# Aluminum Design Manual

2010



The Aluminum Association

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# 2010 Aluminum Design Manual

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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, and illustrative design examples.

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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# 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, and 2005. This ninth edition of the *Specification* combines the previously separate allowable stress and load and resistance factor design specifications. The *Specification,* developed as a consensus document, has been completely reorganized and includes new or revised provisions concerning

- safety and resistance factors
- design for stability
- adding 6005A-T61 and 6082-T6
- notch sensitivity of 6005-T5 and 6105-T5
- a glossary
- shear yield strengths
- shear strength of tubes
- screw pull-over
- screw slot pull-out strength
- serviceability
- evaluating existing structures
- axial compressive strength of complex cross sections
- fatigue strength of light pole bases
- members subject to torsion
- local buckling strength of welded elements
- design for fire conditions
- design of braces

The Aluminum Association gratefully acknowledges the efforts of the Engineering Advisory Committee in developing this edition of 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:

Vice President, Technology
mhskilli@aluminum.org
The Aluminum Association
1525 Wilson Blvd, Suite 600
Arlington, VA 22209
www.aluminum.org

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

Inquiries should be typewritten and 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.3.8.4)
$A_e$ = net effective area (D.2, D.3.2)
$A_f$ = 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.9.2)
$A_g$ = gross cross-sectional area (B.5.4, D.2, E.3, E.3.2, E.4.1, E.4.2, E.5, E.6.2, F.2.2.3, F.8.1.1, G.1, G.3)
$A_{gc}$ = gross cross sectional area of the element in compression (B.5.5)
$A_{gt}$ = gross cross sectional area of the element in tension (F.8.1.2, J.6.3)
$A_{gv}$ = gross area in shear (J.6.3)
$A_i$ = area of element $i$ (E.4.1)
$A_L$ = cross-sectional area of the longitudinal stiffener (B.5.5.3)
$A_n$ = net area (D.3.1, D.3.2)
$A_{nt}$ = net area in tension (J.6.3)
$A_{nv}$ = net area in shear (J.6.3)
$A_{pb}$ = projected bearing area (J.7)
$A_r$ = root area of the screw (J.5.5.3, J.5.6.3)
$A_s$ = area of the intermediate stiffener (B.5.4.4)
$A_{sn}$ = thread stripping area of internal thread per unit length of engagement (J.5.5.1.1)
$A_w$ = web area (G.2)
$A_{we}$ = effective area of a weld (J.2.1.2, J.2.1.3, J.2.3.1, J.2.3.2)
$A_{wz}$ = 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.6.2, F.8.1.1, F.9.2, G.1)
$A_{wzc}$ = cross sectional area of the weld-affected zone in compression (B.5.5)
$A_{wzt}$ = cross sectional area of the weld-affected zone in tension (F.8.1.2)
$B_{br}$ = buckling constant intercept for bending compression in flat elements (B.4, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, F.4.2, F.5)
$B_c$ = buckling constant intercept for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)
$B_p$ = buckling constant intercept for axial compression in flat elements (B.4, B.5.4.1, B.5.4.2, B.5.4.6, F.5)
$B_s$ = buckling constant intercept for shear in flat elements (B.4, G.2, G.3, H.2.1)
$B_t$ = buckling constant intercept for axial compression in curved elements (B.4, B.5.4.5, F.6.2)
$B_{tb}$ = buckling constant intercept for bending compression in curved elements (B.4, F.6.2)
$C$ = torsional shear constant (H.2.2)
$C_b$ = coefficient that accounts for moment gradient along a beam's length (F.1.1, F.1.1.1, F.1.1.2, F.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, F.5(c), F.5.1, F.5.2, 6.3.2.1)
$C_{br}$ = buckling constant intersection for bending compression in flat elements (B.4, B.5.5.2, F.4.2, F.5)
$C_c$ = buckling constant intersection for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)
$C_d$ = brace coefficient (6.3.1.1, 6.3.1.2)
$C_f$ = coefficient used to determine the allowable stress range for fatigue (3.2, 3.3)
$C_n$ = correction factor for the number of tests (1.3.2)
$C_p$ = buckling constant intersection for axial compression in flat elements (B.4, B.5.4.1, F.5)
$C_{pov}$ = coefficient for determining the pull-over strength of a screw (J.5.5.2)
$C_s$ = buckling constant intersection for shear in flat elements (B.4, G.2, G.3, H.2.1)
$C_t$ = buckling constant intersection for axial compression in curved elements (B.4, B.5.4.5, F.6.2)
$C_{tb}$ = buckling constant intersection for bending compression in curved elements (B.4)
$C_w$ = warping constant (E.3.2, F.2.2.3)
$C_{wa}$, $C_{wb}$, $C_{w1}$, $C_{w2}$, $C_{w3}$ = coefficients used to determine web crippling strength (J.8.1)
$C_1$ = coefficient used to determine $U$ (F.2.2.3)
$C_2$ = coefficient used to determine $U$ (F.2.2.3)
$D$ = nominal diameter of the fastener (J.3.2, J.3.5, J.3.6, J.3.7, J.3.10, J.5, J.5.5.1.1, J.5.5.1.2, J.5.5.2, J.5.6.1, J.5.6.2, J.7)
$D$ = diameter of a rod (H.2.3)
$D_{br}$ = buckling constant slope for bending compression in flat elements (B.4, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, F.4.2, F.5)
$D_c$ = buckling constant slope for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)
$D_h$ = nominal diameter of the hole (J.4.6, J.4.7, J.5.5.2)
$D_n$ = nominal dead load (1.3.2, 4.1.3, 5.4)
$D_p$ = buckling constant slope for axial compression in flat elements (B.4, B.5.4.1, B.5.4.2, B.5.4.6, F.5)
$D_S$ = depth of a stiffener (B.5.4.3)
$D_s$ = buckling constant slope for shear in flat elements (B.4, G.2, G.3, H.2.1)
$D_{ss}$ = screw slot inside diameter (J.5.5.1.2)
$D_t$ = buckling constant slope for axial compression in curved elements (B.4, B.5.4.5, F.6.2)
$D_{tb}$ = buckling constant slope for bending compression in curved elements (B.4, F.6.2)
$D_{ws}$ = larger of the nominal washer diameter and the screw head diameter, but no greater than $\frac{5}{8}$ in. (16 mm) (J.5.5.2)



