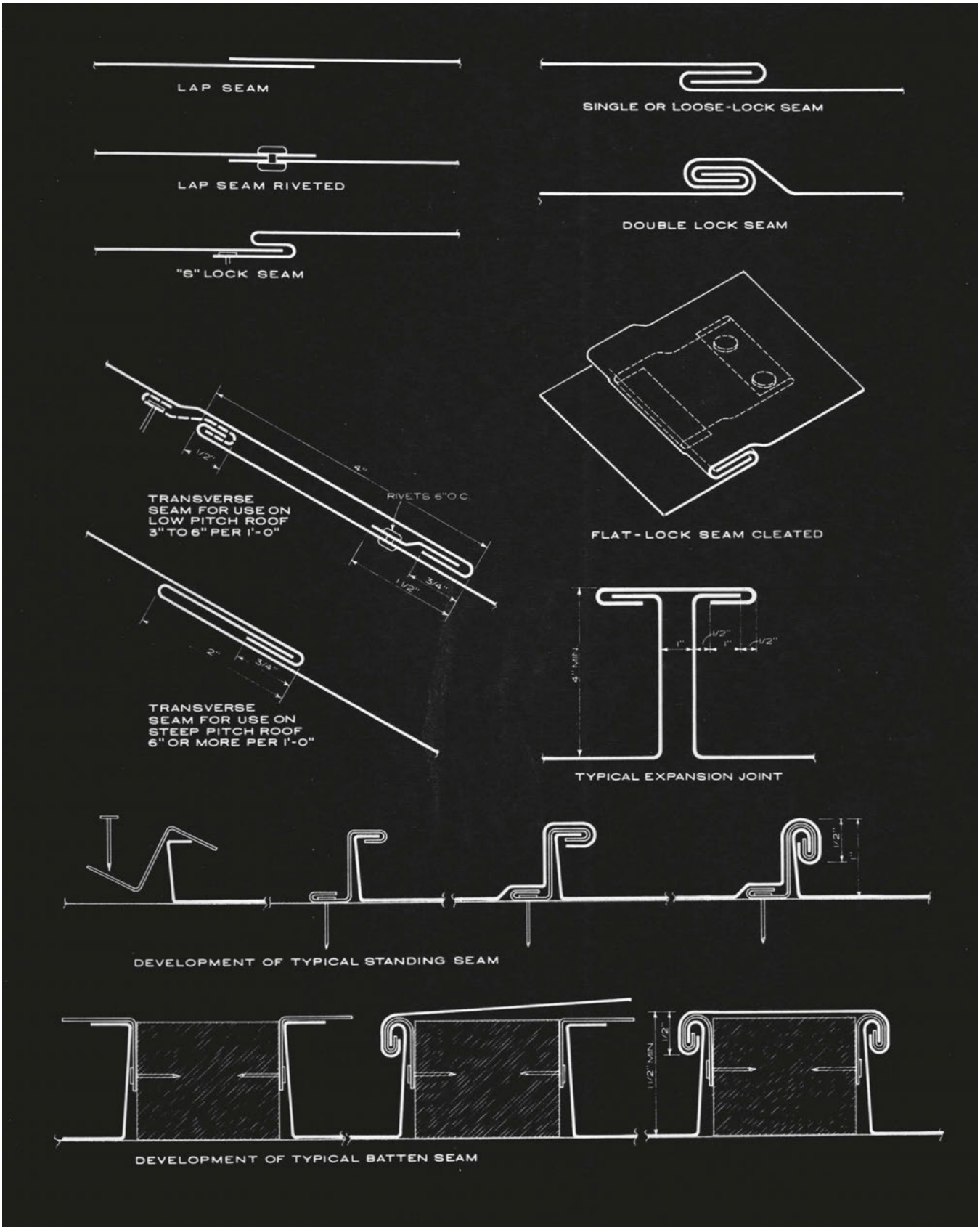
Figure 1
SEAMS AND JOINTS



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1.75 in. (44 mm) high. The first fold shall be a single fold 0.25 in. (6 mm) wide and the second fold shall be 0.5 in. (12 mm) wide. The lock portion of the standing seam shall be 5 plies thick. A space at least 0.125 in. (3 mm) wide shall be provided between adjacent sheets at the bottom of each standing seam. At eaves, ends of standing seams shall be closed by folding over a tab provided at one side of each roof sheet.

5.5 CLEATS

Cleats shall be at least 2 in. (50 mm) wide and shall be spaced not more than 12 in. (300 mm) apart between centers. If the roof deck is a material other than wood, nailers shall be provided to secure the cleats.

5.6 RIDGES AND HIPS

(See Figure 2). Ridges and hips shall be provided with standing seams constructed as for the main roof. Where standing seams of the main roof terminate at ridges or hips they shall be laid flat and folded into ridge or hip standing seams. Standing seams on opposite sides of ridges or hips shall be staggered to avoid excessive thicknesses of metal in the ridge or hip standing seam.

5.7 VALLEYS

Valleys shall be formed from aluminum sheets not exceeding 10 ft (3 m) in length of the same nominal thickness and alloy as used for the roof sheets. Each sheet shall lap the lower one at least 6 in. (150 mm) in the direction of drainage. The valley sheet shall extend at least 6 in. (150 mm) under the roof sheets on both sides. At the valley line adjacent to the lower edge of the roof sheets, a 0.75 in. (20 mm) double fold shall be made to engage a 0.75 in. (20 mm) single fold at the lower ends of the roof sheets. The outer edge of the valley sheets shall be folded 0.5 in. (12 mm) for cleating and in these folds cleats shall be spaced not more than 24 in. (600 mm) apart between centers. Valley sheets shall be nailed along their top edge only.

5.8 EAVES

(See Figure 2). At eaves without gutters, each sheet shall be hooked 0.75 in. (20 mm) over a previously placed aluminum edge strip. Edge strips shall be continuous and shall be formed from sheets not longer than 10 ft (3 m); ends of adjacent lengths shall lap at least 1 in. (25 mm). The edge strip shall extend up the roof deck at least 4 in. (100 mm) and be secured with nails spaced not more than 4 in. (100 mm) apart along the upper edge. The lower edge shall be turned out 0.75 in. (20 mm) to form a drip edge. The edge strip shall not be face nailed.

(See Figure 2). Where seams finish back from eave edges, the lower edge of the roofing shall engage a previously placed apron strip. The connection between the roof sheets and the upper edge of the apron strip shall be as described in 5.3. The lower edge of the apron strip shall be hooked over a previously placed edge strip as previously described.

5.9 GABLE RAKES

(See Figure 2). Side edges of roof sheets at gable rakes shall finish over an edge strip as described in Section 5.8 or shall turn up 1.5 in. (38 mm) and be locked into an aluminum fascia strip forming a standing seam 1 in. (25 mm) high. Where the standing seam finishes at the roof edge, the lower edge of the fascia strip shall be hooked 0.75 in. (20 mm) over a previously placed continuous edge strip that is secured to the deck with aluminum nails spaced no more than 4 in. (100 mm) apart.

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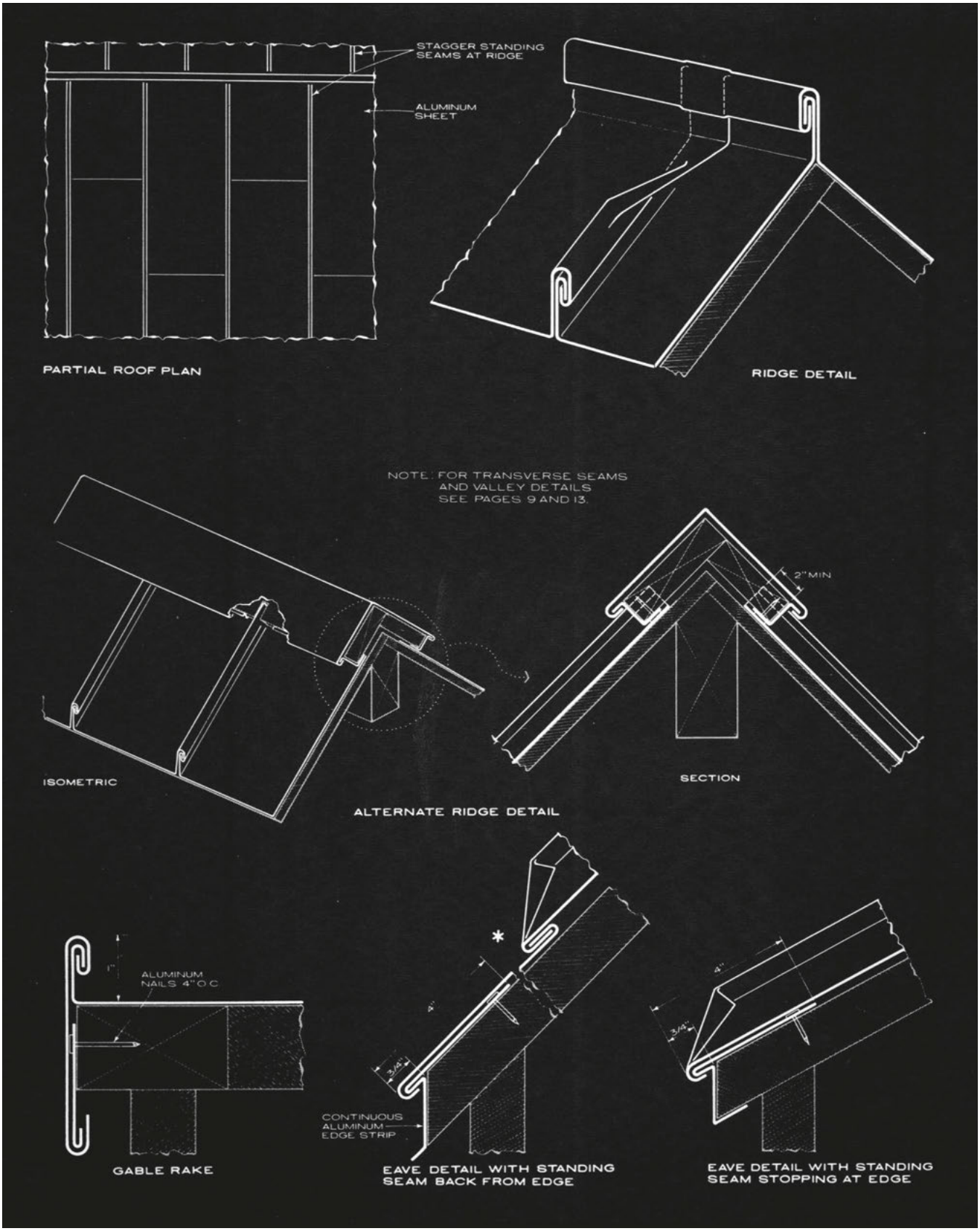
Figure 2
STANDING SEAM ROOFING



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6. BATTEN SEAM ROOFING

6.1 ROOF SLOPES

These specifications do not apply to roofs with slopes less than 3 in 12 (1:4).

6.2 BATTENS

(See Figure 1). Battens shall be aluminum or wood unless otherwise specified and at least 1.5 in. (38 mm) high. Battens shall be attached to concrete roof decks by through bolts or cinch bolts and to gypsum or steel decks by through bolts, none spaced more than 3.5 ft (1 m) between centers. Bolt heads shall be countersunk.

6.3 DIMENSIONS

Roof sheets shall be no longer than 10 ft (3 m) and be installed between battens. Nominal sheet thickness shall be 0.024 in. (0.6 mm) when the distance between battens does not exceed 20 in. (500 mm) and 0.032 in. (0.8 mm) when the distance between battens is from 20 in. (500 mm) to 27 in. (700 mm). To allow for expansion, sheet width shall be 0.125 in. (3 mm) less than the clear distance between the battens. Sides of sheets shall be turned up the height of the batten and terminate in a 0.5 in. (12 mm) horizontal flange.

6.4 TRANSVERSE SEAMS

6.4.1 (See Figures 1 and 3). For roofs with slopes 6 in 12 (1:2) or greater, the lower end of each sheet shall be folded under 0.75 in. (20 mm). The fold shall be slit 1 in. (25 mm) away from the corner to form a tab where the sheet turns up against the batten. The upper end of each sheet shall be folded over 2 in. (50 mm). The 0.75 in. (20 mm) fold on the lower end of the upper sheet shall be hooked into the 2 in. (50 mm) fold on the upper end of the underlying sheet. Transverse seams shall be staggered a distance of one half the sheet length in adjacent roof sheets.

6.4.2 (See Figures 1 and 3). For roofs with slopes at least 3 in 12 (1:4) but less than 6 in 12 (1:2), the lower end of each sheet shall be folded under 0.75 in. (20 mm). The fold shall be slit 1 in. (25 mm) away from the corner to form a tab where the sheet turns up against the batten. The upper end of each sheet shall be folded over 0.5 in. (12 mm). A 1.5 in. (38 mm) wide locking strip the full width of the sheet shall be secured at least 4 in. (100 mm) below the top folded edge by rivets spaced not more than 6 in. (150 mm) apart. The 0.75 in. (20 mm) fold on the lower end of the upper sheet shall hook into the locking strip on the upper end of the underlying sheet. Alternately, transverse seams shall be made as specified in Section 6.4.1 and filling the seams with sealant. Transverse seams shall be staggered a distance of one half the sheet length in adjacent roof sheets.

6.5 CLEATS

Cleats shall not be less than 2 in. (50 mm) wide and spaced not more than 12 in. (300 mm) apart on centers. Cleats shall be secured to the sides of the battens or a U-shaped cleat passing under the batten shall be used.

6.6 COVER STRIPS

Cover strips formed of the same alloy and nominal thickness of aluminum sheets as used for the roof sheets shall be applied over the battens. Edges of cover strips shall lock into the 0.5 in. (12 mm) horizontal flanges of the roof sheets and shall be turned down against the vertical sides of the battens. Lengths of cover strips shall be joined by a 0.5 in. (12 mm) lock or shall be lapped at least 3 in. (75 mm) with the uphill strip on top of the downhill strip. Batten ends shall be covered with an end cap folded and locked into tabs 0.5 in. (12 mm) long on the top and two vertical sides of the cap. The tabs shall be 0.5 in. (12 mm) extensions of the cover strip and vertical legs of the roof sheets.

6.7 HIPS AND RIDGES

(See Figure 3). Hips and ridges shall be aluminum covered battens similar to the roof battens. At their intersection with ridge or hip battens, the edges of roof sheets shall be turned up the height of the ridge or hip batten and terminate in a 0.5 in. (12 mm) horizontal flange. Cover strips, as specified for the roof battens, shall be installed over hip and ridge battens. Alternate methods of finishing hips and ridges shall be as shown in the detail drawings.

6.8 VALLEYS

(See Figure 3). Valleys shall be formed from aluminum sheets no longer than 10 ft (3 m) of the same gauge and alloy as used for the roof sheets. At laps, the uphill valley sheet shall overlap the downhill valley sheet at least 6 in. (150 mm). Each valley sheet shall extend under the roof sheets at least 6 in. (150 mm). At the valley adjacent to the lower edge of the roof sheets, a 0.75 in. (20 mm) double fold shall be made to engage a 0.75 in. (20 mm) single fold at the lower ends of the roof sheets. The outer edge of the valley sheets shall be folded 0.5 in. (12 mm) for cleating and in these folds cleats shall be spaced no more than 24 in. (600 mm) on centers. The under edge of wood battens shall be notched to permit the folded edge of valley sheets to pass under the battens. Valley sheets shall be nailed along the top edge only.

