The Aluminum Association

ALUMINUM DESIGN MANUAL 2015



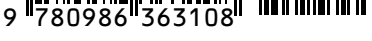
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FOREWORD

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, and guidelines for aluminum sheet metal used in construction.

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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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 10th edition of the *Specification*, developed as a consensus document, includes new or revised provisions concerning

- material specifications (A.3.1)
- modulus of elasticity, compressive yield strength and shear ultimate strength (A.3.1)
- cast alloy strengths (A.3.3)
- effective net area (D.3.2)
- axial compression member buckling strength (E.2)
- alternative methods for determining column and beam elastic strengths (E.2, F.2.1.4)
- flexural strength (F.1, F.2, F.3, F.4)
- shear in webs supported on one edge (G.3)
- shear strengths of rods (G.5)
- shear and torsional strengths (G.1, H.2)
- welded connections (J.2)
- slip-critical connections (J.3.7)
- pins (J.6)
- fabrication of edges (M.2, M.4)
- contact with dissimilar materials (M.7)
- quality control and quality assurance (Chapter N)
- testing (Appendix 1)
- fatigue (Appendix 3)

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

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_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_{gt} = gross cross sectional area of the element in tension (J.7.3)

A_{gv} = gross 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_{pb} = projected bearing area (J.8)

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} = cross-sectional area of the weld-affected zone, which extends 1 in. (25 mm) to each side of the centerline of a weld (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, 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, B.5.5.5, 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, B.5.5.5, 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.9.1)

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.5.4.2, J.5.5.1, J.5.5.2, J.6.4, J.6.5)

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

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, 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, B.5.4.2, B.5.4.6, B.5.5.5, 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)

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D_{ss} = screw slot inside diameter (Table J.5.3, J.5.4.1.2)
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.3.1, 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, B.5.6, E.2, E.2.2, E.4, 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.9.1, 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, F.4.3, F.3.1, F.3.2, 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.3.1, 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, E.2, E.3.1, F.2, F.3.1, F.4, F.5, J.9.1)
F_{cyw} = compressive yield strength of weld-affected zones (E.2)
F_e = elastic buckling stress (B.5.4.6, B.5.5.5, Table B.5.1, E.2.2, E.4, 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.3.3 or Table A.3.3M (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.3.6 (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.3.1, A.3.5, A.3.6, G.2, G.3, G.4, G.5, H.2, 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 zones (G.2, G.3, G.4, G.5, H.2)
F_{sw} = shear stress corresponding to the welded shear strength (G.1, H.2)
F_{sy} = shear yield strength (Table A.3.1, Table B.4.1, Table B.4.2, G.2, G.3, G.4, H.2.1, H.2.3, J.6.4, J.7.2, J.7.3)
F_{syw} = shear yield strength of weld-affected zones (G.2, H.2.3)
F_{tu} = tensile ultimate strength (Table A.3.1, Table A.3.3, A.3.2, A.3.3, A.3.5, D.2, F.2, J.3.4, J.3.6, J.4.6, J.5.4.1.2, 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 zones (A.3.2, A.3.4, D.2, Table J.2.2)
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 (J.5.4.1.1, J.5.5.2)
F_{ty} = tensile yield strength (Table A.3.1, Table A.3.3, Table A.3.4, A.3.2, A.3.3, D.2, F.2, J.6.4, J.7.3, 1.4, Table 4.2)
F_{tym} = tensile yield strength at elevated temperatures (4.2.3.1)
F_{tyw} = tensile yield strength of weld-affected zones (A.3.2, D.2)
F_{ty1} = tensile yield strength of the part in contact with the screw head (J.5.4.2)
F_{ty2} = tensile yield strength of member not in contact with the screw head (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)

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G = shear modulus of elasticity (Table A.3.1, E.2.2)
G_f = the grip of a bolt (J.3.5)

$$H = 1 - \frac{x_0^2 + y_0^2}{r_0^2} \qquad \text{(E.2.2)}$$

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 sub-elements 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.4.1.2, 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.4.1.2, F.4.2.2, F.4.2.5)
I_{yt} = moment of inertia of the tension flange about the y-axis (F.4.2.2)
I_z = moment of inertia about the minor principal axis (F.5.2)
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 (J.5.4.1.1)
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_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, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2, 6.4)
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 or screw slot not including tapping or drilling point (J.5.4.1.1, J.5.4.1.2)
L_n = nominal live load (1.3.2, 4.1.3, 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_c = design or allowable flexural strength (H.1, J.6.4, J.9.3)
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, F.4.1.2)
M_n = nominal strength moment (F.1, F.5, F.5.1, F.5.2, 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 (B.5.5.4, B.5.5.5, F.2, F.4)
M_{nmbw} = lateral-torsional buckling strength if the entire cross section were weld-affected (F.4)
M_r = required flexural strength using LRFD or ASD load combinations (H.1, J.6.4, J.9.3, 6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2, 6.4)
M_{rb} = required bracing flexural strength using LRFD or ASD load combinations (6.3.2.1)
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_c = available axial force (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.1, D.2)
P_{nw} = nominal member buckling strength if the entire cross section were weld-affected (E.2)