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$E$ = compressive modulus of elasticity (A.3.1, A.3.2, A.3.3, B.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, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, B.5.6, E.3, E.3.2, E.5, F.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, F.5, F.5.1, F.5.2, F.6.2, G.2, G.3, H.2.1, J.8.1, 4.2.3.1, 6.3.2.1, 6.3.2.2)

$E_m$ = compressive modulus of elasticity at elevated temperatures (4.2.3.1)

$F_b$ = 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.2.1, F.2.3, F.3.1, F.4.2, F.6.2, F.8, F.8.1.2, F.8.2, F.8.3, H.3.1, H.3.2)

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

$F_{bw}$ = stress corresponding to the flexural compression 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.3, E.4.2, F.8.3, 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.4.1)

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

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

$F_{cy}$ = compressive yield strength (A.3.2, A.3.3, B.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, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, E.3, E.4.1, F.4.1, F.5, F.6.1, F.7, F.8.3, J.8.1)

$F_{cyw}$ = compressive yield strength of weld-affected zones (A.3.2)

$F_e$ = elastic buckling stress (B.5.4.6, B.5.5.4, B.5.6, E.3.2, E.5, F.2.3, L.3)

$F_{ex}$ = elastic buckling stress for buckling about the $x$-axis (E.3.2)

$F_{ey}$ = elastic buckling stress for buckling about the $y$-axis (E.3.2, F.2.2.3)

$F_{ez}$ = elastic buckling stress for torsional buckling (E.3.2, F.2.2.3)

$F_m$ = mean value of the fabrication factor (1.3.2)

$F_n$ = shear strength of an A 325 bolt (J.3.8.4)

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

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

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

$F_{su}$ = shear ultimate strength (A.3.2, A.3.5, A.3.6, J.3.6, J.4.6, J.5.6.3, J.6.2, J.6.3)

$F_{suw}$ = shear ultimate strength of weld-affected zones (A.3.2, G.1, J.2.1.3)

$F_{sw}$ = shear stress corresponding to the welded shear strength (G.1, J.2.2.2, J.2.3.2)

$F_{sy}$ = shear yield strength (A.3.1, B.4, G.2, G.3, H.2.1, H.2.3, J.6.2, J.6.3)

$F_t$ = tensile stress corresponding to the flexural tensile strength (F.8.1.1, F.8.3)

$F_{tu}$ = tensile ultimate strength (A.3.2, A.3.3, A.3.5, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2, J.3.5, J.3.7, J.4.7, J.5.5.1.2, J.5.5.3, J.5.6.1, J.6.3, J.7)

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

$F_{tuw}$ = tensile ultimate strength of weld-affected zones (A.3.2, D.2, F.8.1.1, F.8.1.2, J.2.1.3)

$F_{tu1}$ = tensile ultimate strength of the part in contact with the screw head or washer (J.5.5.2)

$F_{tu2}$ = tensile ultimate strength of member not in contact with the screw head (J.5.5.1.1, J.5.6.2)

$F_{ty}$ = tensile yield strength (A.3.1, A.3.2, A.3.3, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2, J.6.3, 1.4)

$F_{tym}$ = 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.8.1.1, F.8.1.2)

$F_{ty1}$ = tensile yield strength of the part in contact with the screw head (J.5.5.2)

$F_{ty2}$ = tensile yield strength of member not in contact with the screw head (J.5.5.1.1)

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

$G$ = shear modulus of elasticity (A.3.1, E.3.2, F.2.2.3)

$G_f$ = the grip of a bolt (J.3.10)

$H = 1 - \frac{x_0^2 + y_0^2}{r_0^2}$ (E.3.2)

$I_{cy}$ = moment of inertia of the compression flange about the $y$-axis (F.1.1.2, F.2.2.3)

$I_f$ = 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.8.3)

$I_L$ = 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.8.3)

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

$I_x$ = moment of inertia about the $x$-axis (E.3.2, F.2.2.3)