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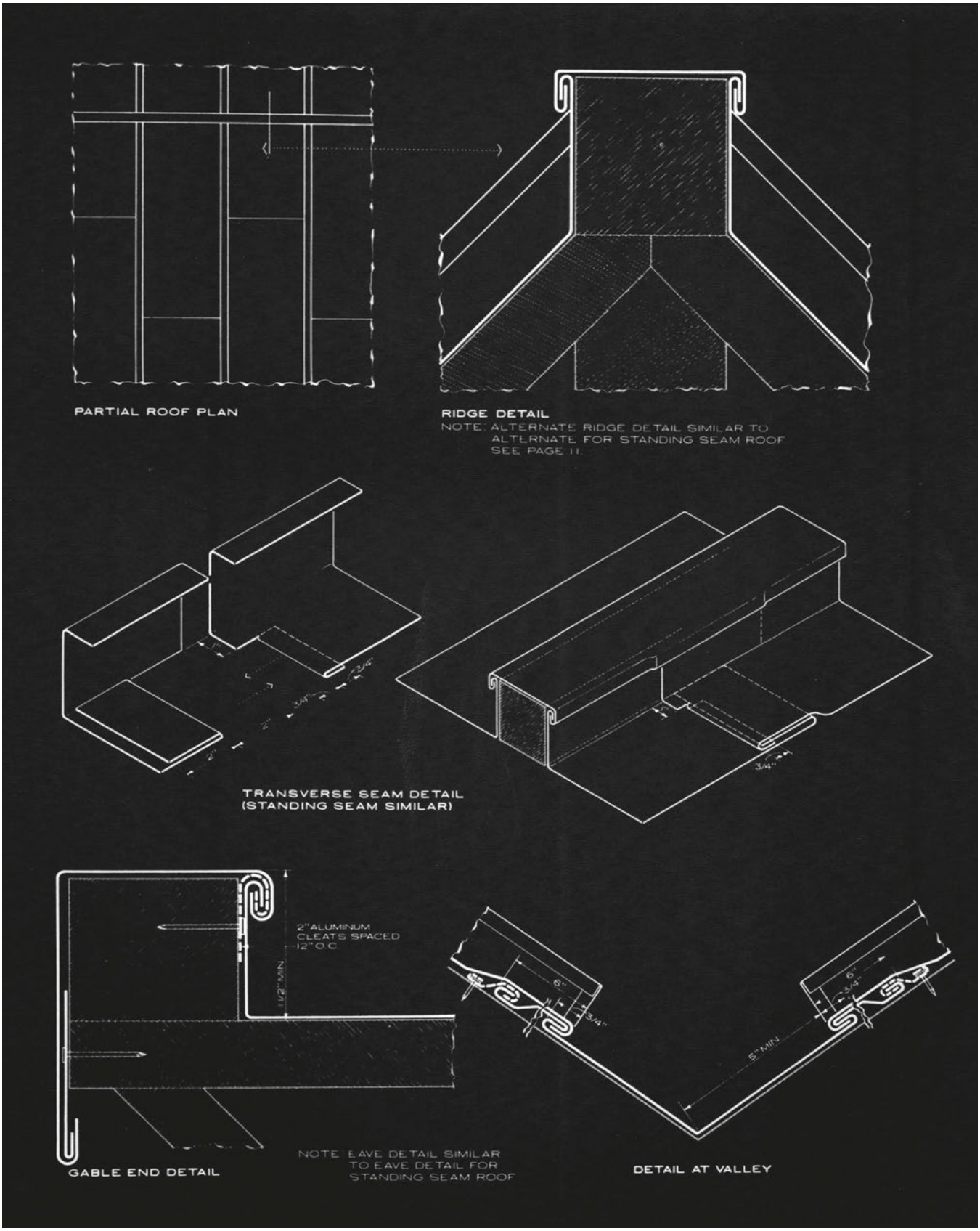
Figure 3
BATTEN SEAM ROOFING



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6.9 EAVES

(See Figure 2). At eaves without gutters, each sheet shall be hooked 0.75 in. (20 mm) over a previously placed aluminum edge strip. Edge strips shall be continuous and shall be formed from sheets no longer than 10 ft (3 m); ends of adjacent lengths shall lap at least 1 in. (25 mm). The edge strip shall extend up the roof deck at least 4 in. (100 mm) and be secured with aluminum nails spaced no more than 4 in. (100 mm) apart along the upper edge. The lower edge shall be turned out 0.75 in. (20 mm) to form a drip edge. The edge strip shall not be face nailed.

(See Figure 2). Where seams finish back from eave edges, the lower edge of the roofing shall engage a previously placed apron strip. The connection between the roof sheets and the upper edge of the apron strip shall be as described in 5.3. The lower edge of the apron strip shall be hooked over a previously placed edge strip as previously described.

6.10 GABLE RAKES

Side edges of roof sheets at gable rakes shall finish over an edge strip as described in Section 6.9 or a batten shall be set flush with the gable end. Where battens occur at gable ends, a cover strip shall lock into the roof sheets and extend over the batten and down the face of the gable end to hook 0.75 in. (20 mm) over a previously placed continuous edge strip that is secured to the deck with aluminum nails spaced no more than 4 in. (100 mm) apart.

Aluminum roof shingles shall be of the size and shape shown on the drawings. Installation shall be in accordance with manufacturer's specifications.

7. ALUMINUM ROOF SHINGLES

Aluminum roof shingles shall be of the size and shape shown on the drawings. Installation shall be in accordance with manufacturer's specications.

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8. FLASHING FOR NON-METALLIC SHINGLE ROOFS

8.1 APRON FLASHING

8.1.1 General

Apron flashing shall be formed of sheets not longer than 10 ft (3 m). The ends of each length of flashing shall be lapped at least 4 in. (100 mm) or a 2 in. (50 mm) sealant filled "S" lock shall be formed at one end of the flashing sheet to receive the end of the adjacent flashing sheet.

8.1.2 Change of Roof Slope Flashing

(See Figure 4). At changes of roof slope the flashing on the uphill side shall extend at least 6 in. (150 mm) under the shingles and be secured by aluminum nails along the uphill side spaced no further than 6 in. (150 mm) apart. An inverted V cant shall be formed in the flashing near the butt edge of the first shingle course or a wood cant strip shall be placed under the butts of the first shingle course and be secured with narrow strips of aluminum attached to the roof deck above the flashing. The flashing on the downhill side shall extend at least 5 in. (125 mm). The downhill edge shall be hemmed 0.5 in. (12 mm) for stiffness and be secured by blind cleats spaced no further apart than 24 in. (600 mm). Where the flashing is to be concealed on the downhill side it shall extend between the shingles of the top double course of shingles to within 0.5 in. (12 mm) of the butts of the top shingles. With slate roofing, sealant shall be applied to the underside of the pre-drilled holes in the slates before the slates are applied.

8.1.3 Flashing Where Sloping Roof Meets Vertical Wall

(See Figure 4). Where sloping roofs meet vertical walls the flashing shall extend up the wall at least 4 in. (100 mm) under the siding and be secured to the sheathing along its upper edge with aluminum nails spaced no further apart than 24 in. (600 mm). At masonry walls, the flashing shall extend up the wall face at least 4 in. (100 mm) and be counter flashed as described in Section 12. The flashing shall extend under the roofing at least 5 in. (125 mm). The lower edge shall be hemmed for stiffness and be secured by blind cleats spaced no further than 24 in. (600 mm) on centers.

8.2 EAVE SNOW FLASHING

(See Figure 4). Eave snow flashing shall be formed and secured as for standing seam roofing. Where the flashing extends more than 4 ft (1.2 m), center to center spacing of standing seams shall not exceed 26 in. (660 mm). The flashing shall extend up the roof at least 18 in. (460 mm) beyond the exterior wall face. Along the upper edge, standing seams shall be laid flat for approximately 6 in. (150 mm), and the top edge shall be folded over 0.5 in. (12 mm) to form a hook dam. The starter course of shingles shall be lapped over the top flat surface at least 6 in. (150 mm).

At eaves, the flashing shall be hooked 0.75 in. (20 mm) over a previously placed aluminum edge strip as described in Section 5.9.

At valleys a 1.5 in. (38 mm) wide locking strip the full length of the snow flashing shall be secured to the valley sheet 6 in. (150 mm) from its outer edge by rivets spaced not more than 6 in. (150 mm) apart. The edge of the snow flashing at the valley shall be folded under 0.75 in. (20 mm) and engage the locking strip that is filled with sealant or the outer edge of the valley shall be folded over 0.75 in. (20 mm), filled with sealant, and the edge of the snow flashing inserted in the fold.

8.3 HIP AND RIDGE FLASHING

(See Figure 5). Hip and ridge flashings shall be formed from sheets not longer than 10 ft (3 m) and ends of adjacent lengths shall lap at least 4 in. (100 mm). The flashing shall be fastened on both side flanges by aluminum screws spaced no farther apart than 24 in. (600 mm). Screws shall be provided with washers having neoprene gaskets under the heads.

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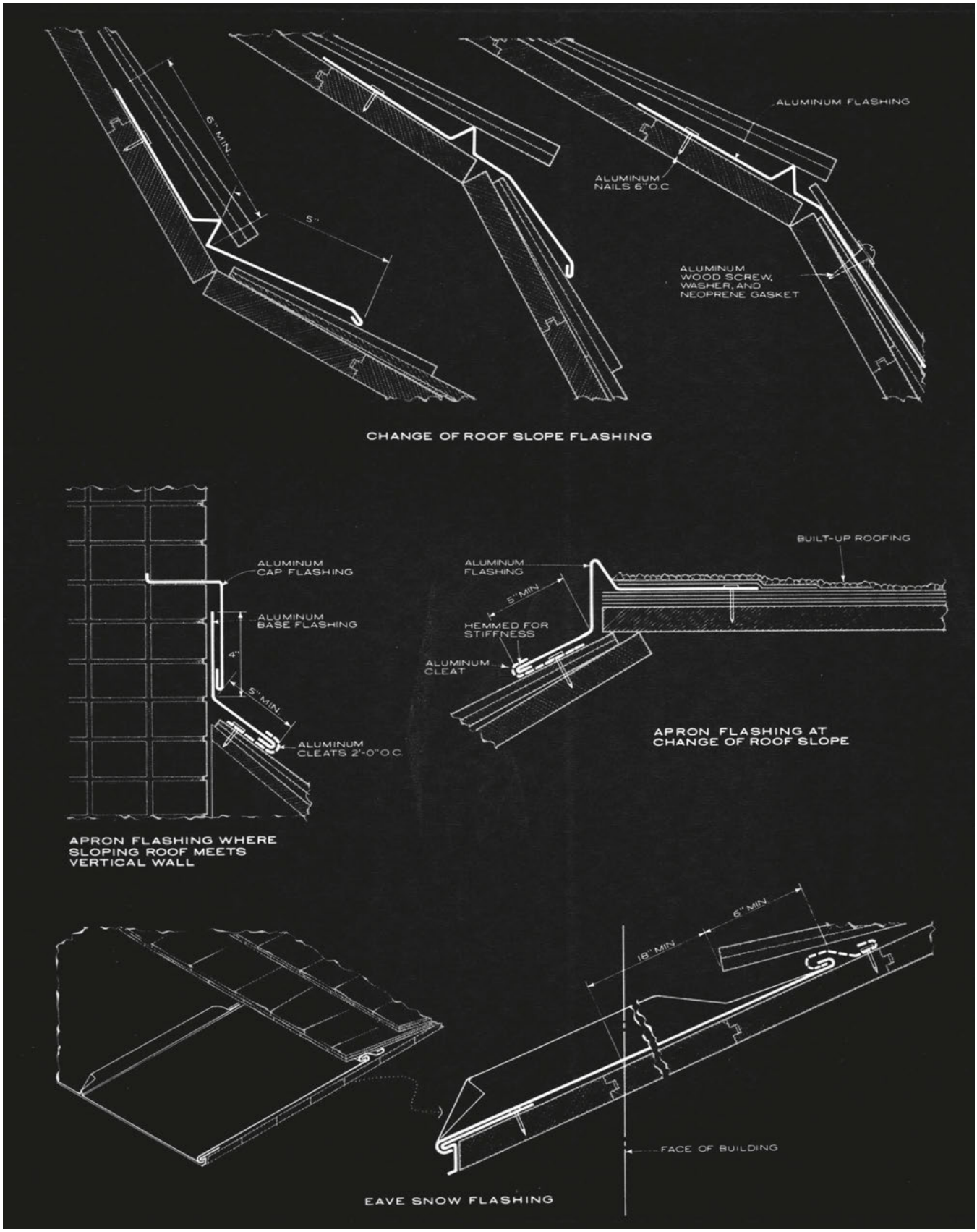
Figure 4
APRON FLASHING



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9. VALLEYS

9.1 OPEN VALLEYS

(See Figure 5). Valley flashing shall be formed of aluminum sheets not longer than 10 ft (3 m). The sheets shall extend at least 6 in. (150 mm) under the roof covering on each side of the valley and the side edges shall be folded 0.5 in. (12 mm) for cleating. Uphill sheets shall overlap downhill sheets by at least 6 in. (150 mm). The upper end of each sheet shall be fastened to the roof deck. Side edges shall be secured with aluminum cleats spaced no farther apart than 24 in. (600 mm) on centers. The open portion of the valley shall not be less than 5 in. (125 mm) wide at the top and shall increase in width 0.125 in. (3 mm) per foot (300 mm) towards the eaves. Where intersecting roofs are on different slopes, an inverted V 1.5 in. (38 mm) high shall be formed along the centerline of the valley flashing and the lap of the valley sheets shall be increased to 8 in. (200 mm) unless otherwise shown on the drawings.

9.2 CLOSED VALLEYS

(See Figure 5). Separate pieces of aluminum sheet shall be built in with each course of roofing material. The flashing shall be as long as the diagonal of the shingle at the center of the valley, and at least 18 in. (460 mm) wide where the roof slope is more than 6 in 12 (1:2) and 24 in. (600 mm) wide where the roof slope is less than or equal to 6 in 12 (1:2). The bottom edge of each piece of flashing shall be 0.5 in. (12 mm) short of the butt line of the shingle in the succeeding course. Each piece of flashing shall be fastened to the roof deck along the upper edge with aluminum nails.

10. GRAVEL STOPS

10.1 SHEET GRAVEL STOPS

(See Figure 6). Sheet gravel stops shall be formed from sheets not longer than 10 ft (3 m). The horizontal flange shall extend at least 4 in. (100 mm) onto the previously built-up roofing and be secured through the roofing and into the deck with aluminum nails not more than 3 in. (75 mm) apart. Wood nailing strips shall be provided on decks that are not wood. Over the horizontal flange a layer of elastic cement shall be applied; a strip of fabric shall be embedded into this elastic cement. A second strip of fabric shall be similarly applied or, alternately, the first strip of fabric shall be covered with hot pitch into which the top strip of felt shall be embedded. The top strip shall be surfaced the same as the adjacent built-up roofing.