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P_r = required axial force using LRFD or ASD load combinations (C.2, H.1, 6.2.1, 6.2.2, 6.4)
P_{rb} = required bracing strength (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)
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_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.9.1 (J.9.3)
R_i = inside bend radius at the juncture of the flange and web; for extruded shapes, $R_i = 0$ (J.9.1)
R_{ti} = strength of ith test (1.3.2)
R_{tm} = mean strength of all tests (1.3.1, 1.3.2)
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.5.4.2, 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, 1.3.1)
R_r = required concentrated force (J.9.3)
R_S = the ratio of minimum stress to maximum stress for fatigue design (Table 3.1)
R_u = required strength for LRFD (B.3.2.1)
S = section modulus (B.5.5.4)
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)
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 (B.5.5.5, F.3.2, F.4, F.4.2.3, F.4.2.5, F.4.3)
T, T_1, T_2 = temperature (A.3.1.1)
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_c = available shear strength (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, 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)
b_e = element's effective width for determining deflections (L.3)
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 other extreme fiber of the element (see c_c) (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.9.1, 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)

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g_o = distance from the shear center to the point of application of the load; g_o 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_o = 0. (F.4.2.5)

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.3.3, A.3.2, D.2, F.2, G.2, G.3, G.4, G.5, H.2, H.2.3, 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)

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)

l_b = length of the bearing at the concentrated force (J.9.1)

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)

n = number of nodal 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, 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, J.9.1)

t = time (A.3.1.1)

t_{avg} = average thickness of a tapered thickness element (B.5.3)

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)

t_{min} = thickness of thinnest material tested (1.4.2)

t_s = beam web stiffener thickness (6.3.2.1)

t_w = beam web thickness (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.3.1.1)

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.3.1.1)

$\bar{x}$ = eccentricity of the connection in the x-axis direction (D.3.2)

x_o = the shear center's x-coordinate (E.2.2)

$\bar{y}$ = 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)

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.3.1)

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 bracing stiffness (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)

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_{Tb} = required bracing torsional 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.3.1)

$\delta = \dfrac{(t_{max} - t_{min})}{t_{min}}$ = a measure of taper in tapered thickness elements (B.5.3)

κ = metric conversion factor (Table B.4.1, Table B.4.2)

ν = Poisson's ratio (Table A.3.1)

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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, 1.3.2, 6.1, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1)

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, 1.3.2, 6.1, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1)

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 ($\theta_w \leq 90^o$) (J.9.1)

ρ_{ST} = stiffener effectiveness ratio (B.5.4.3, B.5.6)

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

$\lambda_e = 1.28\sqrt{E / F_{cy}}$ (B.5.4.3)

$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}}$

= equivalent slenderness for alternate determination of compressive strength for flexural or axial compression (B.5.4.6, B.5.5.5)

λ_s = slenderness of an element with an intermediate stiffener (B.5.4.4, B.5.6)

σ_x = standard deviation of the test strengths (1.3.1)

τ_b = parameter for reduced flexural stiffness (C.2)

μ = mean slip coefficient (J.3.7.5)

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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 approprate 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.

bridge-type structure: a structure not addressed by building codes and designed for highway, pedestrian, or rail traffic.

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.

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 I beam, 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 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).

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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 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 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).

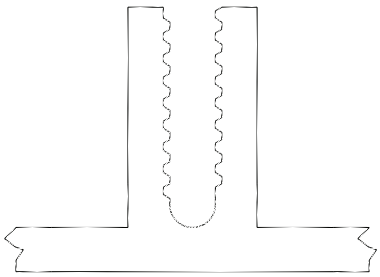


Figure GL.1
TRANSVERSE CROSS SECTION OF A SCREW CHASE

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

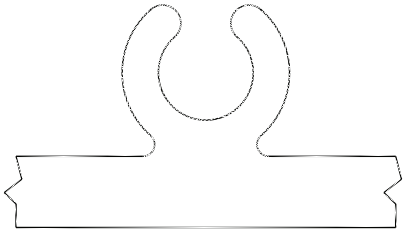


Figure GL. 2
TRANSVERSE CROSS SECTION OF A SCREW SLOT

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.

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: meal within 1 in. (25 mm) of the centerline of a weld.

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Chapter A General Provisions

A.1 SCOPE

The *Specification for Aluminum Structures*, hereafter referred to as the *Specification*, applies to the design 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

Aluminum Standards and Data 2013
Aluminum Standards and Data 2013 Metric SI
Standards for Aluminum Sand and Pemanent Mold Castings (2008)

American Association of State Highway and Traffic Officials (AASHTO)

Guide Specifications for Design of Pedestrian Bridges (1997)
Standard Specifications for Highway Bridges (2002)
Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (2013)

American Institute for Steel Construction

Specification for Structural Steel Buildings (ANSI/AISC 360-10)

American Society for Nondestructive Testing (ASNT)

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

American Society of Civil Engineers (ASCE)

ASCE/SEI 7-10 *Minimum Design Loads 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:2012 *Welding Consumables – Wire Electrodes, Wires and Rods for Welding of Aluminum and Aluminum-Alloys - Classification*
AWS B5.1, *Standard for the Qualification of Welding Inspectors*
AWS D1.2/D1.2M:2014 *Structural Welding Code – Aluminum*

ASTM International (ASTM)