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$I_y$ = moment of inertia about the $y$-axis (E.3.2, F.1.1.2, F.2.2.1, F.2.2.2, F.2.2.3, F.3.1, 6.3.2.1)
$I_z$ = moment of inertia about the minor principal axis (F.5.2)
$J$ = torsion constant (E.3.2, F.2.2.1, F.2.2.2, F.2.2.3, F.3.1, 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.5.5.1.1)
$L$ = member length (E.2, E.3, E.3.1, E.3.2, E.5, E.6.1, F.2.2.3, F.9.1, 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.2.1, F.2.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, 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.5.5.1.1, J.5.5.1.2)
$L_n$ = nominal live load (1.3.2, 4.1.3, 5.4)
$L_s$ = length of tube between circumferential stiffeners, or overall length if no circumferential stiffeners are present (H.2.1)
$L_v$ = length of tube from maximum to zero shear force (G.3)
$L_{we}$ = effective length of a weld (J.2.1.2, J.2.2.1, J.2.2.2)
$L_x$ = unbraced length for buckling about the $x$-axis (E.3.2)
$L_y$ = unbraced length for buckling about the $y$-axis (E.3.2)
$L_z$ = unbraced length for twisting (E.3.2, F.2.2.3)
$M$ = bending moment (J.8.3)
$M_A$ = absolute value of the moment at the quarter point of the unbraced segment (F.1.1.1)
$M_B$ = absolute value of the moment at the midpoint of the unbraced segment (F.1.1.1)
$M_C$ = absolute value of the moment at the three-quarter point of the unbraced segment (F.1.1.1)
$M_c$ = design or allowable flexural strength determined in accordance with Chapter F (H.1, J.8.3)
$M_e$ = elastic lateral-torsional buckling moment (F.2.2.3, F.5, F.5.1, F.5.2)
$M_i$ = bending 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.1.1.1, F.1.1.2)
$M_n$ = nominal strength moment (F.1, F.2.1, F.2.3, F.3.1, F.4.1, F.4.2, F.5, F.5.1, F.5.2, F.6.1, F.6.2, F.7, F.8, F.8.3, F.9.2)
$M_{nc}$ = nominal strength moment for compression (F.8.3)
$M_{no}$ = lateral-torsional buckling strength if no part of the cross section were weld-affected (F.9.2)
$M_{nt}$ = nominal strength moment for tension (F.8.3)
$M_{nw}$ = lateral-torsional buckling strength if the entire cross section were weld-affected (F.9.2)
$M_r$ = required flexural strength using LRFD or ASD load combinations (H.1, 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)
$M_1$ = bending strength of member of thinnest material (1.4.2)
$M_2$ = bending strength of member of thickest material (1.4.2)
$N$ = length of the bearing at the concentrated force (J.8.1)
$N$ = number of cycles to failure (3.2, 3.3)
$N_S$ = number of stress ranges in the spectrum (3.3)
$N_s$ = number of slip planes (J.3.8.5)
$P$ = force (J.8.3)
$P_c$ = design or allowable axial tensile strength determined in accordance with Chapter D, compressive strength determined in accordance with Chapter E, or concentrated force determined in accordance with Section J.8.1 (H.1, J.8.3)
$P_n$ = nominal strength axial force (D.1, D.2, E.1, E.3, E.4.1, E.4.2, E.5, E.6.2)
$P_{no}$ = nominal member buckling strength if no part of the cross section were weld-affected (E.6.2)
$P_{nw}$ = nominal member buckling strength if the entire cross section were weld-affected (E.6.2)
$P_r$ = required axial force using LRFD or ASD load combinations (C.2, H.1, 6.2.1, 6.2.2, 6.4)
$P_{rb}$ = 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 tube (H.2.1)
$R$ = transition radius of a fatigue detail (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.5.6, E.6.1, F.6.2, F.9.1, G.3, H.2.1)
$R_i$ = inside bend radius at the juncture of the flange and web; for extruded shapes, $R_i = 0$ (J.8.1)
$R_n$ = nominal strength (B.3.2.1, B.3.2.2, J.2.1.3, J.2.2.2, J.2.3.2, J.2.4, J.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.5.1.1, J.5.5.1.2, J.5.5.2, J.5.5.3, J.5.6, J.5.6.1, J.5.6.2, J.5.6.3, J.6.1, J.6.2, J.6.3, J.6.4, J.7, J.8.1)
$R_S$ = the ratio of minimum stress to maximum stress for fatigue design (3.1)
$R_u$ = required strength for LRFD (B.3.2.1)
$S$ = section modulus (F.4.1, F.4.2, F.6.1, F.6.2, F.7)
$S_c$ = section modulus on the compression side of the neutral axis (F.2.1, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3, F.3.1, F.5, F.5.1, F.8)
$S_e = 1.28\sqrt{E/F_{cy}}$ (B.5.4.3)
$S_n$ = nominal snow load (4.1.3)