The aluminum shall be bent to form a gravel stop at least 1 in. (25 mm) high and the outer edge shall extend down as a fascia. For fascias 4 in. (100 mm) or less in depth the lower edge shall be hemmed at least 0.5 in. (12 mm) and turned out 0.75 in. (20 mm) at an angle of 45 degrees to form a drip. For fascias more than 4 in. (100 mm) in depth the lower edge shall hook 0.75 in. (20 mm) over a previously placed continuous aluminum edge strip.

End joints shall be made using a back-up plate and top cover plate. The 12 in. (300 mm) long back-up plate shall be nailed in place before the gravel stop is installed. A 0.25 in. (6 mm) opening shall be left between the ends of the gravel stop sections. This opening shall be covered by a 6 in. (150 mm) top cover plate. The cover plate shall be embedded in mastic and fastened through the opening between the sections.

Where depths of fascias vary from 8 to 16 in. (200 to 400 mm), longitudinal steps or ridges shall be formed in the fascia to minimize waviness. Steps or ridges shall be at least 0.5 in. (12 mm) high and proportionally spaced not more than 6 in. (150 mm) apart.

Edge strips shall be continuous and shall be formed of sheets no longer than 10 ft (3 m); ends of adjacent lengths shall lap at least 1 in. (25 mm). The lower edge shall be turned out 45 degrees to form a drip. Edge strips shall be fastened to wood with nails spaced no more than 4 in. (100 mm) apart, or to masonry with screws in expansion sleeves spaced no more than 10 in. (250 mm) apart.

10.2 EXTRUDED GRAVEL STOPS

Extruded gravel stops shall be installed in accordance with manufacturers' specifications.

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Figure 5
HIP, RIB, AND VALLEY FLASHING

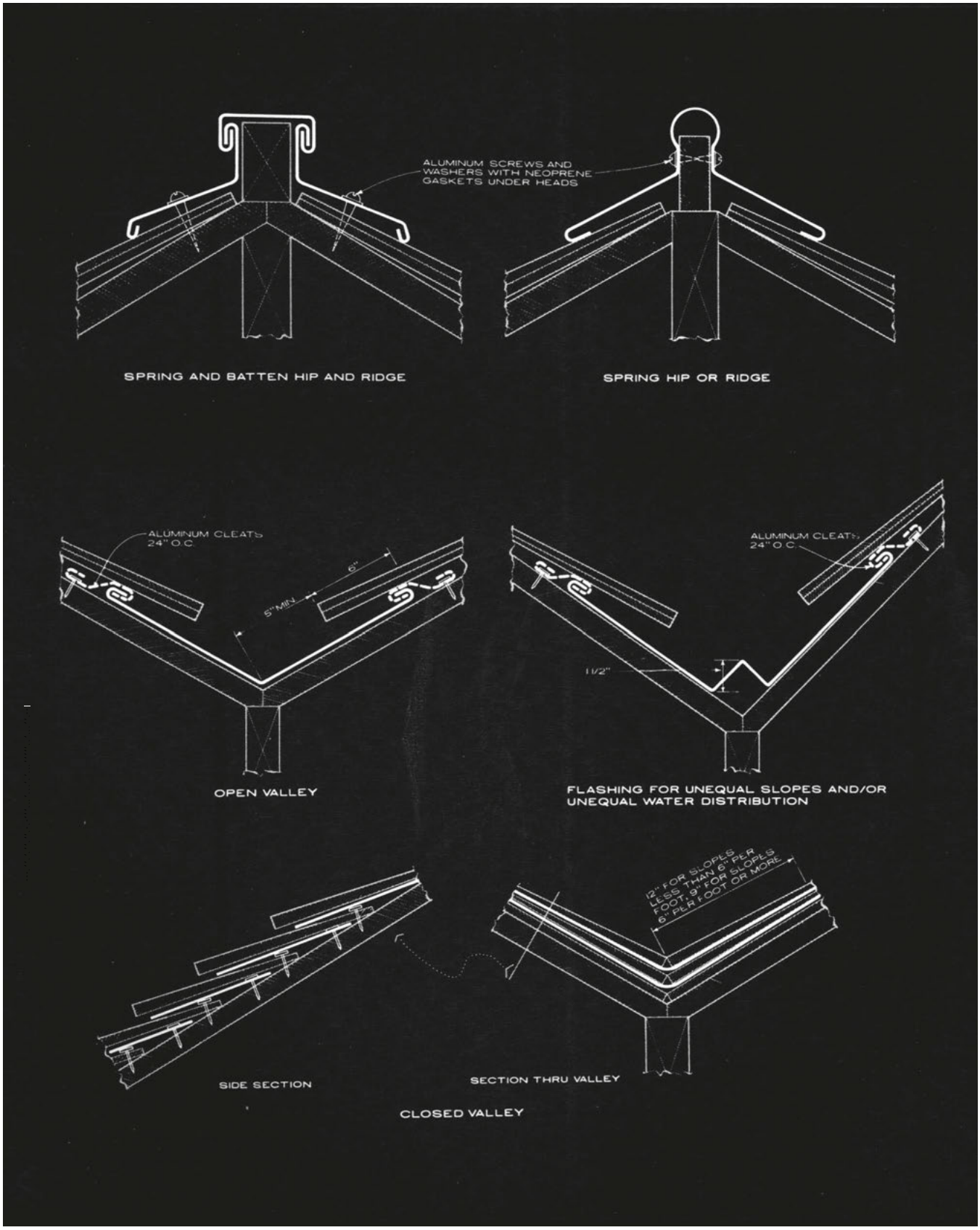

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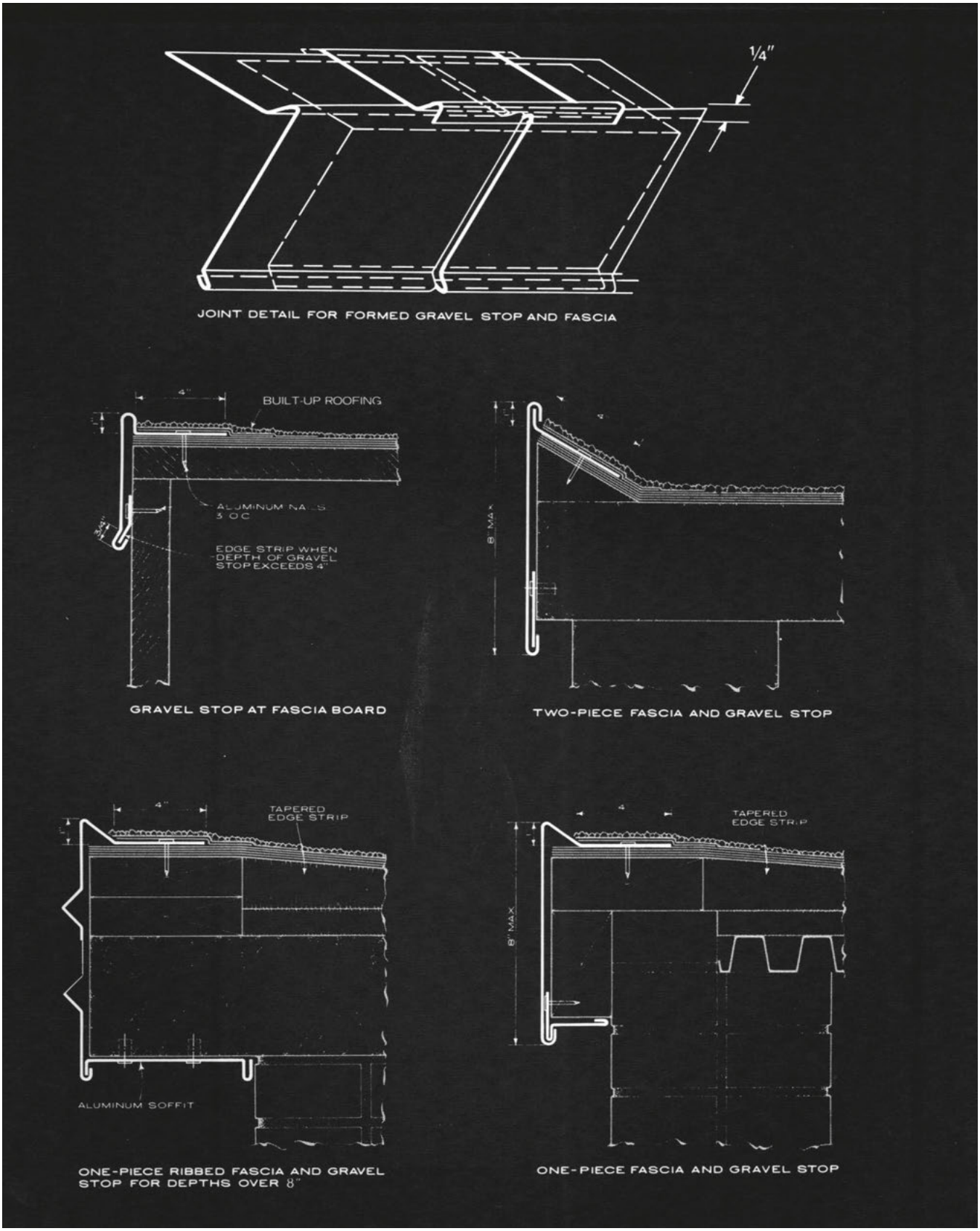
Figure 6
GRAVEL STOPS AND FASCIAS



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11. BASE FLASHING

11.1 STRAIGHT BASE FLASHING

(See Figure 7). Straight base flashing for built-up roofing shall extend up on vertical surfaces at least 8 in. (200 mm) and to a height of at least 3 in. (75 mm) above the bottom of the cap flashing. Base flashing shall extend onto the previously placed built-up roofing at least 4 in. (100 mm).

The base flashing shall be made of aluminum sheets not longer than 10 ft (3 m). Ends of sheets shall be joined by 1 in. (25 mm) wide loose lock seams filled with sealant. The horizontal leg of the base flashing shall be nailed along its outer edge with aluminum nails spaced no more than 3 in. (75 mm) apart. On decks not made of wood, wood nailers shall be provided. Over the horizontal flange a layer of elastic cement shall be troweled; a strip of fabric shall be embedded into this elastic cement. A second strip of fabric shall be similarly applied or, alternately, the first strip of fabric shall be covered with hot pitch into which the top strip of felt shall be embedded. The top strip shall be surfaced in the same manner as the adjacent built-up roofing.

11.2 STEPPED BASE FLASHING

(See Figure 7). Where slate, flat tile or shingle roofs abut vertical brick or other masonry surfaces, separate pieces of aluminum flashing shall be woven in with each course. Each piece of flashing shall extend out onto the roof at least 4 in. (100 mm) and up on the vertical wall at least 4 in. (100 mm) and under the cap flashing or finish siding at least 3 in. (75 mm). The flashing pieces shall extend from the top edge of the shingle on which it rests to within 0.5 in. (12 mm) of the butt of the course placed over the flashing. For slate or tile, the flashing piece shall extend at least 2 in. (50 mm) above the top edge of slate for nailing, or two lugs approximately 1 in. (25 mm) wide shall be made at the top of each flashing piece bent to hook over the top edge of the slate or tile. Flashing used with slate or tile roofing shall be at least 0.032 in. (0.8 mm) thick.

12. CAP FLASHING

12.1 STRAIGHT CAP FLASHING

(See Figure 7). Straight cap flashing shall be provided with all base flashings. The flashing shall be formed of sheets not longer than 10 ft (3 m) and shall be built into the masonry approximately 4 in. (100 mm) with the inner edge terminating in a 0.25 in. (6 mm) hook dam or, alternately, turning up 1 in. (25 mm) behind the first brick course. The built-in portion of the flashing shall be painted (Section 2.6) before installation. The apron shall be of sufficient width to overlap the base flashing at least 3 in. (75 mm). Ends of adjacent lengths of flashing shall overlap at least 3 in. (75 mm) and the built-in horizontal portion of the joint shall be set in elastic cement. The flashing shall have a layer of mortar above and below the horizontal flange in the wall.

12.2 STEPPED CAP FLASHING

(See Figure 7). Stepped cap flashing shall be provided at the intersection of pitched roofs with vertical surfaces. The flashing pieces shall extend into the wall at least 4 in. (100 mm) and terminate in a 0.25 in. (6 mm) hook dam. The steps shall lap at least 3 in. (75 mm) over each other and at least 3 in. (75 mm) over the base flashing.

12.3 ATTACHING CAP FLASHING TO EXISTING MASONRY WALLS

(See Figure 7). On existing masonry walls the mortar joint to receive the flashing shall be raked out to a depth of 1 in. (25 mm). The flashing shall extend into the raked-out joint with the inner edge bent back to form a hook dam. It shall be secured by aluminum wedges or plugs spaced not more than 8 in. (200 mm) apart and the raked-out joint shall be filled with sealant.