A 194/A 194M-12a *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*
A 325-10e1 *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*
A 325M-13 *Standard Specification for Structural Bolts, Steel, Heat Treated 830 MPa Minimum Tensile Strength [Metric]*
A 563-07a *Standard Specification for Carbon and Alloy Steel Nuts*
A 563M-07 *Standard Specification for Carbon and Alloy Steel Nuts [Metric]*
B 26/B 26M-12 *Standard Specification for Aluminum-Alloy Sand Castings*
B 108/B 108M-12e1 *Standard Specification for Aluminum-Alloy Permanent Mold Castings*
B 209-10 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*
B 209M-10 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate [Metric]*
B 210-12 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*
B 210M-12 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes [Metric]*
B 211-12e1 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire*
B 211M-12e1 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire [Metric]*
B 221-13 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*
B 221M-13 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]*
B 241/B 241M-12e1 *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*
B 247-09 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*
B 247M-09 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings [Metric]*
B 308/B 308M-10 *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*
B 316/B 316M-10 *Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*
B 429/B 429M-10e1 *Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube*

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B 557-10 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*
B 557M-10 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)*
B 632/B 632M-08 *Standard Specification for Aluminum-Alloy Rolled Tread Plate*
B 928/B 928M-09 *Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*
E 119 - 12a *Standard Test Methods for Fire Tests of Building Construction and Materials*
E 330-02(2010) *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*
E 1592-05(2010) *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*
F 436-11 *Standard Specification for Hardened Steel Washers*
F 436M-11 *Standard Specification for Hardened Steel Washers [Metric]*
F 467-13 *Standard Specification for Nonferrous Nuts for General Use*
F 467M-06a(2012) *Standard Specification for Nonferrous Nuts for General Use [Metric]*
F 468-12 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws, and Studs for General Use*
F 468M-06(2012) *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]*
F 606 - 11a *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*
F 606M - 13 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets [Metric]*

Research Council on Structural Connections (RCSC)
Specification for Structural Joints Using High Strength Bolts, 2009

A.3 MATERIAL

A.3.1 General Provisions

The properties listed in Table A.3.1 shall be used unless more precise values are specified.

Table A.3.1
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.3.1.1 Properties at Elevated Temperatures

Except as noted in Section A.3.1.2, the properties given in Section A.3 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.3.2 held at the temperatures listed in Table A.3.2 for cumulative periods of time no greater than the times listed in Table A.3.2. When alloys not addressed in Table A.3.2 are heated above 200°F or alloy-tempers addressed in Table A.3.2 are heated beyond the time-temperature limits of Table A.3.2, 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.

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Table A.3.2
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

Interpolate time t for other temperatures T using

$$\log t = \log t_2 + \frac{\log\left(T_2 / T\right)}{\log\left(T_2 / T_1\right)} \log\left(t_1 / t_2\right) \qquad \text{(A.3-1)}$$

where

T_1 = next lower temperature in Table A.3.2 than T
T_2 = next higher temperature in Table A.3.2 than T
t_1 = time corresponding to T_1
t_2 = time corresponding to T_2

A.3.1.2 Temperature Limits

Alloys 535.0, 5083, 5086, 5154, and 5456 shall not be subjected to temperatures greater than 150°F (66°C), except during fabrication in accordance with Section M.3.

A.3.2 Wrought Products

This *Specification* applies to the wrought products listed in Table A.3.3 and produced to one of the ASTM specifications listed in Table A.3.3 or A.3.3M.

The tensile ultimate strength F_{tu}, tensile yield strength F_{ty}, and tension coefficient k_t of non-weld affected material and the tensile ultimate strength F_{tuw} and tensile yield strength F_{tyw} of weld-affected material used to determine available strength shall be as listed in Table A.3.3 or A.3.3M.

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Table A.3.3
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	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	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	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	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	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	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	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	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	B209, sheet & plate	0.017	2.000	16	11	13	4.5	1
Alclad 3003	H14	B209, sheet & plate	0.009	1.000	19	16	13	4.5	1
Alclad 3003	H16	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	B209, sheet & plate	0.017	2.000	28	21	22	8.5	1
3004	H34	B209, sheet & plate	0.009	1.000	32	25	22	8.5	1
3004	H36	B209, sheet & plate	0.006	0.162	35	28	22	8.5	1
3004	H38	B209, sheet & plate	0.006	0.128	38	31	22	8.5	1
Alclad 3004	H32	B209, sheet & plate	0.017	2.000	27	20	21	8	1
Alclad 3004	H34	B209, sheet & plate	0.009	1.000	31	24	21	8	1
Alclad 3004	H36	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	B209, sheet & plate	0.017	2.000	17	12	15	5	1