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$S_{ra}$ = applied stress range, the algebraic difference between the minimum and maximum calculated stress (3.2)
$S_{rd}$ = allowable stress range (3.2, 3.3)
$S_{re}$ = equivalent stress range (3.3)
$S_{ri}$ = *i*th stress range in the spectrum (3.3)
$S_t$ = section modulus on the tension side of the neutral axis (F.8)
$S_w$ = size of a weld (J.2.1.2, J.2.2.1, J.2.2.2)
$S_x$ = standard deviation of the test results (1.3.1)
$S_1$ = slenderness ratio at the intersection of the equations for yielding and inelastic buckling
$S_2$ = slenderness ratio at the intersection of the equations for inelastic buckling and elastic buckling
$T$ = 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)
$T_b$ = minimum fastener tension (J.3.8.5)
$T_n$ = nominal torsional strength (H.2, H.2.1, H.2.2, H.2.3)
$T_{uw}$ = tensile strength of the stud in Table J.2.2 or Table J.2.2M (J.2.4)
$T_1$ = temperature (A.3.1.1)
$T_2$ = temperature (A.3.1.1)
$U$ = coefficient used to determine $M_e$ (F.2.2.3)
$V$ = shear force on the web at the transverse stiffener (G.2)
$V_F$ = 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)
$V_P$ = 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)
$X_a$ = strength which 99% of the material is expected to exceed with a confidence of 95% (1.3.1)
$X_i$ = result of the *i*th test (1.3.2)
$X_m$ = mean of the test results (1.3.1, 1.3.2)
$a$ = fraction of the length of a member (F.2.2.3)
$a$ = fatigue detail dimension parallel to the direction of stress (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, B.5.5.1, B.5.5.2, B.5.5.3, B.5.6, F.5, F.5.1, F.5.2, G.1, G.2, J.1.3, L.3)
$b$ = fatigue detail dimension normal to the direction of stress and the surface of the base metal (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.9.2)
$c_c$ = distance from neutral axis to the element extreme fiber with the greatest compression stress (B.5.5.1)
$c_{cf}$ = distance from the centerline of the compression flange to the cross section's neutral axis (F.8.3)
$c_{cs}$ = distance from the cross section's neutral axis to the extreme fiber of compression flange stiffeners (F.8.3)
$c_{cw}$ = distance from the web group's extreme compression fiber to the cross section's neutral axis (F.8.3)
$c_o$ = distance from neutral axis to other extreme fiber of the element (see $c_c$) (B.5.5.1)
$c_{tf}$ = distance from the extreme tension fiber to the cross section's neutral axis (F.8.3)
$c_{tw}$ = distance from the web group's extreme tension fiber to the cross section's neutral axis (F.8.3)
$d$ = full depth of the section (F.2.2.1, F.2.2.2, F.4.2, G.2, J.8.1, J.9.1)
$d_e$ = distance from the center of the fastener to the edge of the part in the direction of force (J.3.7, J.4.7, J.5.6.1, J.7)
$d_f$ = 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.2.2.3)
$d_s$ = stiffener's flat width (B.5.4.3)
$d_1$ = distance from the neutral axis to the compression flange (B.5.5.3)
$e$ = base for natural logarithms = 2.71828 . . . (1.3.2)
$f$ = compressive stress at the toe of the flange (B.5.5.3)
$f_a$ = maximum compressive stress in the element from the service load combinations (L.3)
$f_b$ = compressive stress due to flexure (H.3.1, H.3.2)
$f_c$ = compressive stress due to axial compression (H.3.1, H.3.2)
$f_s$ = shear stress due to shear and torsion (H.3.1, H.3.2)
$g$ = transverse center-to-center spacing (gage) between fastener gage lines (D.3.1, J.1.3)
$g_0$ = distance from the shear center to the point of application of the load; $g_0$ is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$. (F.2.2.3)
$h_o$ = distance between flange centroids (6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2)
$h_{sc}$ = hole factor for slip-critical bolted connections (J.3.8.5)
$j = \frac{1}{2I_x}\left(\int_A y^3\,dA + \int_A yx^2\,dA\right) - y_o$ (F.2.2.3)
$k$ = effective length factor for buckling (C.3, E.2, E.3, E.3.1, E.3.2, E.5, J.1.3, 6.1, 6.2.2)
$k_t$ = tension coefficient (A.3.1.3, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2)
$k_x$ = effective length factor for flexural buckling about the $x$-axis (E.3.2)
$k_y$ = effective length factor for flexural buckling about the $y$-axis (E.3.2)
$k_y$ = effective length factor for the compression flange about the $y$-axis (F.2.2.3)
$k_z$ = effective length factor for torsional buckling (E.3.2, F.2.2.3)


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$k_1$ = coefficient for determining the $S_2$ slenderness limit for elements with postbuckling strength (B.4, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.4)

$k_2$ = coefficient for determining postbuckling strength (B.4, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.4)

$m$ = 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 (3.2, 3.3)

$n$ = number of threads/in. (mm) (J.3.5, J.3.6, J.5.5.1.1)

$n$ = 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, E.3, E.3.1, E.3.2, E.5)

$r_o$ = polar radius of gyration of the cross section about the shear center (E.3.2, F.2.2.3)

$r_s$ = 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.3.2, F.2.2.3)

$r_y$ = radius of gyration about the $y$-axis (E.3.2, F.2.1, F.2.2.3)

$r_{ye}$ = effective radius of gyration about the $y$-axis for lateral-torsional buckling (F.2.1, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3)

$r_z$ = 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, B.5.5.1, B.5.5.2, B.5.5.3, B.5.6, E.6.1, F.4.2, F.5, F.5.1, F.5.2, F.6.2, F.9.1, G.1, G.2, G.3, H.2.1, J.1.3, J.3.7, J.4.7, J.5.6.1, J.7, J.8.1,)

$t$ = 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.5.5.2, J.5.6.2)

$t_1$ = 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.5.6.2)

$t_2$ = 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.3.2, F.2.2.3)

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

$y_o$ = the shear center's $y$-coordinate (E.3.2, F.2.2.3)

$z_o$ = coordinate along the $z$-axis of the shear center with respect to the centroid (F.5.2)

$\alpha$ = factor used to determine reduced flexural stiffness (C.2)

$\alpha$ = ratio of nominal dead load to nominal live load (1.3.2)

$\alpha$ = coefficient of thermal expansion (A.3.1)

$\alpha_i$ = number of cycles in the spectrum of the $i$th stress range divided by the total number of cycles (3.3)

$\alpha_s$ = coefficient for a longitudinal stiffener (B.5.5.3)

$\beta_{br}$ = required bracing stiffness (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)

$\beta_o$ = target reliability index (1.3.2)

$\beta_{sec}$ = web distortional stiffness (6.3.2.1, 6.3.2.2)

$\beta_{Tb}$ = required bracing torsional stiffness (6.3.2.1)

$\beta_w$ = section property for unequal leg angles (F.5.2)

$\gamma$ = density (A.3.1)

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

$\kappa$ = metric conversion factor (Table B.4.1, Table B.4.2)

$\nu$ = Poisson's ratio (A.3.1)

$\phi$ = 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.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.6, J.6.2, J.6.3, J.7, J.8.1, 1.3.2, 6.1)

$\Omega$ = 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.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.6, J.6.2, J.6.3, J.7, J.8.1, 1.3.2, 6.1)

$\theta$ = angle between a stiffener and the stiffened element (B.5.4.3)

$\theta$ = angle between the plane of web and the plane of the bearing surface ($\theta \leq 90°$) (J.8.1)

$\rho_{ST}$ = stiffener effectiveness ratio (B.5.4.3, B.5.6)

$\lambda_{eq} = \pi\sqrt{\dfrac{E}{F_e}}$ = equivalent slenderness ratio for alternate determination of compressive strength for flexure or axial compression (B.5.4.6, B.5.5.4)

$\lambda_s$ = slenderness ratio of an element with an intermediate stiffener (B.5.4.4, B.5.6)

$\lambda_t$ = slenderness ratio for round or oval tubes in shear or torsion (G.3, H.2.1)

$\tau_b$ = parameter for reduced flexural stiffness (C.2)

$\mu$ = mean slip coefficient (J.3.8.5)



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*allowable strength:* nominal strength divided by the safety factor, $R_n/\Omega$.