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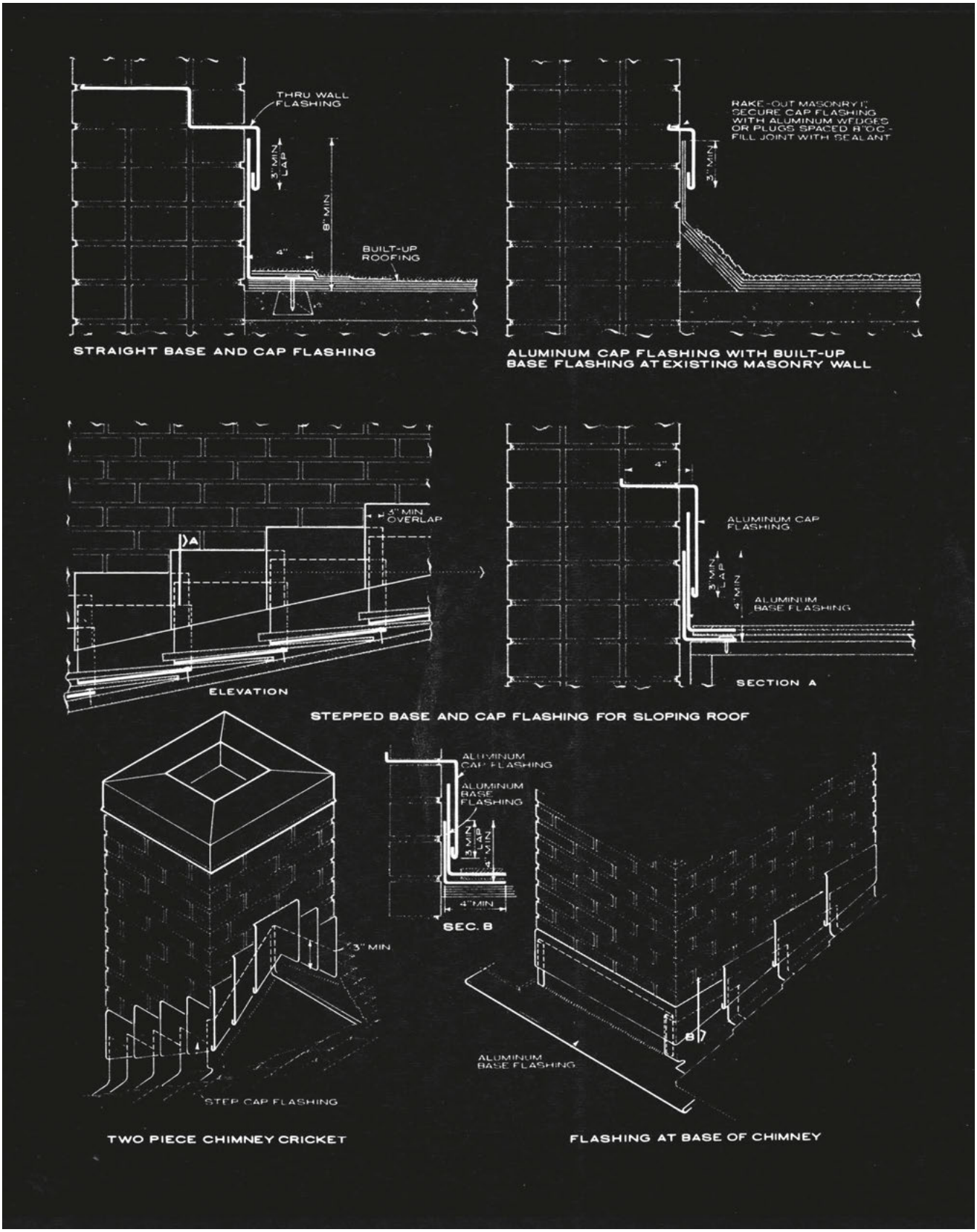
Figure 7
BASE AND CAP FLASHING



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13. CHIMNEY FLASHING

13.1 CHIMNEYS ON SLOPED ROOFS

(See Figure 7). At the front of the chimney, an apron flashing of aluminum shall extend over the roofing material at least 5 in. (125 mm) and up the chimney face at least 4 in. (100 mm). The lower edge of the apron flashing shall be hemmed 0.5 in. (12 mm) for stiffness and be secured in place with blind cleats or screws with neoprene gaskets not more than 18 in. (460 mm) apart. Along the chimney sides, separate pieces of flashing at least 8 in. (200 mm) long bent to extend at least 4 in. (100 mm) onto the roof and at least 4 in. (100 mm) onto the chimney wall shall be woven in with each course of roofing material. At the chimney corners, the base flashing shall be connected to the apron flashing by a lapped or locked seam filled with sealant. Crickets above chimneys shall be flashed and the flashing shall extend under the roofing material at least 6 in. (150 mm) and terminate in a 0.5 in. (12 mm) fold. All joints shall be lapped or locked and filled with sealant.

Cap flashing shall extend through the chimney wall and the back edge shall turn up 1 in. (25 mm) against the flue lining. Pieces of stepped cap flashing shall lap the base flashing at least 3 in. (75 mm) and each other at least 3 in. (75 mm).

13.2 CHIMNEYS ON FLAT ROOFS

Chimneys on flat roofs shall be flashed as straight base and cap flashing (Sections 11 and 12).

14. THROUGH-WALL FLASHING

14.1 GENERAL

Through-wall flashing shall be installed under parapet copings, for counter flashing in parapets and in rising masonry walls where roofs abut, over lintels of exterior openings, under window sills and stone band courses, and continuously over spandrel beams. All flashing in exterior walls shall extend through the wall to within 0.5 in. (12 mm) of the exterior face and turn up 2 in. (50 mm) on the interior wall face unless otherwise shown on the drawings. Cap flashing shall turn extend at least 4 in. (100 mm) down the face of the wall and shall overlap the base flashing at least 3 in. (75 mm). Flashing over spandrel beams and lintels and under band courses and sills shall be installed as indicated on the drawings and specified elsewhere.

All through-wall flashing shall be set with a bed of mortar above and below the flashing. The flashing shall be factory formed to provide a mechanical bond in the mortar bed in all directions. Where aluminum flashing is to be embedded in masonry walls, it shall first be coated with bituminous paint or methacrylate lacquer (Section 2.6). Alternately, painted sheet shall be used.

14.2 SPANDREL FLASHINGS

(See Figure 8). A continuous through-wall flashing shall be installed on top of all spandrel beams. The flashing shall extend through the masonry to within 0.5 in. (12 mm) of the exterior wall face. The rear edge of the flashing shall be turned up at least 2 in. (50 mm) against the interior face of the wall. Where the flashing intersects columns, it shall turn up at least 2 in. (50 mm) against the sides and face of columns. At the bottom of concrete spandrel beams the flashing shall be set into a continuous reglet, placed so that the bottom edge of the receiving slot is 2.5 in. (63 mm) above the top edge of the lintel or carrier angles or as detailed on the drawings. It shall extend down to the second brick joint or first stone joint above the horizontal leg of the carrier or lintel angle, and out within 0.5 in. (12 mm) of the exterior wall face. The ends of each length of flashing shall lap at least 3 in. (75 mm) and be sealed with elastic cement.

Where the front face of the steel spandrel beams are fireproofed with brick masonry, the through-wall flashing on top of the beam shall be installed as heretofore specified. At the bottom of the spandrel, the lintels or carrier angles shall be flashed with a separate strip of flashing. The flashing shall extend through the masonry to within 0.5 in. (12 mm) of the exterior wall face in the second brick joint, or first stone joint above the horizontal leg of the angle. The flashing shall turn up at least 2 in. (50 mm) against the web of the steel beam and the joint between the flashing and steel shall be sealed with elastic cement.

14.3 SILL FLASHING

(See Figure 8). The flashing under masonry sills shall extend the full depth of the sill or as detailed and at least 4 in. (100 mm) beyond the ends of the sill. The front edge of the flashing shall be 0.5 in. (12 mm) back of the exterior wall face and the back edge shall turn up at least 2 in. (50 mm) unless shown otherwise on the drawings.

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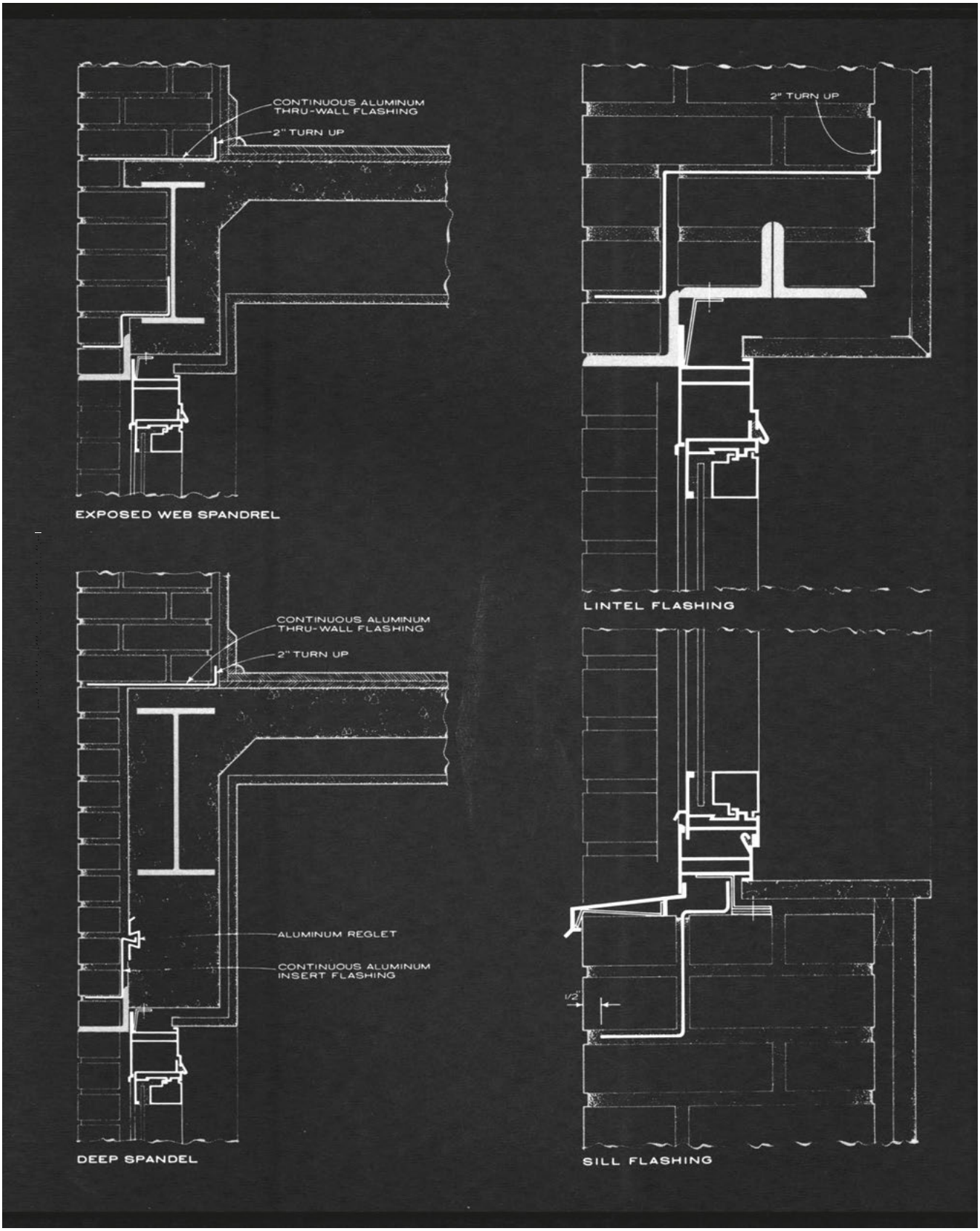
Figure 8
THROUGH-WALL FLASHING AT SPANDRELS, SILLS, AND LINTELS



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14.4 LINTEL FLASHING

(See Figure 8). Where openings occur in solid brick or tile walls, the flashing shall extend the full length of the lintel. It shall extend through the wall one brick course above the outer lintel to within 0.5 in. (12 mm) of the exterior face of the masonry wall, or alternately, shall be bent down to lap over the vertical leg of the outer lintel angle at least 2 in. (50 mm). The back edge of the flashing shall be bent up at least 2 in. (50 mm) against the interior wall face.

Where the bottom of concrete spandrels form the head of openings a reglet shall be installed in the face of the spandrel the full length of the lintel. The reglet shall be so placed that the bottom edge of the receiving slot is 2.5 in. (63 mm) above the top edge of the lintel, or as detailed on the drawings. the flashing shall be inserted the full depth of the reglet and shall extend horizontally through the mortar joint to within 0.5 in. (12 mm) of the exterior face of the masonry wall, or alternately, shall lap over the vertical leg of the lintel by at least 2 in. (50 mm).

Where the front face of the steel spandrel beams are fireproofed with brick masonry, the flashing shall extend the full length of the lintel. The flashing strip shall lap over the vertical leg of the lintel at least 2 in. (50 mm) and shall be bent to extend up onto the web of the steel spandrel at least 2 in. (50 mm). The joint between the flashing and steel shall be sealed with elastic cement.

14.5 BRICK PARAPET WALLS

(See Figure 9). Where the height of the parapet is 6 in. (150 mm) to 15 in. (380 mm) from the roof line to the underside of the coping, the through-wall flashing shall be placed directly under the coping stone. Where the height to the underside of the coping is less than 6 in. (150 mm), a one piece combination coping and base flashing shall be installed. The outer edge of the combination flashing shall extend over the coping and be secured as specified under coping covers (Section 16). The inner edge of flashing shall extend 4 in. (100 mm) onto the roof deck and be installed as specified in Section 11, Base Flashing.

(See Figure 9). Where the height of the parapet is more than 15 in. (380 mm) from the roof line to the underside of the coping, a through-wall flashing shall be installed directly under the coping stone. The flashing shall extend to within 0.5 in. (12 mm) of the exterior wall face and the edge shall be folded over 0.25 in. (6 mm) to form a hook dam. At the inside face of the wall, the flashing shall project 0.5 in. (12 mm) and be bent down at an angle of 45 degrees to form a drip. Directly above the base flashing a cap flashing that extends 4 in. (100 mm) into the wall shall be installed.

14.6 CONCRETE PARAPETS AND WALLS

(See Figure 9). For counter flashing and other flashing which connect with concrete walls, furnish and install a reglet in the concrete to receive metal flashing where indicated on the drawings.

The flashing shall be inserted into the reglet and secured with aluminum wedges no farther apart than 16 in. (400 mm). The reglet shall then be filled with sealant. The ends of each piece of counter flashing shall lap at least 3 in. (75 mm). A slight bend shall be made in the counter flashing to provide spring action of the lower edge against the base flashing.

15. STANDING SEAM SIDING

Where drawings call for metal covering minor vertical surfaces (walls of penthouses, monitors, skylights, fascias, the inside face of parapet walls, etc.), covering shall be standing seam siding constructed according to the Section 5, standing seam roofing.

The upper edge of the siding shall be counterflashed and the lower edge shall lap over the base flashing a minimum of 3 in. (75 mm).