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Table A.3.3 (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	B209, sheet & plate	0.009	1.000	20	15	15	5	1
5005	H36	B209, sheet & plate	0.006	0.162	23	18	15	5	1
5050	H32	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	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	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	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	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	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	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	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	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	B209, sheet & plate	0.020	2.000	36	26	31	12	1
5454	H34	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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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	13	1.25
6005A	T61	B221, extrusion	–	1.000	38	35	24	13	1
6061	T6, T651	B209, sheet & plate	0.010	4.000	42	35	24	11① or 15②	1
6061	T6	B632, tread plate	0.100	0.625	42	35	24	11① or 15②	1
6061	T6, T6510, T6511	B221, extrusion	All		38	35	24	11① or 15②	1
6061	T6, T651	B211, bar, rod, & wire	0.125	8.000	42	35	24	11① or 15②	1
6061	T6	B210, drawn tube	0.025	0.500	42	35	24	11① or 15②	1
6061	T6	B241, pipe & tube	All		38	35	24	11① or 15②	1
6061	T6	B429, pipe & tube	All		38	35	24	11① or 15②	1
6061	T6	B247, forging	–	4.000	38	35	24	11① or 15②	1
6061	T6	B308, std structural profile	0.062	–	38	35	24	11① or 15②	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
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	11① or 15②	1
6351	T6	B221, extrusion	–	0.749	42	37	24	11① or 15②	1
6463	T6	B221, extrusion	–	0.500	30	25	–	–	1
7005	T53	B221, extrusion	–	0.750	50	44	40	24	1

① When welded with 4043, 5554, or 5654 alloy filler for thicknesses > 0.375 in.
② When welded with 5183, 5356, or 5556 alloy filler regardless of thickness, and when welded with 4043, 5554, or 5654 alloy filler for thicknesses ≤ 0.375 in.
③ 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.3.3M
NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			over	thru	MPa	MPa	MPa	MPa	
1060	H12	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	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	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	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	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	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	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	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	B209, sheet & plate	0.40	50.00	115	80	90	30	1
Alclad 3003	H14	B209, sheet & plate	0.20	25.00	135	110	90	30	1
Alclad 3003	H16	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	B209, sheet & plate	0.40	50.00	190	145	150	60	1
3004	H34	B209, sheet & plate	0.20	25.00	220	170	150	60	1
3004	H36	B209, sheet & plate	0.15	4.00	240	190	150	60	1
3004	H38	B209, sheet & plate	0.15	3.20	260	215	150	60	1
Alclad 3004	H32	B209, sheet & plate	0.40	50.00	185	140	145	55	1
Alclad 3004	H34	B209, sheet & plate	0.20	25.00	215	165	145	55	1
Alclad 3004	H36	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	B209, sheet & plate	0.40	50.00	120	85	105	35	1

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Table A.3.3M (Continued)

NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			over	thru	MPa	MPa	MPa	MPa	
5005	H34	B209, sheet & plate	0.20	25.00	140	105	105	35	1
5005	H36	B209, sheet & plate	0.15	4.00	160	125	105	35	1
5050	H32	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	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	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	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	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	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	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	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	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	B209, sheet & plate	0.50	50.00	250	180	215	85	1
5454	H34	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
5456	H116	B928, sheet & plate	40.00	80.00	285	200	285	125	1

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Table A.3.3M (Continued)

NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	ASTM SPECIFICATION, PRODUCT	THICKNESS mm		F_{tu}	F_{ty}	F_{tuw}	F_{tyw}	k_t
			over	thru	MPa	MPa	MPa	MPa	
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	90	1.25
6005A	T61	B221, extrusion	–	25.00	260	240	165	90	1
6061	T6	B209, sheet & plate	0.15	6.30	290	240	165	80① or 105②	1
6061	T651	B209, sheet & plate	6.30	100.00	290	240	165	80① or 105②	1
6061	T6	B632, tread plate	5.00	16.00	290	240	165	80① or 105②	1
6061	T6, T6510, T6511	B221, extrusion	All		260	240	165	80① or 105②	1
6061	T6, T651	B211, bar, rod, & wire	3.20	200.00	290	240	165	80① or 105②	1
6061	T6	B210, drawn tube	0.63	12.50	290	240	165	80① or 105②	1
6061	T6, T6510, T6511	B241, pipe & tube	All		260	240	165	80① or 105②	1
6061	T6, T6510, T6511	B429, pipe & tube	All		260	240	165	80① or 105②	1
6061	T6	B247, forging	–	100.00	260	240	165	80① or 105②	1
6061	T6	B308, std structural profile	1.20	–	260	240	165	80① or 105②	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
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	80① or 105②	1
6351	T6	B221, extrusion	–	20.00	290	255	165	80① or 105②	1
6463	T6	B221, extrusion	–	12.50	205	170	–	–	1
7005	T53	B221, extrusion	–	25.00	345	305	275	165	1

① When welded with 4043, 5554, or 5654 alloy filler for thicknesses > 9.50 mm.
② When welded with 5183, 5356, or 5556 alloy filler regardless of thickness, and when welded with 4043, 5554, or 5654 alloy filler for thicknesses ≤ 9.50 mm.
③ 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.3.4
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.

A.3.3 Castings

This *Specification* applies to cast products listed in Table A.3.4 and that meet all of the following requirements:

a) Sand casting meet the requirements of B 26/B 26M *Aluminum-Alloy Sand Castings* and permanent mold castings meet the requirements of B 108/B 108M *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 B 26 Grade C or B 108 Grade C criteria is performed. The number of castings radiographed and the lot acceptance criteria shall be as listed in Table A.3.5.

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.3.4. Welded strengths of castings shall be those established in the AWS D1.2 weld procedure qualification test.

Table A.3.5
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

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A.3.4 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.3.6.

Table A.3.6
NOMINAL STRENGTHS OF FILLER METAL

Filler	Tensile Ultimate Strength F_{tuw} ksi	Tensile Ultimate Strength F_{tuw} MPa
1100	11	75
2319	35	240
4043	24	165
4047	25	170
5183	40	275
5356	35	240
5554	31	215
5556	42	290
5654	30	205

A.3.5 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.3.7.