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

*aluminum:* aluminum or an aluminum alloy.

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

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

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

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

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

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

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

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

*block shear rupture:* in a connection, the limit state of tension 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.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, $\phi R_n$.

*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.

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

*fastener:* bolts, rivets, screws, or other connection devices.

*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).

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



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*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 pin (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.*

*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.

*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.

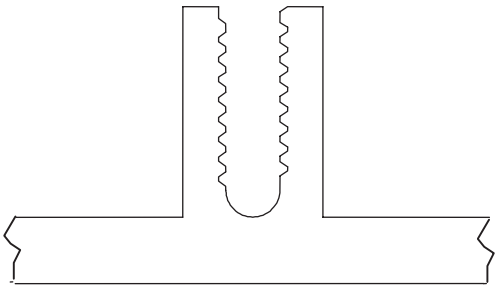


**Figure GL.1**
**TRANSVERSE CROSS SECTION OF A SCREW CHASE**

*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).

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

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

*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.

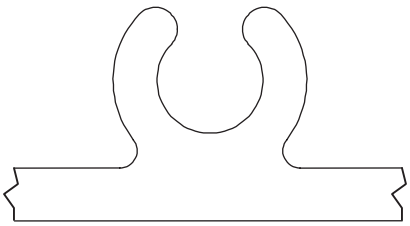


**Figure GL.2**
**TRANSVERSE CROSS SECTION OF A SCREW SLOT**



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

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

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

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

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

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

*weld-affected zone:* metal within 1in. (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 M, and Appendices 1 through 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 2009*
*Aluminum Standards and Data 2009 Metric SI*
*Standards for Aluminum Sand and Permanent 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* (2009)

American Society of Civil Engineers (ASCE)
ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures*

American Society of Mechanical Engineers (ASME)
ASME B18.6.4-1999 *Thread Forming and Thread Cutting Tapping Screws and Metallic Drive Screws, Inch Series*
ASME B46.1-2002 *Surface Texture, Surface Roughness, Waviness and Lay*

American Welding Society (AWS)
AWS A.5.10/A5.10M:1999(R2007) *Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods*
AWS D1.2/D1.2M:2008 *Structural Welding Code—Aluminum*

ASTM International (ASTM)
A 123/A 123M-09 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*
A 153/A 153M-09 *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*
A 193/A 193M-09 *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*
A 194/A 194M-09 *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*
A 320/A 320M-08 *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*
A 325-09a *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*
A 325M-09 *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*]
A 641/A 641M-09a *Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire*
B 26/B 26M-09 *Standard Specification for Aluminum-Alloy Sand Castings*
B 108/B 108M-08 *Standard Specification for Aluminum-Alloy Permanent Mold Castings*
B 209-07 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*
B 209M-07 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate* [*Metric*]
B 210-04 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*
B 210M-05 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes* [*Metric*]
B 211-03 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire*
B 211M-03 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire* [*Metric*]
B 221-08 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*
B 221M-07 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes* [*Metric*]
B 241/B 241M-02 *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-02 *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*
B 316/B 316M-02 *Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*
B 429/B 429M-06 *Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube*



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B 456-03 *Standard Specification for Electrodeposited Coatings of Copper Plus Nickel Plus Chromium and Nickel Plus Chromium*
B 557-06 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*
B 557M-07e1 *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 695-04 *Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel*
B 928/B 928M-09 *Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*
E 119-09c *Standard Test Methods for Fire Tests of Building Construction and Materials*
E 330-02 *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*
E 1592-05 *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*
F 436-09 *Standard Specification for Hardened Steel Washers*
F 436M-09 *Standard Specification for Hardened Steel Washers* [*Metric*]
F 467-08e1 *Standard Specification for Nonferrous Nuts for General Use*
F 467M-06ae2 *Standard Specification for Nonferrous Nuts for General Use* [*Metric*]
F 468-06e1 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use*
F 468M-06e1 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use* [*Metric*]
F 593-02(2008) *Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs*
F 594-08 *Standard Specification for Stainless Steel Nuts*
F 606-09 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*
F 606M-07e1 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets* [*Metric*]

Federal Specification
TT-P-645B(1) *Primer, Paint, Zinc-Molybdate, Alkyd Type*

Research Council on Structural Connections (RCSC)
*Specification for Structural Joints Using ASTM A325 or A490 Bolts,* 2004

## A.3 Material

### A.3.1 General Properties

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

**Table A.3.1**
**GENERAL PROPERTIES**

| Property | Symbol | Value |
|---|---|---|
| Poisson's ratio | $\nu$ | 0.33 |
| Shear modulus of elasticity | $G$ | $3E/8$ |
| Coefficient of thermal expansion | $\alpha$ | $13 \times 10^{-6}$/°F = $23 \times 10^{-6}$/°C |
| Density | $\gamma$ | 0.10 lb/in$^3$ = $2.7 \times 10^3$ kg/m$^3$ |
| Shear yield strength | $F_{sy}$ | 0.6 $F_{ty}$ |

#### A.3.1.1 Mechanical Properties

Except as noted in Section A.3.1.2, the mechanical properties given in Sections A.3.2 through A.3.6 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, mechanical properties shall be reduced to the mechanical properties after heating.