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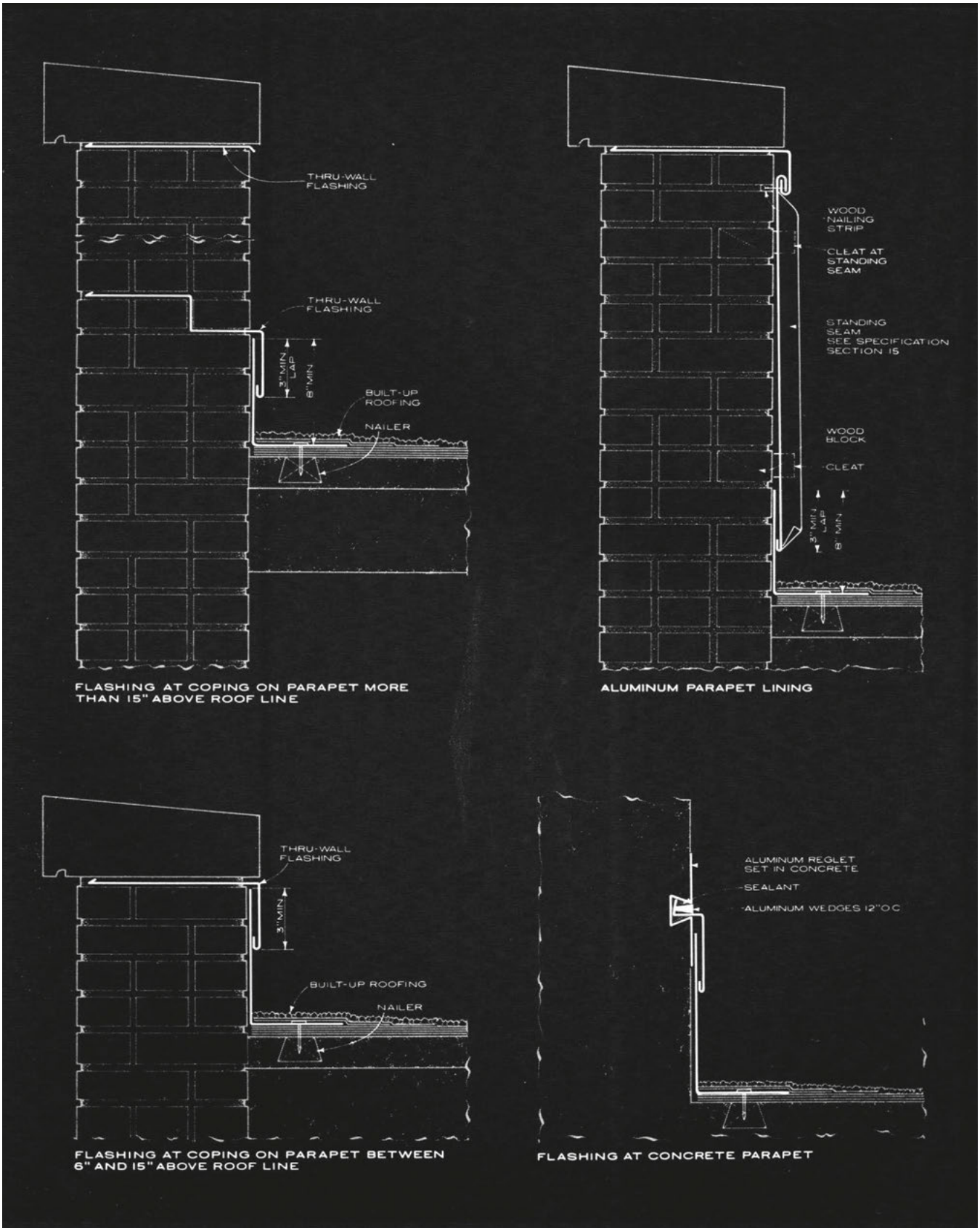
Figure 9
THROUGH-WALL FLASHING AT PARAPETS AND WALLS



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16. COPING COVERS

16.1 FLAT SEAM COPING COVERS

Flat seam coping covers shall be formed of sheets not longer than 10 ft (3 m), joined by 1 in. (25 mm) loose lock seams that are filled with sealant.

(See Figure 10). On stone copings where the covering extends down over the front face of the stone, the aluminum sheet shall hook 0.75 in. (20 mm) over a continuous edge strip made of 8 or 10 ft (2.5 or 3 m) lengths of aluminum. Edge strips shall be secured with aluminum screws in expansion sleeves spaced no farther than 10 in. (250 mm) apart. Ends of adjacent lengths shall lap at least 1 in. (25 mm).

(See Figure 10). Where the covering does not extend over the front face a separate continuous locking strip of aluminum shall be secured into a reglet in the stone with aluminum wedges, or aluminum screws in expansion sleeves, and the reglet filled with sealant. Ends of adjacent lengths of locking strip shall lap at least 2 in. (50 mm). The aluminum covering shall engage the locking strip with a 0.75 in. (20 mm) loose lock seam. The inner edge of the coping shall lock into the aluminum base flashing or be secured by cleats spaced not more than 2 ft (0.6 m) apart. Cleats shall be secured to the stone coping with two aluminum screws in expansion sleeves.

(See Figure 10). Walls topped with wood plate shall have a continuous edge strip, made of 8 or 10 ft (2.5 or 3 m) long lengths of aluminum , secured along the front edge with aluminum nails spaced no farther than 4 in. (100 mm) apart. The coping cover shall be hooked over the edge strip with a 0.75 in. (20 mm) loose lock seam. The inner edge of the aluminum coping shall lock into the top of the aluminum base flashing with a 0.75 in. (20 mm) loose lock seam. Where aluminum base flashing is not provided, the coping shall hook over an edge strip as specified for the front edge, or, alternately, it shall be secured by aluminum cleats spaced no more than 2 ft (0.6 m) apart. Cleats shall be secured to the wood plate with two aluminum nails.

(See Figure 10). Where the height of the coping above the roof deck is less than 6 in. (150 mm), a one-piece combination coping cover and base flashing shall be installed. The inner edge of the flashing shall extend onto the previously placed built-up roofing 4 in. (100 mm) and shall be nailed along its outer edge with aluminum nails spaced no more than 3 in. (75 mm) apart. The horizontal flange shall then be stripped into the built-up roofing. Where the height of the coping above the roof deck is more than 6 in. (150 mm), the inner edge of the coping cover shall lock into the aluminum base flashing or be secured by cleats not more than 2 ft (0.6 m) apart.

16.2 STANDING SEAM COPING COVERS

(See Figure 10). Standing seam coping covers shall be formed from sheets not longer than 10 ft (3 m). Ends of sheets shall be connected by a single fold standing seam finishing at least 1.25 in. (32 mm) high. The tab at the ends of standing seams shall be folded over to close the ends of seams. Front and rear sides of the aluminum coping shall extend down over the edge of the masonry at least 2 in. (50 mm). The lower edges shall be bent out to form a drip and hook over continuous edge strips. Edge strips, in 8 or 10 ft (2.5 or 3 m) lengths, shall be attached to the inner and outer faces of the wood plate with aluminum nails spaced no more than 4 in. (100 mm) apart. Edge strips shall extend over the top of the wood plate at least 2 in. (50 mm).

16.3 EXTRUDED COPING COVERS

Extruded coping covers shall be of the size and shape shown on the drawings. Installation shall be in accordance with manufacturer's specifications.

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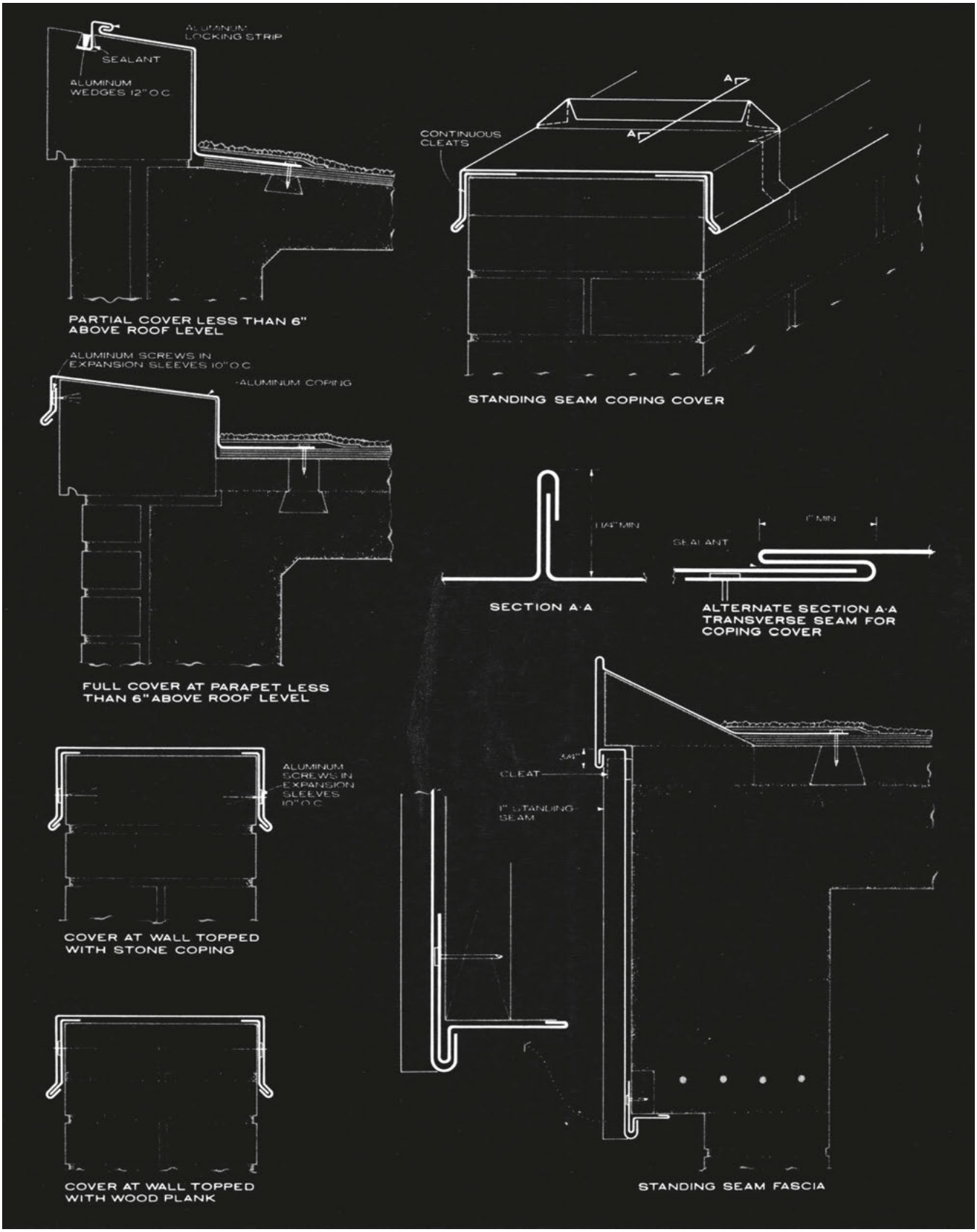
Figure 10
COPING COVERS AND STANDING SEAM FASCIA



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17. MISCELLANEOUS

17.1 SCUPPER FLASHING

(See Figure 11). Scupper flashing shall cover the interior of the opening in the wall and shall extend through and project outside the wall as shown on the drawings. The dimensions of the flashing shall be 0.5 in. (12 mm) less than the masonry opening. On the roof side, the scupper lining shall be of sufficient length to be built into a membrane base flashing at least 4 in. (100 mm) or locked to the aluminum base flashing with a 0.75 in. (20 mm) sealant filled seam. The bottom edge shall extend at least 4 in. (100 mm) into the built-up roofing and where required a 0.75 in. (20 mm) high gravel stop ridge shall be formed around the scupper inlet.

17.2 SPLASH PANS

(See Figure 11). Splash pans shall be installed under all downspouts discharging onto composition roofs. Pans shall be made of sheets 24 in. (600 mm) long by 18 in. (460 mm) wide unless otherwise indicated on the drawings. 1 in. (25 mm) inverted V members placed 4 in. (100 mm) from the outside edges shall be formed on two sides and one end of the sheet. Filler pieces shall be provided at the corners so that they lap over the flanges on the sides at least 3 in. (75 mm) with the lapped joints being set in elastic cement. The rear side of the pan shall be at least 8 in. (200 mm) high and shall extend under the side wall covering or be cap flashed on masonry walls. Pans shall be bedded in elastic cement and the 4 in. (100 mm) side flanges shall be stripped and mopped into the built-up roofing as specified in Section 11.1.

17.3 CURB FLASHING

Curb flashing shall be provided on all curbs, roof scuttles, etc. The flashing shall extend up the full height and over the top of the curbs. The lower edge shall extend 4 in. (100 mm) onto the roof deck and with built-up roofing be installed as specified in Section 11.1 or with slate, tile or shingle roofing be installed as specified in Section 10.2.

17.4 DOOR SILLS

(See Figure 11). The sills of doors leading onto flat roofs (except where the bottom of the sill is at or above the level of cap flashing) shall be provided with aluminum flashing. The flashing shall extend under the sill and be turned up behind and at the two ends of the sill at least 2 in. (50 mm). The sill flashing shall be joined to the base flashing by a 0.75 in. (20 mm) lock seam filled with sealant. All lock seams and joints shall be made watertight with sealant.

18. RAINWATER GOODS

18.1 HUNG GUTTERS

(See Figure 11). Hung gutters shall be of the size and shape shown on the drawings. Outer edges shall be rolled or beaded to provide stiffness. Inner edges shall finish at least 1 in. (25 mm) above outer edges. Gutters shall be secured by cleats engaged along the inner edge and by hangers or straps spaced not more than 32 in. (800 mm) apart. Ends of gutter sections shall be joined in a separate S lock or, alternately, the ends shall lap at least 3 in. (75 mm) in the direction of flow, be riveted and the joint covered with sealant. Gutters shall slope at least 1/16 in. per ft (1:192) toward leaders. Expansion joints shall be provided on long straight runs at spacings not greater than 50 ft (15 m) and at inside and outside corners at spacings not greater than 20 ft (6 m).

18.2 OUTLET TUBES

(See Figure 11). Outlet tubes shall be of the size and shape required to fit the gutter. They shall be located as shown on the drawings, but at spacings not more than 50 ft (15 m). Holes shall be provided in the gutter bottom through which the outlet shall extend. The flanges formed at the top of the outlet tube shall be riveted to the gutter and the connection sealed with sealant. Outlet tubes shall extend at least 3 in. (75 mm) into leaders.

18.3 LEADER HEADS

Leader heads shall be of the size and shape shown on the drawings.

18.4 LEADERS

Leaders or downspouts shall be of the size and shape shown on the drawings. End joints shall telescope at least 1.5 in. (38 mm) and longitudinal joints shall be locked. All necessary elbows, offsets, and other fittings shall be provided.

18.5 LEADER STRAPS

Leader straps shall hold leaders clear of the wall. Leader straps shall be spaced as shown on the drawings, but not more than 10 ft (3 m) apart. They shall be securely attached to the wall with aluminum fasteners and shall grip the leader securely by means of punched prongs, screws, rivets, or other mechanical fasteners.