Table A.3.7
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.3.6 Rivets

This *Specification* applies to rivets of material that meets ASTM B 316/B 316M. Nominal strengths used to determine available strength for aluminum rivets shall be as listed in Table A.3.8.

Table A.3.8
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
7178-T6	46	315

① From ASTM B 316/B 316M

A.3.7 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 not vary by more than the tolerances given in *Aluminum Standards and Data*.

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. In the absence of a building code or contract documents, ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, shall be used.

B.2.2 Bridge-Type Structures

Bridge-type structures shall be designed for the nominal loads and load combinations given in the contract documents. In the absence of contract documents, highway bridges shall be designed for the nominal loads and load combinations given in AASHTO's *Standard Specifications for Highway Bridges*, and pedestrian bridges shall be designed for the nominal loads and load combinations given in AASHTO's *Guide Specifications for Design of Pedestrian Bridges*.

B.2.3 Other Structures

Structural supports for highway signs, luminaires, and traffic signals shall be designed for the loads given in *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. Other structures shall be designed for the loads given in the contract documents. In the absence of contract documents, other structures shall be designed for the loads given in ASCE 7 where applicable.

B.3 DESIGN BASIS

Designs shall be made according to the provisions for Load and Resistance Factor Design (LRFD) or Allowable Strength Design (ASD). LRFD is limited to building-type structures.

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*.

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 and bridge-type structures shall be as given in this *Specification*.

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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.

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 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	$B_{tb} = 1.5F_{cy}\left(1+\left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb}-B_t}{D_{tb}-D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\frac{F_{sy}}{240\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{20}\left(\frac{6B_s}{E}\right)^{1/2}$	$C_s = \frac{2B_s}{3D_s}$

① κ = 1.0 ksi (6.895 MPa)
② C_t shall be determined using a plot of curves of limit state stress based on elastic and inelastic buckling or by trial and error solution.

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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 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	$B_{tb} = 1.5F_{cy}\left(1+\left(\frac{F_{cy}}{50,000\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb}-B_t}{D_{tb}-D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\frac{F_{sy}}{800\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{10}\left(\frac{B_s}{E}\right)^{1/2}$	$C_s = 0.41\frac{B_s}{D_s}$

① κ = 1.0 ksi (6.895 MPa)
② C_t shall be determined using a plot of curves of limit state stress based on elastic and inelastic buckling or by trial and error solution.

Table B.4.3
POSTBUCKLING CONSTANTS

TYPE OF ELEMENT	k_1	k_2
Flat Elements in 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 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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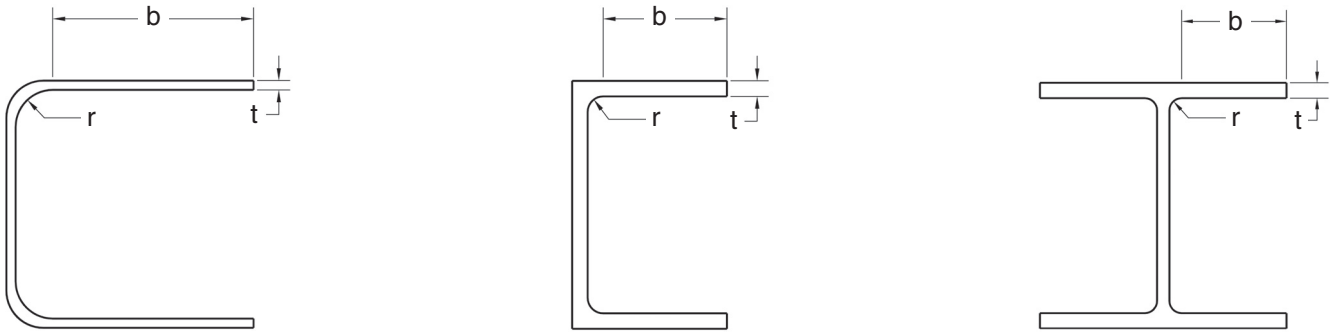