**Table A.3.2**
**TIME-TEMPERATURE LIMITS FOR T5 AND T6 TEMPERS OF 6005, 6061, AND 6063**

| Temperature | | |
|---|---|---|
| °F | °C | Time |
| 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

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

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.



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### A.3.1.3 Tension Coefficient $k_t$

The tension coefficient $k_t$ shall be as listed in Table A.3.3.

**Table A.3.3**
**TENSION COEFFICIENT $k_t$**

| Alloy and Temper | Unwelded | Weld-Affected Zones |
|---|---|---|
| 2014-T6, -T651, -T6510, -T6511 Alclad 2014-T6, -T651 | 1.25 | – |
| 6005-T5, 6105-T5 | 1.25 | – |
| 6066-T6, -T6510, -T6511 | 1.1 | – |
| 6070-T6, -T62 | 1.1 | – |
| all others listed in Table A.3.4 and Table A.3.6 | 1.0 | 1.0 |

## A.3.2 Wrought Products

This *Specification* applies to the wrought alloys listed in Tables A.3.4, A.3.8, and A.3.9 and produced to the following ASTM specifications:

B 209 *Aluminum and Aluminum-Alloy Sheet and Plate*
B 209M *Aluminum and Aluminum-Alloy Sheet and Plate* [*Metric*]
B 210 *Aluminum and Aluminum-Alloy Drawn Seamless Tubes*
B 210M *Aluminum and Aluminum-Alloy Drawn Seamless Tubes* [*Metric*]
B 211 *Aluminum and Aluminum-Alloy Bar, Rod, and Wire*
B 211M *Aluminum and Aluminum-Alloy Bar, Rod, and Wire* [*Metric*]
B 221 *Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*
B 221M *Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes* [*Metric*]
B 241/B 241M *Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*
B 247 *Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*
B 247M *Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings* [*Metric*]
B 308/B 308M *Aluminum-Alloy 6061-T6 Standard Structural Profiles*
B 316/B 316M *Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*
B 429/B 429M *Aluminum-Alloy Extruded Structural Pipe and Tube*
B 632/B 632M *Aluminum-Alloy Rolled Tread Plate*
B 928/B 928M *High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*

Mechanical properties for unwelded metal shall be as listed in Table A.3.4 or A.3.4M. Mechanical properties for weld-affected zones shall be as listed in Table A.3.5 or A.3.5M.

## A.3.3 Castings

This *Specification* applies to cast products listed in Table A.3.6 and produced to the following ASTM specifications:

B 26/B 26M *Aluminum-Alloy Sand Castings*
B 108/B 108M *Aluminum-Alloy Permanent Mold Castings*

Dimensional tolerances shall conform to *Standards for Aluminum Sand and Permanent Mold Castings.*

The purchaser shall require the casting producer to report tensile yield strengths. For sand castings, the purchaser shall require that tensile ultimate and tensile yield strengths of specimens cut from castings shall be at least 75% of the values specified in ASTM B 26.

Radiographic inspection in accordance with ASTM B 26 Grade C or B 108 Grade C criteria is required. The number of castings radiographed and the lot acceptance criteria shall be as listed in Table A.3.7.

Strengths shall be taken from Table A.3.6 or Table A.3.6M. The compressive yield strength $F_{cy}$ of castings shall be taken as the tensile yield strength $F_{ty}$. The modulus of elasticity $E$ of castings shall be taken as 10,000 ksi (70,000 MPa).

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

## A.3.4 Filler Metal for Welding

This *Specification* applies to filler alloys produced to AWS A.5.10/A5.10M and listed in Tables M.9.1 and M.9.2. Mechanical properties for filler metal shall be as listed in Table J.2.1 or Table J.2.1M.

## A.3.5 Bolts and Nuts

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

F 468 *Nonferrous Bolts, Hex 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*]

Strengths for aluminum bolts shall be as listed in Table A.3.8 or A.3.8M.

## A.3.6 Rivets

This *Specification* applies to rivets of material that meets ASTM B 316/B 316M. Strengths for aluminum rivets shall be as listed in Table A.3.9 or Table A.3.9M.

## A.3.7 Screws

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



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# Table A.3.4
# MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS

| ALLOY | TEMPER | PRODUCT | THICKNESS in. | $F_{tu}$ ksi | $F_{ty}$ ksi | $F_{cy}$ ksi | $F_{su}$ ksi | $E$ ksi |
|---|---|---|---|---|---|---|---|---|
| 1100 | -H12 | Sheet, Plate, Drawn Tube, | All | 14 | 11 | 10 | 9 | 10,100 |
| | -H14 | Rod & Bar | All | 16 | 14 | 13 | 10 | 10,100 |
| 2014 | -T6 | Sheet | 0.040 to 0.249 | 66 | 58 | 59 | 40 | 10,900 |
| | -T651 | Plate | 0.250 to 2.000 | 67 | 59 | 58 | 40 | 10,900 |
| | -T6, T6510, T6511 | Extrusions | All | 60 | 53 | 52 | 35 | 10,900 |
| | -T6, T651 | Rod & Bar, Drawn Tube | All | 65 | 55 | 53 | 38 | 10,900 |
| Alclad 2014 | -T6 | Sheet | 0.025 to 0.039 | 63 | 55 | 56 | 38 | 10,800 |
| | -T6 | Sheet | 0.040 to 0.249 | 64 | 57 | 58 | 39 | 10,800 |
| | -T651 | Plate | 0.250 to 0.499 | 64 | 57 | 56 | 39 | 10,800 |
| 3003 | -H12 | Sheet & Plate | 0.017 to 2.000 | 17 | 12 | 10 | 11 | 10,100 |
| | -H14 | Sheet & Plate | 0.009 to 1.000 | 20 | 17 | 14 | 12 | 10,100 |
| | -H16 | Sheet | 0.006 to 0.162 | 24 | 21 | 18 | 14 | 10,100 |
| | -H18 | Sheet | 0.006 to 0.128 | 27 | 24 | 20 | 15 | 10,100 |
| | -H12 | Drawn Tube | All | 17 | 12 | 11 | 11 | 10,100 |
| | -H14 | Drawn Tube | All | 20 | 17 | 16 | 12 | 10,100 |
| | -H16 | Drawn Tube | All | 24 | 21 | 19 | 14 | 10,100 |
| | -H18 | Drawn Tube | All | 27 | 24 | 21 | 15 | 10,100 |
| Alclad 3003 | -H12 | Sheet & Plate | 0.017 to 2.000 | 16 | 11 | 9 | 10 | 10,100 |
| | -H14 | Sheet & Plate | 0.009 to 1.000 | 19 | 16 | 13 | 12 | 10,100 |
| | -H16 | Sheet | 0.006 to 0.162 | 23 | 20 | 17 | 14 | 10,100 |
| | -H18 | Sheet | 0.006 to 0.128 | 26 | 23 | 19 | 15 | 10,100 |
| | -H14 | Drawn Tube | 0.025 to 0.259 | 19 | 16 | 15 | 12 | 10,100 |
| | -H18 | Drawn Tube | 0.010 to 0.500 | 26 | 23 | 20 | 15 | 10,100 |
| 3004 | -H32 | Sheet & Plate | 0.017 to 2.000 | 28 | 21 | 18 | 17 | 10,100 |
| | -H34 | Sheet & Plate | 0.009 to 1.000 | 32 | 25 | 22 | 19 | 10,100 |
| | -H36 | Sheet | 0.006 to 0.162 | 35 | 28 | 25 | 20 | 10,100 |
| | -H38 | Sheet | 0.006 to 0.128 | 38 | 31 | 29 | 21 | 10,100 |
| | -H34 | Drawn Tube | 0.018 to 0.450 | 32 | 25 | 24 | 19 | 10,100 |
| | -H36 | Drawn Tube | 0.018 to 0.450 | 35 | 28 | 27 | 20 | 10,100 |
| Alclad 3004 | -H32 | Sheet | 0.017 to 0.249 | 27 | 20 | 17 | 16 | 10,100 |
| | -H34 | Sheet | 0.009 to 0.249 | 31 | 24 | 21 | 18 | 10,100 |
| | -H36 | Sheet | 0.006 to 0.162 | 34 | 27 | 24 | 19 | 10,100 |
| | -H38 | Sheet | 0.006 to 0.128 | 37 | 30 | 28 | 21 | 10,100 |
| | -H131, H241, H341 | Sheet | 0.024 to 0.050 | 31 | 26 | 22 | 18 | 10,100 |
| | -H151, H261, H361 | Sheet | 0.024 to 0.050 | 34 | 30 | 28 | 19 | 10,100 |
| 3005 | -H25 | Sheet | 0.013 to 0.050 | 26 | 22 | 20 | 15 | 10,100 |
| | -H28 | Sheet | 0.006 to 0.080 | 31 | 27 | 25 | 17 | 10,100 |
| 3105 | -H25 | Sheet | 0.013 to 0.080 | 23 | 19 | 17 | 14 | 10,100 |
| 5005 | -H12 | Sheet & Plate | 0.017 to 2.000 | 18 | 14 | 13 | 11 | 10,100 |
| | -H14 | Sheet & Plate | 0.009 to 1.000 | 21 | 17 | 15 | 12 | 10,100 |
| | -H16 | Sheet | 0.006 to 0.162 | 24 | 20 | 18 | 14 | 10,100 |
| | -H32 | Sheet & Plate | 0.017 to 2.000 | 17 | 12 | 11 | 11 | 10,100 |
| | -H34 | Sheet & Plate | 0.009 to 1.000 | 20 | 15 | 14 | 12 | 10,100 |
| | -H36 | Sheet | 0.006 to 0.162 | 23 | 18 | 16 | 13 | 10,100 |
| 5050 | -H32 | Sheet | 0.017 to 0.249 | 22 | 16 | 14 | 14 | 10,100 |
| | -H34 | Sheet | 0.009 to 0.249 | 25 | 20 | 18 | 15 | 10,100 |
| | -H32 | Rod & Bar, Drawn Tube | All | 22 | 16 | 15 | 13 | 10,100 |
| | -H34 | Rod & Bar, Drawn Tube | All | 25 | 20 | 19 | 15 | 10,100 |
| 5052 | -O | Sheet & Plate | 0.006 to 3.000 | 25 | 9.5 | 9.5 | 16 | 10,200 |
| | -H32 | Sheet & Plate, Rod & Bar, | All | 31 | 23 | 21 | 19 | 10,200 |
| | -H34 | Drawn Tube | All | 34 | 26 | 24 | 20 | 10,200 |
| | -H36 | Sheet | 0.006 to 0.162 | 37 | 29 | 26 | 22 | 10,200 |