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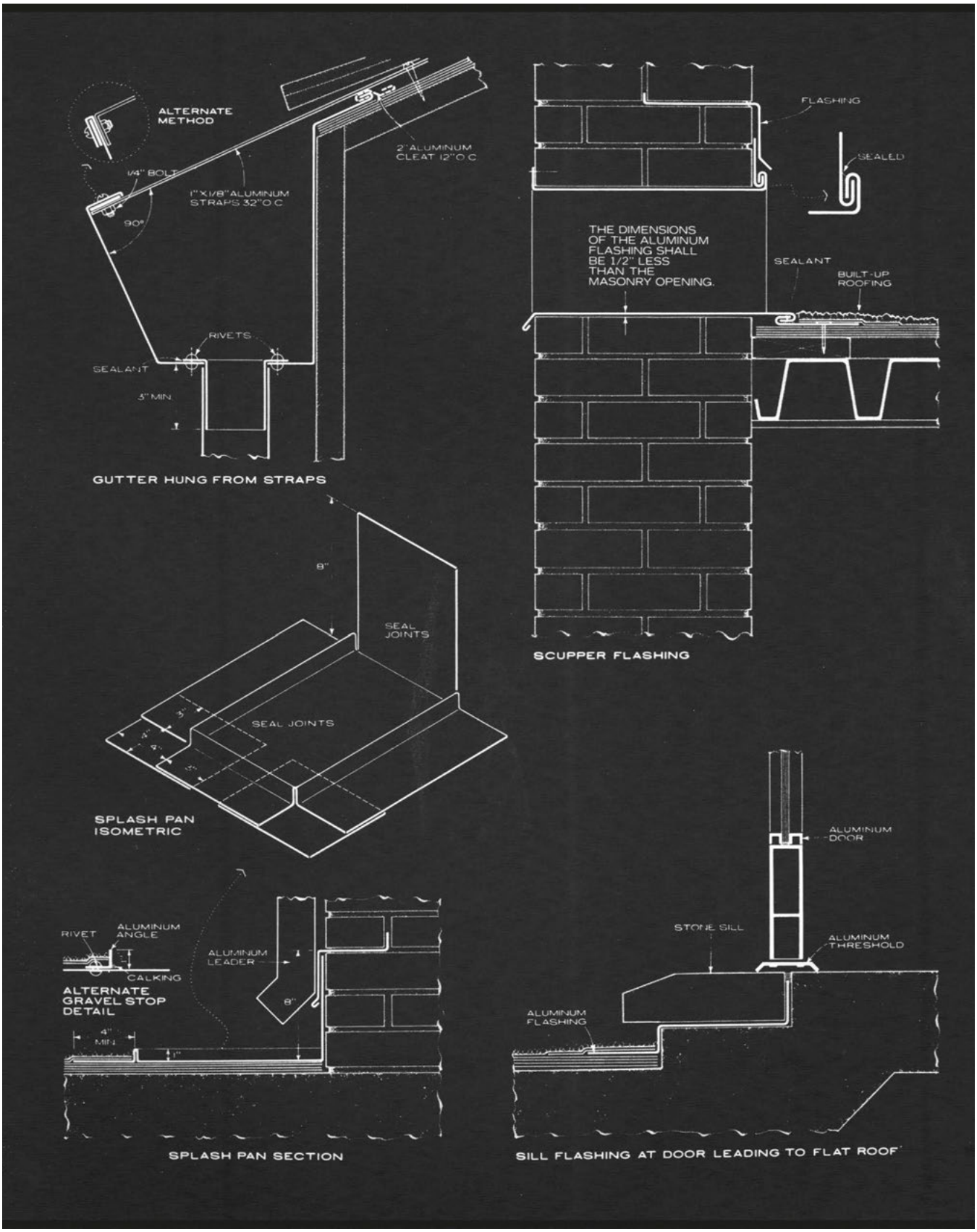
Figure 11
RAINWATER GOODS AND MISCELLANEOUS DETAILS



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19. ALUMINUM COMPOSITE MATERIAL

19.1 ALUMINUM COMPOSITE MATERIAL (ACM)

ACM shall be composed of a thermoplastic compound core sandwiched between two aluminum sheets formed in a continuous manufacturing process. Aluminum skin thickness shall be minimum nominal 0.020 in (0.5mm). thick and total panel thickness shall not be less than 4 mm for architectural cladding applications. Maximum panel sizes for architectural cladding are 62 in. wide by 20 ft – 3 in. long.

19.2 ROUT AND RETURN (R&R) ATTACHMENT METHOD

Rout and return is a standard fabrication method for providing an attachment system for composite panels. A flat sheet of material is continuously routed around the entire perimeter with a vee-shaped groove to remove the back skin and all but 0.020 in. (0.50 mm) thick of the panel core. The minimum distance from edge of panel to centerline of the groove is 1.0 in. (25 mm). The corners are removed and the remaining panel edges are folded to create a 1 in. deep pan, or cassette. The panel corners are reinforced with aluminum angles to stiffen the unit. Pre-punched aluminum angles are installed at approximately 12" (305 mm) centers to the returned panel edges with two non-corrosive fasteners. Corrosion resistant screws are run through pre-punched holes in the clip angles into the supporting sub structure. Horizontal slotted holes shall be utilized in the legs of the clip angles if significant panel thermal growth is anticipated. The joints between the R&R panels should be caulk sealed to prevent air and moisture infiltration between the panels.

19.3 CONTINUOUS EDGE GRIP (CEG) ATTACHMENT METHOD

Continuous edge grip is another common method for providing an attachment system for composite panels. CEG panels are perimeter framed on the non-exposed side of the panel with extruded aluminum shapes which provide registration and a mechanical grip on the panel edge. CEG lends itself to dry set reveal joints (no exposed sealants). The CEG perimeter extrusion typically has a small lip which seats into a rectangular groove in the panel's edge. CEG extrusions are mitered and mechanically fastened at the corners and set in a continuous bead of silicone sealant, which provides structural attachment of the frame to the panel. Composite panels may have to be squared to form proper corner joints. CEG joints should be a minimum 5/8 in. (16 mm) wide to allow for thermal movement. Slotted holes at fastener connection points on the CEG extrusions may be needed to accommodate thermal movement.

19.4 STIFFENERS

Composite panel stiffeners can be provided to resist wind load and reduce panel deflections. Metal stiffeners should be made of aluminum so that the thermal growth coefficient of the panel and stiffeners is the same. Stiffeners are most effective when they span the shortest dimension of the panel. They shall be adhered to the back of the panel with a structural silicone caulking and the ends of the stiffeners should be mechanically connected to the perimeter of the sheet.

20. ALUMINUM FACE SHEET AND LINER WITH INSULATION

20.1 THICKNESS

Aluminum roll formed sheeting used for double skin, field insulated wall panel systems shall be 0.024", 0.032", 0.040", or 0.050" thick.

20.2 FASTENERS

Liner Sheets shall be fastened to structural supports with non-corrosive screws in accordance with manufacturer's recommendations. Care should be taken to avoid dissimilar metal (galvanic action) contact between the supports and the aluminum liner. Refer to the Aluminum Association *Specification for Aluminum Structures,* Section M.7.

20.3 INSULATION

Insulation shall be placed in the cavity of the liner sheet. Insulation materials shall not be corrosive to the liner, subgirts, or face sheet.

20.4 SUPPORTS

Horizontal subgirts shall be placed against the liner sheet flanges 48 in. on center or per the manufacturer's recommendations. Subgirts shall be made of steel or aluminum and of sufficient strength to resist the applied dead and wind loads applied through the face sheet. Steel members shall be galvanized or painted in accordance with the *Specification for Aluminum Structures* such that a barrier is created between the aluminum steel mating surfaces. Subgirt fasteners shall run through the liner lips into the building support substrate.

20.5 LOADS

Aluminum face sheets shall be designed to resist applied wind loads. Fasteners shall be applied through the profile cells resting against the subgirt for maximum mechanical clamping force.

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2.1.1 Where severe forming is involved a softer temper may be employed and where little forming is required a harder temper may be used. Minimum bend radii for common alloy/tempers and thicknesses can be found in *Aluminum Standards and Data*. Alclad sheet provides extra protection against pitting in corrosive environments.

2.1.2 The smallest nominal thickness preferred is 0.024 in. (0.60 mm).

2.5.3 The use of washers increases the fastener's resistance to the sheet pulling over the head of the fastener. The strength of tapping screw connections is addressed in the *Aluminum Design Manual, Specification for Aluminum Structures*, Section J.5.

3.2 Indoors under dry conditions, galvanic corrosion of aluminum will not occur and therefore aluminum may be used in contact with any metal commonly used in buildings.

Outdoors and indoors where moisture is present galvanic corrosion may occur. Galvanic corrosion between aluminum and zinc, stainless steel, monel, or lead is insignificant. Between aluminum and iron or steel, such corrosion is very slow and can be prevented readily by painting the iron or steel with a good quality exterior grade primer and top coat or bituminous paint. Galvanic corrosion between aluminum and galvanized steel is insignificant, but once the zinc is consumed, steel will rust which may cause staining. In severe industrial environments this can happen in a short time and painting may be required.

Highly corrosive environments such as those on the seacoast and around industrial plants may promote galvanic corrosion even though aluminum by itself has good corrosion resistance. Consult specialists in such cases.

3.3 Kiln dried lumber, impregnated against decay, is recommended for sheathing, cant strips, coping blocks, and fascia boards. Preservatives that are compatible with aluminum are coal tar creosote, coal tar oil, chlorinated naphthalenes, zinc naphthenate, pentachloroxide, and orthophenylphenol. Other preservatives may be used but assurance should be obtained from the manufacturer that they are not harmful to aluminum.

Aluminum paint, consisting of 2 pounds of aluminum paste pigment (ASTM D962, Type 2, Class B) per gallon of varnish meeting Federal Specification TT-V-81F, Type II or equivalent, is an excellent primer and paint for wood. However, any good quality exterior paint may be used.

4.1 Solar radiation can develop material temperatures of 140°F (60°C) on bare aluminum and up to 180°F (80°C) on dark painted metal. Radiation to the night sky can produce surface temperatures 10°F to 15°F (5°C to 7°C) below ambient air (more in arid regions and at higher altitudes), so joints should be designed for temperature variations of 100°F (50°C) minimum or more depending on the application.

4.4 Filler alloy selection is a function of the alloys of the metals to be welded and may be made using the *Aluminum Design Manual, Specification for Aluminum Structures,* Table M.9.1 for MIG and TIG welds.

5.1 Standing seam roofs with slopes less than 3 in 12 (1:4) require special precautions in design and installation to ensure leaktightness.

5.3 Standing seam roofing is best installed over wood decks since the cleats used to secure the aluminum roofing are nailed directly to the deck. If decks other than wood are used, properly located nailers should be incorporated in the deck.

When standing seams are formed or finished in the field the cleats become rigidly locked into the multiple folds of the seam; slippage does not occur between standing seam roof sheets and the cleats that are secured to the deck. Long runs of roofing may eventually loosen the nails in the deck. Where runs of standing seam roofing over 30 ft (9 m) are unavoidable, expansion or sliding cleats should be used.

6.1 Batten seam roofs with slopes less than 3 in 12 (1:4) require special precautions in design and installation to ensure leaktightness.

6.3 The size and spacing of battens may vary within reasonable limits to suit architectural style, scale of buildings, and width of sheets.

18.1 Alclad sheet is recommended for gutters, especially in corrosive environments.

18.4 Leaders should be formed in lengths at least 10 ft (3 m) long where possible.

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REFERENCES

1. Metal Construction Association, *Guide Specification for Residential Metal Roofing*, Glenview, IL, 1995.

2. Aluminum Association, *Aluminum Standards and Data*, Arlington, VA, 2017.

3. National Roofing Contractors Association, T*he Metal Roofing Manual,* Rosemont, IL, 1996.

4. American Architectural Manufacturer's Association (AAMA) *Standard Specifications for Aluminum Siding, Soffit and Fascia* (ANSI/AAMA 1402-09), Schaumburg, IL, 2009.

5. American Welding Society, D1.2 *Structural Welding Code – Aluminum*, Miami, FL, 2014.

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PART IX

CODE OF STANDARD PRACTICE FOR FABRICATING AND ERECTING STRUCTURAL ALUMINUM

The Aluminum Association

ALUMINUM DESIGN MANUAL 2020

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Aluminum Design Manual

PART IX

Code of Standard Practice for Fabricating and Erecting Structural Aluminum

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Code of Standard Practice for Fabricating and Erecting Structural Aluminum

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Preface

This Code provides a common understanding of acceptable standards when contracting for structural aluminum. It is useful for owners, architects, engineers, general contractors, construction managers, fabricators, detailers, erectors, and others associated with constructing aluminum structures.

Glossary

contract documents: the documents that define the responsibilities of the parties that are involved with bidding, fabricating, and erecting structural aluminum. These documents include the design drawings, the specifications, and the contract.

erector: the party responsible for erecting the structural aluminum.

fabrication drawings: drawings of the individual structural aluminum pieces to be produced by the fabricator.

fabricator: the party responsible for fabricating the structural aluminum.

owner: the party identified as such in the contract documents.

owner's designated representative for construction: the owner or the party responsible to the owner for the construction of the project, including its planning, quality, and completion. This is usually the general contractor, the construction manager, or similar authority at the job site.

owner's designated representative for design: the owner or the party responsible to the owner for the structural design of the project, including the structural aluminum. This is usually the structural engineer of record.

RFI: a written request for information or clarification from the fabricator or erector to the owner's designated representative.

specifications: the portion of the contract documents consisting of the requirements for design, materials, standards, and workmanship.

structural aluminum: aluminum elements required to support the design loads.

structural engineer of record: the licensed professional responsible for sealing the contract documents, which indicates that he or she has performed or supervised the analysis, design, and document preparation for the structure and has knowledge of the load-carrying structural system.

1. General Provisions

1.1 SCOPE

Unless otherwise required by the contract documents, structural aluminum shall be fabricated and erected in accordance with this Code. In this Code, aluminum structures include structures designed, fabricated, and erected in a manner similar to buildings and with vertical and lateral load resisting elements.

1.2 REFERENCED DOCUMENTS

This code references the following documents:

Aluminum Design Manual 2020
AWS D1.2:2014 *Structural Welding Code – Aluminum*
Aluminum Standards and Data 2017

1.3 UNITS

This code has requirements given in two alternate systems of units. Users shall comply with either:

a) all the requirements given in this code in US customary units, or

b) all the requirements given in this code in SI units.

The system used shall be used consistently for a given structure.

1.4 DESIGN CRITERIA

Aluminum structures shall be designed in accordance with the *Aluminum Design Manual*, Part I, *Specification for Aluminum Structures.*

1.5 RESPONSIBILITY FOR DESIGN

When the owner's designated representative for design provides the design, design drawings, and specifications, the owner's designated representative for design is responsible for complying with the building code, and the fabricator and erector are not responsible for the suitability, adequacy, or building-code conformance of the design. When the owner contracts with the fabricator for the design and fabrication of the structure, the fabricator is responsible for complying with performance criteria the owner specifies and the building code.

1.6 PATENTS AND COPYRIGHTS

Parties specifying the use of patented or copyrighted designs shall obtain the necessary rights for their use.

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1.7 EXISTING STRUCTURES

The following are not in the fabricator or erector's scope of work:

a) Demolition and shoring of existing structures;

b) Protection of existing structures, their contents, or equipment;

c) Surveying or field dimensioning existing structures;

d) Abatement or removal of hazardous material.

If such work is required, it shall be performed in a timely manner so as not to interfere with or delay the work of the fabricator or erector.

1.8 ERECTION MEANS, METHODS, AND SAFETY

The erector is responsible for erection means, methods, and safety.

2. Design Drawings and Specifications

2.1 RESPONSIBILITY FOR DESIGN DRAWINGS AND SPECIFICATIONS

The owner's designated representative for design shall furnish the design drawings and specifications, unless the owner contracts with the fabricator for the design and fabrication of the structure, in which case the fabricator shall furnish design drawings for review and approval by the owner's designated representative for design. The owner's designated representative for design shall approve the design drawings or indicate required changes in a timely manner to avoid delaying the fabricator's work.

Approval of the design drawings shall authorize the fabricator to commence fabrication.

2.2 CONTENTS

The structural design drawings and specifications shall be based on consideration of the design loads to be resisted by the structural aluminum in the completed structure. The structural design drawings and specifications shall be numbered and dated, show the work to be performed, and provide the following information as applicable:

a) Size, section, alloy, temper, and location of members;

b) Geometry, elevations, and work points;

c) Magnitude, direction, and location of camber;

d) Joining requirements for built-up members;

e) Locations, thicknesses, and sizes of any leveling plates;

f) Other elements with which the structural aluminum in the completely erected state requires interaction for strength or stability;

g) Quantities, details, and fabrication requirements for permanent bracing, stiffeners, doubler plates, web reinforcement, openings for other trades, and other special details;

h) Portions of members to be painted, surface preparation, paint specification, and dry-film thickness;

i) Any special requirements for the fabrication and erection of the structural aluminum;

j) One of the following options for each connection:

1) The complete connection design shall be shown, or

2) The connection shall be designated to be designed by a licensed professional engineer working on behalf of the fabricator. In this case, the owner's designated representative for design shall provide the following information in the structural design drawings and specifications:

(a) Any restrictions on the type of connections allowed;

(b) Forces and moments to be resisted by the members and their connections sufficient to allow the design of the connection details;

(c) Whether the forces and moments given in (b) are at the service-load or the factored-load level;

(d) Whether LRFD or ASD is to be used for the connection design, and

(e) What substantiating connection information is to be provided with the shop and erection drawings to the owner's designated representative for design.