Figure B.5.1
FLAT ELEMENTS SUPPORTED ON ONE EDGE

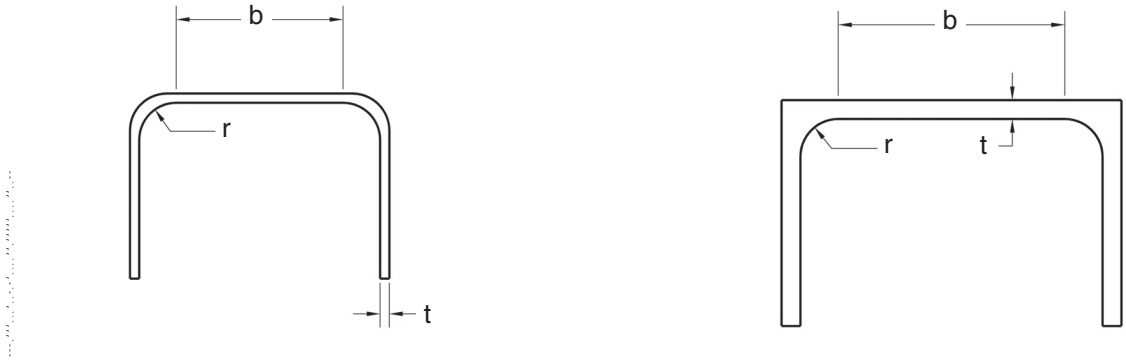


Figure B.5.2
FLAT ELEMENTS SUPPORTED ON BOTH EDGES

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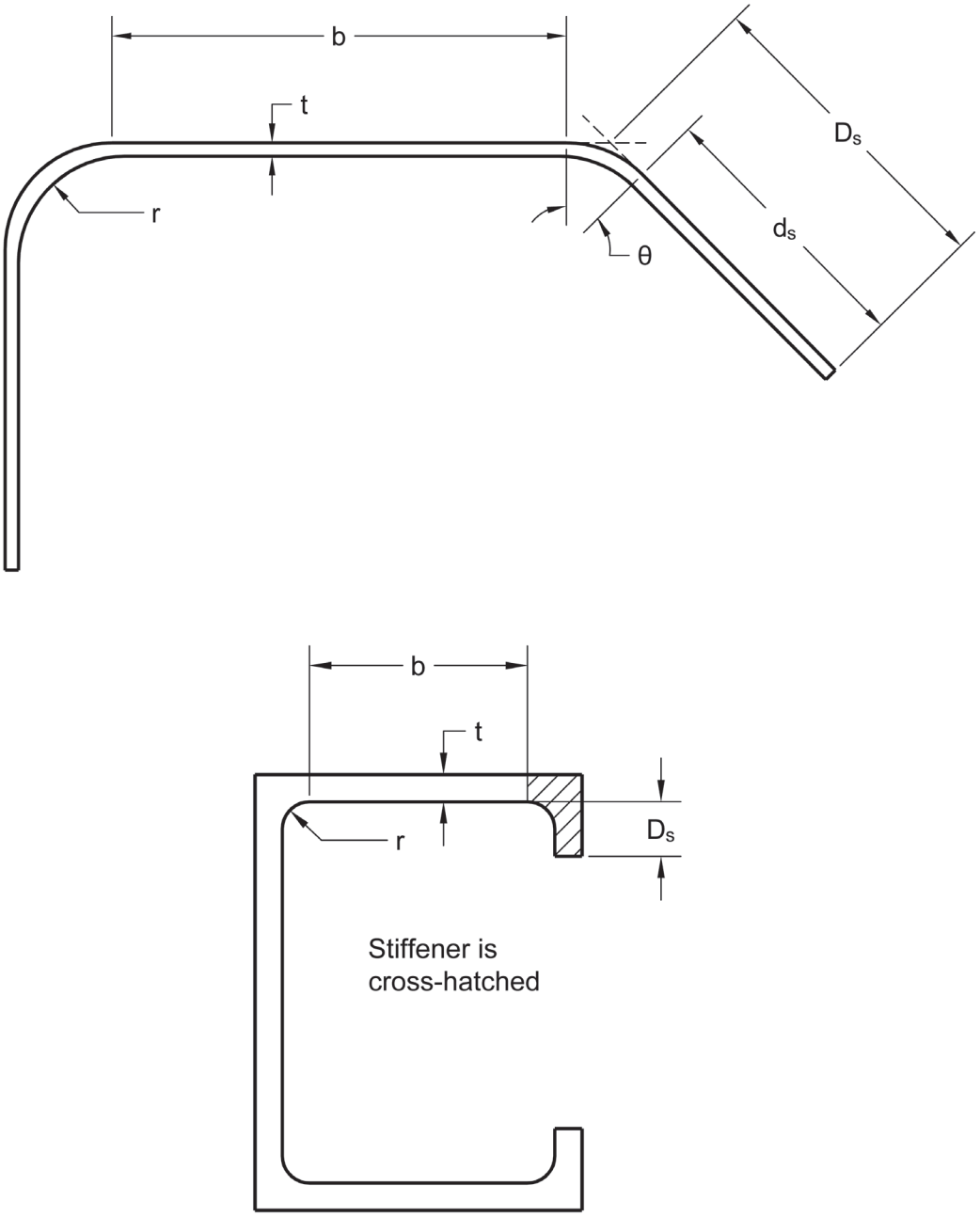