2.3 DISCREPANCIES

In the event of discrepancies between:

a) the design drawings and specifications, the design drawings shall govern.

b) scaled dimensions in the design drawings and the figures written in them, the figures shall govern.

c) the structural design drawings and architectural, electrical, or mechanical design drawings, the structural design drawings shall govern.

When the fabricator discovers a discrepancy in the contract documents, the fabricator shall promptly notify the owner's designated representative for construction so that the discrepancy can be resolved by the owner's designated representative for design. The owner's designated representative for design shall resolve the discrepancy in a timely manner to avoid delaying the fabricator's work.

2.4 LEGIBILITY OF DESIGN DRAWINGS

Design drawings shall be legible and drawn to an identified scale sufficient to clearly convey the required information.

2.5 REVISIONS TO DESIGN DRAWINGS AND SPECIFICATIONS

Revisions shall be clearly and individually identified on the contract documents. The contract documents shall

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be dated and identified by revision number. Each design drawing shall be identified by the same number throughout the project duration regardless of revisions.

3. Fabrication and Erection Drawings

3.1 OWNER RESPONSIBILITY

When the owner's designated representative for design provides the design drawings and specifications, the owner shall furnish to the fabricator complete structural design drawings and specifications that have been released for construction. Unless otherwise noted, issuing design drawings for bid constitutes authorization by the owner that the design drawings are released for construction.

3.2 FABRICATOR RESPONSIBILITY

The fabricator shall produce fabrication and erection drawings for the structural aluminum and is responsible for the following:

a) The transfer of information from the contract documents into accurate and complete fabrication and erection drawings, and
b) The development of accurate, detailed dimensional information to provide for the fit of the parts in the field.

Each fabrication and erection drawing shall be identified by the same drawing number throughout the duration of the project and shall be identified by revision number and date, with each revision clearly identified.

To request a change to details shown in the contract documents, the fabricator shall notify the owner's designated representatives for design and construction in writing before submitting the fabrication and erection drawings. The owner's designated representative for design shall review and approve or reject the request in a timely manner.

3.3 USE OF DESIGN DRAWINGS

The fabricator shall neither use nor reproduce any part of the design drawings as part of the fabrication or erection drawings without the written permission of the owner's designated representative for design.

3.4 APPROVAL

When the owner's designated representative for design provides the design drawings and specifications, the fabricator shall submit fabrication and erection drawings and, if required, substantiating connection information to the owner's designated representative for design for review and approval. The fabrication and erection drawings shall be returned to the fabricator within 14 calendar days.

Approved fabrication and erection drawings shall be individually annotated by the owner's designated representatives for design and construction as either approved or approved subject to corrections noted. When required by the owner's designated representatives for design and construction, the fabricator shall subsequently make the corrections noted and furnish corrected fabrication and erection drawings to the owner's designated representatives for design and construction.

Approval of the fabrication and erection drawings, approval subject to corrections noted, and similar approvals shall constitute:

a) Confirmation that the fabricator has correctly interpreted the contract documents in preparing the fabrication and erection drawings;
b) Confirmation that the owner's designated representative for design has reviewed and approved the connection details shown on the fabrication and erection drawings; and
c) Release by the owner's designated representatives for design and construction for the fabricator to begin fabrication using the approved fabrication drawings.

Such approval does not relieve the fabricator of the responsibility for either the accuracy of the detailed dimensions on the fabrication and erection drawings or the fit of parts to be assembled in the field.

Unless noted otherwise, any additions, deletions, or revisions that are indicated in response to RFIs or on the approved fabrication and erection drawings shall constitute authorization by the owner that the additions, deletions, or revisions are released for construction. The fabricator and erector shall promptly notify the owner's designated representative for construction when any direction in response to RFIs or on the fabrication and erection drawings will result in additional cost or a delay.

3.5 FABRICATION AND ERECTION DRAWINGS NOT FURNISHED BY THE FABRICATOR

Fabrication and erection drawings not prepared by the fabricator but prepared by others shall be delivered to the fabricator in a timely manner. The fabricator is not responsible for the completeness or accuracy of such drawings, nor the fit of parts fabricated from them.

3.6 RFIs

The fabricator and erector shall submit written requests for information (RFIs) related to interpretation of the contract documents to the owner's designated representative for design, who shall maintain a written record of responses.

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3.7 ERECTION DRAWINGS

Erection drawings shall be provided to the erector in a timely manner to allow the erector to properly perform the work.

4. Materials

4.1 ORDERING

Unless otherwise specified in the contract documents, the fabricator is permitted to order materials needed for fabrication when the fabricator receives contract documents that have been released for construction.

4.2 CERTIFICATION

Unless otherwise specified in the contract documents, the fabricator shall obtain only the material certification documentation required by the *Specification for Aluminum Structures* Section N.2.

5. Shop Fabrication and Delivery

5.1 IDENTIFICATION OF MATERIAL

The fabricator shall be able to demonstrate by written procedure and actual practice a method of identifying material, visible up to the point of assembling members. Identification capability shall include shape designation and material alloy and temper. Material test reports shall be furnished by the fabricator if requested by the owner's designated representative for design, either in the contract documents or in separate written instructions given to the fabricator before the fabricator orders materials.

5.2 PREPARATION OF MATERIAL

Surfaces specified as "finished" in the contract documents shall have a roughness height value measured in accordance with ASME B46.1 that is equal to or less than 500 μin [12.5 μm].

5.3 EXTENSION AND BACKING BARS

Extension and backing bars shall be removed if required by AWS D1.2 or the contract documents.

5.4 FABRICATION TOLERANCES

5.4.1 Length

For members with both ends finished, the tolerance on length shall be 1/32 in. [1 mm]. For other members, the tolerance on length shall be 1/16 in. [2 mm].

5.4.2 Straightness

For straight compression or flexural members, the variation in straightness shall be equal to or less than 1/960 of the axial length between points that are to be laterally supported. For all other straight structural members, the variation in straightness shall be equal to or less than that specified in *Aluminum Standards and Data.* For curved structural members, the variation from theoretical curvature shall be equal to or less than the variation in straightness specified for a straight member of the same length in *Aluminum Standards and Data*.

5.4.3 Camber

Beams or trusses that are detailed without specified camber shall be fabricated so that after erection any incidental camber due to fabrication is upward.

For beams, the tolerance on camber shall be minus zero/plus ½ in. (- 0, + ½ in. [-0, +13 mm]) plus 1/8 in. for each 10 ft or fraction thereof (13 mm plus 3 mm for each 3000 mm or fraction thereof) in excess of 50 ft (15000 mm) in length. For trusses, the variation in camber at each specified camber point shall be 1/800 of the distance from that point to the nearest point of support.

For inspection, camber shall be measured in the fabrication shop in the unstressed condition.

5.5 SHOP CLEANING

The fabricator shall clean structural aluminum of oil, dirt, and foreign material.

5.6 MARKING AND SHIPPING OF MATERIALS

Unless otherwise specified in the contract documents, piece marks shall be applied to the structural aluminum members by painting or other suitable means.

Fasteners shall be shipped in separate closed containers according to length, diameter, type, alloy, and coating. Other small parts shall be shipped in closed containers. Quantities and descriptions of parts shipped in closed containers shall be listed on the outside of each container.

5.7 DELIVERY OF MATERIALS

Fabricated structural aluminum shall be delivered in a sequence that permits efficient and economical fabrication and erection and that is consistent with requirements in the contract documents. If the owner or owner's designated representative for construction wishes to prescribe or control the sequence of delivery, that party shall specify the required sequence in the contract documents. If the owner's designated representative for construction contracts separately for delivery and for erection, the owner's

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designated representative for construction shall coordinate planning between parties.

Structural aluminum that is to be embedded in concrete or masonry shall be shipped so that it will be available when needed. The owner's representative for construction shall allow the fabricator sufficient time to fabricate and ship such material.

The receiving party shall promptly notify the fabricator of any shortage or damage claimed for delivered materials so the claim can be investigated.

6. Erection

6.1 METHOD OF ERECTION

Fabricated structural aluminum shall be erected using methods and a sequence that will permit efficient and economical performance of erection, and that is consistent with the contract documents. If the owner or the owner's designated representative for construction wishes to prescribe the method or sequence of erection, that party shall specify the required method and sequence in the contract documents. If the owner's designated representative for construction contracts separately for fabrication and erection, the owner's designated representative for construction shall coordinate the fabrication and erection work.

6.2 JOB-SITE CONDITIONS

The owner's designated representative for construction shall provide and maintain the following for the fabricator and erector:

a) Adequate access roads into and through the job site for the safe delivery and movement of material to be erected and of cranes, trucks, and other necessary equipment under their own power;

b) A firm, properly graded, drained, convenient, and adequate space at the job site for the operation of the erector's equipment, free from overhead obstructions such as power lines or telephone lines; and

c) Adequate storage space, when the structure does not occupy the full available job site, to enable the fabricator and erector to operate at maximum practical speed.

Otherwise, before bidding, the owner's designated representative for construction shall inform the fabricator and erector of the actual job-site conditions and any special delivery requirements.

6.3 FOUNDATIONS

The accurate location, strength, suitability of, and access to foundations shall be the responsibility of the owner's designated representative for construction.

6.4 LINES AND BENCH MARKS

The owner's designated representative for construction shall be responsible for the accurate location of lines and benchmarks at the job site and shall furnish the erector with a plan that contains this information.

6.5 INSTALLATION OF ANCHOR RODS, FOUNDATION BOLTS, AND OTHER EMBEDDED ITEMS

Anchor rods, foundation bolts, and other embedded items shall be set by the owner's designated representative for construction in accordance with embedment drawings that have been approved by the owner's designated representatives for design and construction. The tolerance on location of these items shall be as follows unless other tolerances are provided on the design drawings or specifications:

a) The tolerance between locations of any two anchor rods within an anchor-rod group shall be 1/8 in. [3 mm].

b) The tolerance between locations of adjacent anchor-rod groups shall be 1/4 in. [6 mm].

c) The tolerance on elevation of the tops of anchor rods shall be ½ in. [13 mm].

d) The tolerance on locations of anchor-rod groups along a column line shall be ¼ in. [6 mm] per 100 ft [2 mm per 10000 mm], but not more than 1 in. [25 mm].

The tolerances specified in (b), (c), and (d) apply to offset dimensions shown in the structural design drawings, measured parallel and perpendicular to the nearest column line for individual columns that are shown in the structural design drawings as offset from column lines.

Unless otherwise specified in the contract documents, anchor rods shall be set with their longitudinal axis perpendicular to the theoretical bearing surface.

Work performed by the owner's designated representative for construction shall be completed so as not to delay or interfere with the work of the fabricator or erector. The owner's designated representative for construction shall conduct a survey of the as-built locations of the anchor rods, foundation bolts, and other embedded items, and shall verify that all items addressed in this Section meet the required tolerances. When corrective action is required, the owner's designated representative for construction shall obtain the approval of the owner's designated representative for design.

6.6 INSTALLATION OF BEARING DEVICES

The owner's designated representative for construction shall set to line and grade all leveling plates, leveling nuts and washers, and loose base and bearing plates that can be handled without a crane. Loose base and bearing plates

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that require handling with a crane shall be set by the erector to lines and grades established by the owner's designated representative for construction. The fabricator shall scribe loose base and bearing plates with lines or other suitable marks to facilitate proper alignment.

The owner's designated representative for construction shall check bearing devices for line and grade promptly after setting them. The tolerance on elevation of bearing devices shall be 1/8 in. [3 mm].

6.7 GROUTING

Grouting shall be the responsibility of the owner's designated representative for construction. Leveling plates and loose base and bearing plates shall be promptly grouted after they are set and checked for line and grade. Columns with attached base plates, beams with attached bearing plates and other similar members with attached bearing devices that are temporarily supported on leveling nuts and washers, shims, or other similar leveling devices, shall be promptly grouted after the structural aluminum frame or portion thereof has been plumbed.

6.8 FIELD CONNECTION MATERIAL

When the fabricator is responsible for erection, the fabricator shall furnish all materials required for both temporary and permanent connection of the parts of the structural aluminum frame.

When erection is not performed by the fabricator, the fabricator shall furnish the following connection material:

a) Fasteners for all structural aluminum field connections that are to be permanently fastened, including an extra 2% of each fastener diameter and length;

b) Shims necessary for make-up of permanent structural aluminum to structural aluminum field connections; and

c) Backing and extension bars required for field welding.

The erector shall furnish all welding electrodes, fit-up fasteners, and drift pins used for the erection of the structural aluminum.

6.9 LOOSE MATERIAL

Unless otherwise specified in the contract documents, loose structural aluminum items not connected to the structural aluminum frame shall be set by the owner's designated representative for construction without assistance from the erector.

6.10 TEMPORARY SUPPORT OF STRUCTURAL ALUMINUM FRAMES

6.10.1 Responsibilities of the Owner's Designated Representative for Design

The owner's designated representative for design shall identify the following in the contract documents:

a) The lateral-load resisting system and connecting diaphragm elements that provide for lateral strength and stability in the completed structure.

b) Special erection conditions or other considerations required by the design, such as the use of shores, jacks, or loads that must be applied as erection progresses to set or maintain camber, position, or prestress.

6.10.2 Installation Schedule

Before bidding, the owner's designated representative for construction shall indicate to the erector the installation schedule for non-structural aluminum elements of the lateral-load resisting system and connecting diaphragm elements identified by the owner's designated representative for design in the contract documents.

6.10.3 Installation

Based on the information provided in 6.10.1 and 6.10.2, the erector shall determine, furnish, and install temporary supports, such as guys, beams, falsework, cribbing, or other elements required for erection. These temporary supports shall be sufficient to secure the structural aluminum frame and any portion thereof against loads likely to be encountered during erection, including those due to wind and those that result from erection operations.

The erector need not consider loads during erection that result from the work of other trades, except as identified by the owner's designated representatives for design and construction, nor those that are unpredictable such as loads due to tornadoes, earthquakes, explosions, or collisions.

Temporary supports required during or after erection of the structural aluminum frame for the support of loads caused by non-structural aluminum elements, including cladding, interior partitions, or other such elements that apply loads to the structural aluminum frame during or after erection are the responsibility of others.

6.10.4 Removal

Temporary supports required for erection and furnished by the erector remain the property of the erector and shall not be modified, moved, or removed without the erector's consent. Temporary supports provided by the erector shall remain in place until the portion of the structural aluminum frame that they brace is complete and the lateral load resisting system and connecting diaphragm elements identified

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by the owner's designated representative for construction in accordance with 6.10.1 are installed. Temporary supports that are required to be left in place after the completion of the structural aluminum frame erection shall be removed by the owner's designated representative for construction when no longer needed and returned to the erector in the condition in which they were installed.

6.11 SAFETY PROTECTION

The erector shall provide floor coverings, handrails, walkways, and other safety protection for the erector's personnel as required by applicable safety regulations. Unless otherwise specified in the contract documents, the erector is permitted to remove such protection from areas where erection operations are completed.

When safety protection provided by the erector is left for the use of other trades after the structural aluminum erection activity is completed, the owner's designated representative for construction shall:

a) Accept responsibility for and maintain this protection;

b) Indemnify the fabricator and erector from damages that may be incurred from the use of this protection by others;

c) Ensure that this protection is adequate for use by other affected trades;

d) Ensure that this protection complies with applicable regulations when being used by others;

e) Remove this protection when it is no longer required and return it to the erector in the condition in which it was received.

Safety protection for personnel not employed by the erector is the responsibility of the owner's designated representative for construction.

Unless the activities of other trades is coordinated with the work of the erector by the owner's designated representative for construction, such activities are not permitted until erection is completed by the erector and accepted by the owner's designated representative for construction.

6.12 MATERIAL AND FABRICATION TOLERANCES

The accumulation of material and fabrication tolerances shall not cause erection tolerances to be exceeded.

6.13 ERECTION TOLERANCES

Erection tolerances shall be defined relative to member work points and work lines, defined as follows:

a) For members other than horizontal members, the member work point shall be the center of the member at each end of each shipping piece.

b) For horizontal members, the work point shall be the centerline of the top surface of the member at each end.

c) The member work line shall be the straight line that connects the member's work points.

If work points or work lines are defined differently, this shall be shown on the erection drawings.

6.13.1 Tolerances

Tolerances on locations of members with respect to member work points and work lines shall be in accordance with this Section.

For a vertical member, the tolerance on plumbness shall be 1/500 of the distance between work points.

For members other than vertical members, the tolerances shall be as follows:

a) For a member that consists of an individual shipping piece, the variation in elevation shall be acceptable if it is caused solely by the variations in the elevations of the supporting members within the permissible variations for the fabrication and erection of those members.

b) For a member that consists of an individual straight shipping piece and that is a segment of a field assembled unit containing field splices between points of support, the plumbness, elevation, and alignment shall be acceptable if the angular variation, vertically and horizontally, of the work line from a straight line between points of support is equal to or less than 1/500 of the distance between work points.

c) For a cantilevered member that consists of an individual, straight shipping piece, the plumbness, elevation, and alignment shall be acceptable if the variation of the working line from a straight line that is extended in the plan direction from the work point at its supported end is equal to or less than 1/500 of the distance from the work point at the free end.

6.13.2 Clearances to the Work of Other Trades

The owner's designated representative for design shall provide for the necessary clearances for material furnished by other trades to accommodate the material, fabrication, and erection tolerances in this Code for the structural aluminum frame.

6.13.3 Acceptability

Before supporting, attaching, or applying other materials to the structural aluminum frame, the owner's designated representative for construction shall determine that the location of the structural aluminum is acceptable for plumbness, elevation, and alignment. The owner's designated

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representative for construction shall, in a timely manner, give the erector either a notice of acceptance or a list of specific items to be corrected in order to obtain acceptance.

6.14 CORRECTING ERRORS

Correcting minor misfits by moderate amounts of reaming, grinding, or cutting and the drawing of elements into line with drift pins shall be acceptable. The erector shall promptly report errors that cannot be corrected by the foregoing means to the owner's designated representatives for design and construction, to enable efficient and economical correction to be performed by others.

6.15 CUTS, ALTERATIONS, AND HOLES FOR OTHER TRADES

Neither the fabricator nor the erector shall cut, drill, or otherwise alter their work, nor the work of other trades, to accommodate other trades unless such work is specified in the contract documents. When such work is specified, the owner's designated representatives for design and construction shall furnish information as to material, size, and location of such work in a timely manner so as not to delay preparation of the fabrication and erection drawings. Other trades shall not weld to, cut, drill, or otherwise alter the structural aluminum unless such work is indicated on the design drawings and specifications.

6.16 HANDLING AND STORAGE

The erector shall take reasonable care in handling and storing structural aluminum during erection to avoid accumulating dirt or foreign matter on the aluminum. The erector shall not be responsible for removing from structural aluminum dust, dirt, or other foreign matter that accumulates during erection as the result of job-site conditions or exposure to the elements. The erector shall handle and store all fasteners in a manner that preserves their function.

6.17 FIELD PAINTING

Neither the fabricator nor the erector is responsible for painting fasteners installed in the field or welds made in the field, or to touch up abrasions of shop coatings, or any other field painting.

6.18 FINAL CLEAN UP

The erector shall remove all of the erector's falsework, rubbish, and temporary facilities upon completion of erection and before final acceptance.

7. Quality Control and Quality Assurance

7.1 GENERAL

The fabricator and erector shall comply with the requirements of the *Specification for Aluminum Structures,* Chapter N.

When the owner requires additional inspection not included in the quality control programs of the fabricator or erector or independent inspection, these requirements shall be specified in the contract documents.

7.2 INSPECTION OF MATERIAL

Written certification that material complies with the appropriate ASTM specification shall constitute sufficient evidence that the material is acceptable. The fabricator shall visually inspect material received, but need not perform any additional inspection unless the contract documents specify additional inspection.

7.3 NON-DESTRUCTIVE INSPECTION

The method, extent, and acceptance criteria for any non-destructive inspection shall be specified in the contract documents.

7.4 INDEPENDENT INSPECTION

When inspection by personnel other than those of the fabricator or erector is specified in the contract documents, the following requirements shall be met:

a) The fabricator and the erector shall provide the inspector with access to all places where the work is being performed, and notify the inspector at least 24 hours before beginning the work.

b) Inspection of fabrication by the inspector shall be performed at the fabricator's shop to the fullest extent possible. Such inspections shall be timely, in-sequence, and performed in a manner that will not disrupt fabrication.

c) Inspection of field work shall be timely, in-sequence, and performed in a manner that will not disrupt erection.

d) Rejection of material or workmanship not in conformance with the contract documents shall be permitted at any time during the progress of the work. However, this provision shall not relieve the owner or inspector of the obligation for timely, in-sequence inspections.

e) The inspector shall inform the fabricator, erector, and owner's designated representatives for design and construction of deficiencies noted by the inspector promptly. The inspector shall give copies of all inspection reports to the fabricator, erector, and owner's designated representatives for design and construction. Corrective work shall be performed in a timely manner.

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f) The inspector shall not direct or approve any deviation from the contract documents or approved fabrication or erection drawings without the written approval of the owner's designated representatives for design and construction.

8. Contracts

8.1 TYPES OF CONTRACTS

For contracts that stipulate a lump sum price, the contract documents shall specify the work required to be performed by the fabricator and erector.

For contracts that stipulate a price by weight, the work required to be performed by the fabricator and erector, the materials, and the character of fabrication and conditions of erection shall be specified in the contract documents.

For contracts that stipulate a price per item, the work required to be performed by the fabricator and the erector shall be based on the quantity and character of the items described in the contract documents.

8.2 CALCULATION OF WEIGHTS

For contracts stipulating a price by weight for fabricated structural aluminum that is delivered or erected, weights shall be calculated from the gross weight of materials shown on the fabrication drawings.

The unit weight of aluminum shall be taken as 0.1 lb/in3 [2700 kg/m3].

The weights of fabrication or erection weld metal and protective coatings shall not be included in calculating the weight for purposes of payment.

8.3 REVISIONS TO THE CONTRACT DOCUMENTS

Revisions to the contract documents shall be confirmed by change order. Unless otherwise noted, the issuance of a revision to the contract documents shall constitute authorization by the owner that the revision is released for construction. The contract price and schedule shall be adjusted in accordance with Sections 8.4 and 8.5.

8.4 CONTRACT PRICE ADJUSTMENT

When the scope of work of the fabricator or erector is changed from that previously established by the contract documents, the contract price shall be adjusted appropriately. To determine the adjustment, the fabricator and erector shall consider the quantity of work added or deleted, modifications in the character of the work, and timing of the change with respect to the status of material ordering, detailing, and fabrication and erection operations.

The fabricator and erector shall submit requests for contract price adjustments to the owner in a timely manner and shall provide a description of the change sufficient to permit evaluation.

Price-per item and price by weight contracts shall provide for additions or deletions to the quantity of work made before the work is released for construction. When changes are made to the character of the work at any time, or when additions or deletions are made to the quantity of the work after it is released for construction, the contract price shall be suitably adjusted.

8.5 SCHEDULE

If design drawings are not available at the time of bidding, the contract schedule shall state when design drawings will be released for construction. The contract schedule shall state when the job site will be ready and accessible to the erector.

The fabricator and erector shall inform the owner's designated representatives for design and construction in a timely manner of the effect any revision has on the contract schedule. If fabrication or erection is delayed due to revisions to the contract or the actions of others, the fabricator or erector shall be compensated for additional costs incurred.

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9. Architectual Exposed Structural Aluminum

9.1 GENERAL

When members are designated as architecturally exposed structural aluminum (AESA) in the contract documents, the requirements of Sections 1 through 8 shall apply as modified in Section 9. When AESA is specified, the contract documents shall:

a) Identify the members or components that are AESA;
b) Specify fabrication and erection tolerances if they are more restrictive than specified in Sections 1 through 8; and
c) Provide requirements, if any, for mock-up components to be provided by the fabricator to the owner's designated representative for design and construction before the start of fabrication.

9.2 FABRICATION

Unless specific visual inspection acceptance criteria for weld show-through are specified in the contract documents, members shall be acceptable as produced. The appearance of welds exposed to view shall be acceptable if they meet the requirements of AWS D1.2, except groove welds in butt joints and outside corner joints and plug welds shall not project more than 1/16 in. [2 mm] above the surface. Finishing or grinding of welds is not necessary unless it is required to provide for clearance or fit of other parts.

Copes, miters, and cuts in surfaces exposed to view shall be made with uniform gaps of 1/8 in. [3 mm] if shown as open joints on the erection drawings, or in contact if shown without gap.

Erection or piece marks shall not be made on surfaces exposed to view in the completed structure.

9.3 DELIVERY OF MATERIALS

The fabricator shall provide a means of protecting the appearance of materials during shipping and delivery to the job site.

9.4 ERECTION

The erector shall unload, handle, and erect the structural aluminum in a manner that protects its appearance.

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APPENDIX A
SI GUIDE

The Aluminum Association

ALUMINUM
DESIGN MANUAL
2020

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Aluminum Design Manual

Appendix A

SI Guide

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Appendix A
SI Guide

Table A.1
SI CONVERSION FACTORS

Quantity	Multiply		By	To obtain	
Length	inch	in.	25.400	millimeter	mm
	foot	ft	0.3048	meter	m
	mile	mi	1.609	kilometer	km
	millimeter	mm	0.03937	inch	in.
	meter	m	3.281	foot	ft
	kilometer	km	0.621	mile	mi
Area	square inch	in^2	645.16	square millimeter	mm^2
	square foot	ft^2	0.093	square meter	m^2
	square mile	mi^2	2.590	square kilometer	km^2
	square millimeter	mm^2	0.001550	square inch	in^2
	square meter	m^2	10.764	square foot	ft^2
	square kilometer	km^2	0.386	square mile	mi^2
Volume	cubic inch	in^3	16387	cubic millimeter	mm^3
	cubic foot	ft^3	0.028317	cubic meter	m^3
	cubic yard	yd^3	0.765	cubic meter	m^3
	gallon (U.S. liquid)	gal	3.785	liter	L
	quart (U.S. liquid)	qt	0.946	liter	L
	cubic millimeter	mm^3	61.024×10^{-6}	cubic inch	in^3
	cubic meter	m^3	35.315	cubic foot	ft^3
	cubic meter	m^3	1.308	cubic yard	yd^3
	liter	L	0.2642	gallon (U.S. liquid)	gal
	liter	L	1.057	quart (U.S. liquid)	qt
Mass	ounce	oz	28.350	gram	g
	pound	lbm	0.4536	kilogram	kg
	short ton (2,000 lb)		907.2	kilogram	kg

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Table A.1
SI CONVERSION FACTORS (Continued)

Quantity	Multiply		By	To obtain	
	gram	g	0.035274	ounce	oz
	kilogram	kg	2.205	pound	lbm
	kilogram	kg	0.001102	short ton (2,000 lb)	
Force	pound-force	lbf	4.448	newton	N
	kip	k	4.448	kilonewton	kN
	newton	N	0.2248	pound-force	lbf
	kilonewton	kN	0.2248	kip	k
Bending Moment	pound-force-inch	lbf-in.	0.113	newton-m	N-m
	pound-force-ft	lbf-ft	1.356	newton-m	N-m
	newton-m	N-m	8.851	pound-force-inch	lbf-in.
	newton-m	N-m	0.738	pound-force-ft	lbf-ft
Stress, Pressure	pound-force per square inch	lbf/in^2	6.895	kilopascal	kPa
	pound-force per square foot	lbf/ft^2	0.04788	kilopascal	kPa
	inch of water	in. w.c.	0.249	kilopascal	kPa
	kip per square inch	k/in^2	6.895	megapascal	MPa
	kilopascal	kPa	0.145	pound-force per square inch	lbf/in^2
	kilopascal	kPa	20.885	pound-force per square foot	lbf/ft^2
	kilopascal	kPa	4.015	inch of water	in. w.c.
	megapascal	MPa	0.145	kip per square inch	k/in^2
Energy, Work, Heat	foot-pound-force	ft-lbf	1.356	joule	J
	British thermal unit	Btu	1055	joule	J
	calorie	cal	4.187	joule	J
	kilowatt-hour	kW-h	3.600×10^6	joule	J

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Table A.1
SI CONVERSION FACTORS (Concluded)

Quantity	Multiply		By	To obtain	
	joule	J	0.738	foot-pound-force	ft-lbf
	joule	J	0.948×10^{-3}	British thermal unit	Btu
	joule	J	0.239	calorie	cal
	joule	J	0.278×10^{-6}	kilowatt-hour	kW-h
Density	pound per cubic foot	lb/ft^3	16.0185	kilogram per cubic meter	kg/m^3
	kilogram per cubic meter	kg/m^3	0.06243	pound per cubic foot	lb/ft^3
Angle	degree	deg	0.017453	radian	rad
	radian	rad	57.296	degree	deg
Temperature	°C = (°F − 32)/1.8				
	°F = 1.8°C + 32				

For complete information see IEEE/ASTM SI-10

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Table A.2
SI PREFIXES

Multiplication Factor	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto[a]	h
10^{1}	deka[a]	da
10^{-1}	deci[a]	d
10^{-2}	centi[a]	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

a: not recommended

Table A.3
SI DERIVED UNITS WITH SPECIAL NAMES

Quantity	Unit	Symbol	Formula
force	newton	N	$kg\text{-}m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work	joule	J	N-m
power	watt	W	J/s

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