Figure B.5.3
EDGE STIFFENED ELEMENTS

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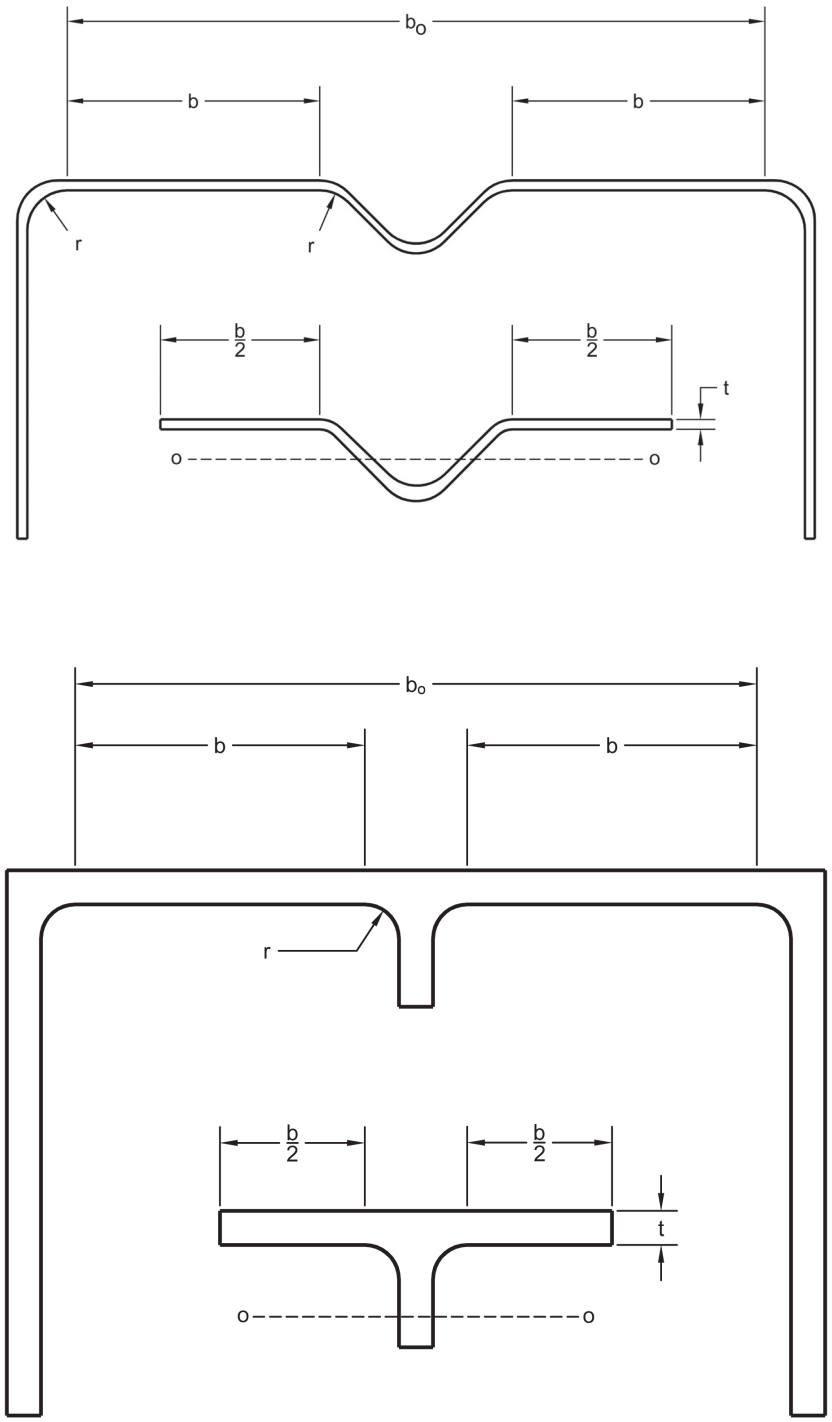


Figure B.5.4
FLAT ELEMENTS WITH AN INTERMEDIATE STIFFENER

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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 $\delta \leq 2.0$:

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

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

= 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 $b/t \leq \lambda_1$, $F_{cw} = F_{co}$.

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	b/t
yielding	F_{cy}	$b/t \leq \lambda_1$
inelastic buckling	$B_p - 5.0D_p\, b/t$	$\lambda_1 < b/t < \lambda_2$
in columns whose buckling axis is not an axis of symmetry:		
elastic buckling	$\dfrac{\pi^2 E}{(5.0\, b/t)^2}$	$b/t \geq \lambda_2$
in all other columns and all beams:		
post-buckling	$\dfrac{k_2\sqrt{B_p E}}{5.0 b/t}$	$b/t \geq \lambda_2$

where

$$\lambda = \frac{B_p - F_{cy}}{5.0 D_p}$$

$$\lambda_2 = \frac{k_2\sqrt{B_p E}}{5.0 b/t} \text{ for elastic buckling}$$

$$\lambda_2 = \frac{B_p - F_{cy}}{1.6 D_p} \text{ for post-buckling}$$

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	b/t
yielding	F_{cy}	$b/t \leq \lambda_1$
inelastic buckling	$B_p - 1.6D_p\, b/t$	$\lambda_1 < b/t < \lambda_2$
post- buckling	$\dfrac{k_2\sqrt{B_p E}}{1.6 b/t}$	$b/t \geq \lambda_2$

where

$$\lambda_1 = \frac{B_p - F_{cy}}{1.6 D_p}$$

$$\lambda_2 = \frac{k_1 B_p}{1.6 D_p}$$

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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

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

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

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.

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

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	λ_s
yielding	F_{cy}	$\lambda_s \le \lambda_1$
inelastic buckling	$B_c - D_c\lambda_s$	$\lambda_1 < \lambda_s < \lambda_2$
elastic buckling	$\dfrac{\pi^2 E}{\lambda_s^2}$	$\lambda_s \ge \lambda_2$

where

$$\lambda_1 = \frac{B_c - F_{cy}}{D_c}$$

$$\lambda_2 = C_c$$

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

A_s = area of the stiffener

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 of the section parallel to the stiffened element (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.

F_c need not be less than F_c determined using Section B.5.4.2 and neglecting the stiffener.

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	R_b/t
yielding	F_{cy}	$R_b/t \le \lambda_1$
inelastic buckling	$B_t - D_t\sqrt{\dfrac{R_b}{t}}$	$\lambda_1 < R_b/t < \lambda_2$
elastic buckling	$\dfrac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1 + \frac{\sqrt{R_b/t}}{35}\right)^2}$	$R_b/t \ge \lambda_2$

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where

$$\lambda_1 = \left(\frac{B_t - F_{cy}}{D_t} \right)^2$$

$$\lambda_2 = C_t$$

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:

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

where

$$\lambda_1 = \frac{B_p - F_{cy}}{D_p}$$

$$\lambda_2 = \frac{k_1 B_p}{D_p}$$

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

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	b/t
yielding	$1.5F_{cy}$	$b/t \le \lambda_1$
inelastic buckling	$B_{br} - mD_{br}\, b/t$	$\lambda_1 < b/t < \lambda_2$
post- buckling	$\frac{k_2\sqrt{B_{br}E}}{(mb/t)}$	$b/t \ge \lambda_2$

where

$$\lambda_1 = \frac{B_{br} - 1.5F_{cy}}{mD_{br}}$$

$$\lambda_2 = \frac{k_1 B_{br}}{mD_{br}}$$

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

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

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:

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

where

$$\lambda_1 = \frac{B_{br} - 1.5F_{cy}}{3.5D_{br}}$$

$$\lambda_2 = \frac{C_{br}}{3.5}$$

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

where

$$\lambda_1 = \frac{B_{br} - 1.5F_{cy}}{0.29D_{br}}$$

$$\lambda_2 = \frac{k_1 B_{br}}{0.29D_{br}}$$

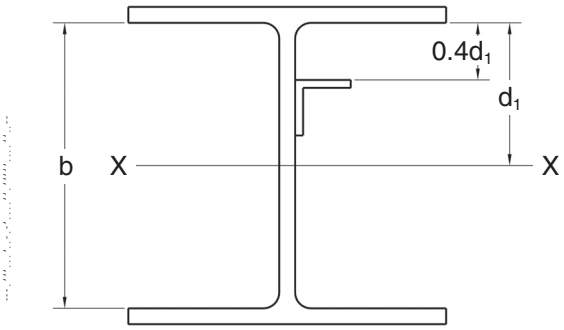


Figure B.5.5
FLAT ELEMENT WITH A LONGITUDINAL STIFFENER

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	R_b/t
upper inelastic buckling	$B_{tb} - D_{tb}\sqrt{\dfrac{R_b}{t}}$	$R_b/t \le \lambda_1$
lower inelastic buckling	$B_t - D_t\sqrt{\dfrac{R_b}{t}}$	$\lambda_1 < R_b/t < \lambda_2$
elastic buckling	$\dfrac{\pi^2 E}{16\left(\dfrac{R_b}{t}\right)\left(1 + \dfrac{\sqrt{R_b/t}}{35}\right)^2}$	$R_b/t \ge \lambda_2$

where

$\lambda_1 = C_{tb}$

$\lambda_2 = C_t$

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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LIMIT STATE	F_b	λ_{eq}
yielding	M_{np}/S_{xc}	$\lambda_{eq} \le \lambda_1$
inelastic buckling	$\frac{M_{np}}{S_{xc}} - \left(\frac{M_{np}}{S_{xc}} - \frac{\pi^2 E}{C_p^{\ 2}}\right)\left(\frac{\lambda_{eq}-\lambda_1}{C_p-\lambda_1}\right)$	$\lambda_1 < \lambda_{eq} < \lambda_2$
post- buckling	$\frac{k_2\sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$

where

$$\lambda_1 = \frac{B_p - F_{cy}}{D_p}$$

$$\lambda_2 = C_p$$

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

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.

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

① λ_s is determined from equation B.5-10

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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:

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

2) 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);

3) 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.

4) 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)

5) 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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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 ($\phi_t P_{nt}$ for LRFD and P_{nt}/Ω_t for ASD) shall be determined in accordance with Chapter D where P_{nt} is nominal tensile strength and

LIMIT STATE	ϕ_t building-type structures	Ω_t building-type structures	Ω_t bridge-type structures
tensile rupture	0.75	1.95	2.20
tensile yielding	0.90	1.65	1.85

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:

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

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.

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

$\bar{y}$ = 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 ($\phi_c P_{nc}$ for LRFD and P_{nc}/Ω_c for ASD) shall be determined in accordance with Chapter E where P_{nc} is the nominal compressive strength and

$\phi_c =$ 0.90 (LRFD)
$\Omega_c =$ 1.65 (ASD building-type structures)
$\Omega_c =$ 1.85 (ASD bridge-type structures)

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	λ
yielding	F_{cy}	$\lambda \le \lambda_1$
inelastic buckling	$\left(B_c - D_c\lambda\right)\left(0.85 + 0.15\dfrac{C_c - \lambda}{C_c - \lambda_1}\right)$	$\lambda_1 < \lambda < C_c$
elastic buckling	$\dfrac{0.85\pi^2 E}{\lambda^2}$	$\lambda \ge \lambda_2$

where

$$\lambda_1 = \frac{B_c - F_{cy}}{D_c}$$

$$\lambda_2 = C_c$$

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 $P_{nc} = P_{no}$ 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

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

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

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

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

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

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