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## Table A.3.4
## MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS (Continued)

| ALLOY | TEMPER | PRODUCT | THICKNESS in. | $F_{tu}$ ksi | $F_{ty}$ ksi | $F_{cy}$ ksi | $F_{su}$ ksi | $E$ ksi |
|---|---|---|---|---|---|---|---|---|
| 5083 | -O | Extrusions | up thru 5.000 | 39 | 16 | 16 | 24 | 10,400 |
| | -H111 | Extrusions | up thru 0.500 | 40 | 24 | 21 | 24 | 10,400 |
| | -H111 | Extrusions | 0.501 to 5.000 | 40 | 24 | 21 | 23 | 10,400 |
| | -O | Sheet & Plate | 0.051 to 1.500 | 40 | 18 | 18 | 24 | 10,400 |
| | -H116, H32, H321 | Sheet & Plate | 0.188 to 1.500 | 44 | 31 | 26 | 26 | 10,400 |
| | -H116, H32, H321 | Plate | 1.501 to 3.000 | 41 | 29 | 24 | 24 | 10,400 |
| 5086 | -O | Extrusions | up thru 5.000 | 35 | 14 | 14 | 21 | 10,400 |
| | -H111 | Extrusions | up thru 5.000 | 36 | 21 | 18 | 21 | 10,400 |
| | -O | Sheet & Plate | 0.020 to 2.000 | 35 | 14 | 14 | 21 | 10,400 |
| | -H112 | Plate | 0.025 to 0.499 | 36 | 18 | 17 | 22 | 10,400 |
| | -H112 | Plate | 0.500 to 1.000 | 35 | 16 | 16 | 21 | 10,400 |
| | -H112 | Plate | 1.001 to 2.000 | 35 | 14 | 15 | 21 | 10,400 |
| | -H112 | Plate | 2.001 to 3.000 | 34 | 14 | 15 | 21 | 10,400 |
| | -H116 | Sheet & Plate | All | 40 | 28 | 26 | 24 | 10,400 |
| | -H32 | Sheet & Plate, Drawn Tube | All | 40 | 28 | 26 | 24 | 10,400 |
| | -H34 | Sheet & Plate, Drawn Tube | All | 44 | 34 | 32 | 26 | 10,400 |
| 5154 | -H38 | Sheet | 0.006 to 0.128 | 45 | 35 | 33 | 24 | 10,300 |
| 5454 | -O | Extrusions | up thru 5.000 | 31 | 12 | 12 | 19 | 10,400 |
| | -H111 | Extrusions | up thru 0.500 | 33 | 19 | 16 | 20 | 10,400 |
| | -H111 | Extrusions | 0.501 to 5.000 | 33 | 19 | 16 | 19 | 10,400 |
| | -H112 | Extrusions | up thru 5.000 | 31 | 12 | 13 | 19 | 10,400 |
| | -O | Sheet & Plate | 0.020 to 3.000 | 31 | 12 | 12 | 19 | 10,400 |
| | -H32 | Sheet & Plate | 0.020 to 2.000 | 36 | 26 | 24 | 21 | 10,400 |
| | -H34 | Sheet & Plate | 0.020 to 1.000 | 39 | 29 | 27 | 23 | 10,400 |
| 5456 | -O | Sheet & Plate | 0.051 to 1.500 | 42 | 19 | 19 | 26 | 10,400 |
| | -H116 | Sheet & Plate | 0.188 to 1.250 | 46 | 33 | 27 | 27 | 10,400 |
| | -H32, H321 | Sheet & Plate | 0.188 to 0.499 | 46 | 33 | 27 | 27 | 10,400 |
| | -H116 | Plate | 1.251 to 1.500 | 44 | 31 | 25 | 25 | 10,400 |
| | -H32, H321 | Plate | 0.500 to 1.500 | 44 | 31 | 25 | 25 | 10,400 |
| | -H116, H32, H321 | Plate | 1.501 to 3.000 | 41 | 29 | 25 | 25 | 10,400 |
| 6005 | -T5 | Extrusions | up thru 1.000 | 38 | 35 | 35 | 24 | 10,100 |
| 6005A | -T61 | Extrusions | up thru 1.000 | 38 | 35 | 35 | 24 | 10,100 |
| 6061 | -T6, T651 | Sheet & Plate | 0.010 to 4.000 | 42 | 35 | 35 | 27 | 10,100 |
| | -T6, T6510, T6511 | Extrusions | All | 38 | 35 | 35 | 24 | 10,100 |
| | -T6, T651 | Rod & Bar | up thru 8.000 | 42 | 35 | 35 | 25 | 10,100 |
| | -T6 | Drawn Tube | 0.025 to 0.500 | 42 | 35 | 35 | 27 | 10,100 |
| | -T6 | Pipe | All | 38 | 35 | 35 | 24 | 10,100 |
| 6063 | -T5 | Extrusions | up thru 0.500 | 22 | 16 | 16 | 13 | 10,100 |
| | -T5 | Extrusions | 0.501 to 1.000 | 21 | 15 | 15 | 12 | 10,100 |
| | -T52 | Extrusions | up thru 1.000 | 22 | 16 | 16 | 13 | 10,100 |
| | -T6 | Extrusions & Pipe | All | 30 | 25 | 25 | 19 | 10,100 |
| 6066 | -T6, T6510, T6511 | Extrusions | All | 50 | 45 | 45 | 27 | 10,100 |
| 6070 | -T6, T62 | Extrusions | up thru 2.999 | 48 | 45 | 45 | 29 | 10,100 |
| 6082 | -T6, T6511 | Extrusions | 0.200 thru 6.000 | 45 | 38 | 38 | 25 | 10,100 |
| 6105 | -T5 | Extrusions | up thru 0.500 | 38 | 35 | 35 | 24 | 10,100 |
| 6351 | -T5 | Extrusions | up thru 1.000 | 38 | 35 | 35 | 24 | 10,100 |
| 6351 | -T6 | Extrusions | up thru 0.750 | 42 | 37 | 37 | 27 | 10,100 |
| 6463 | -T6 | Extrusions | up thru 0.500 | 30 | 25 | 25 | 19 | 10,100 |
| 7005 | -T53 | Extrusions | up thru 0.750 | 50 | 44 | 43 | 28 | 10,500 |

Note: Rod & Bar is rolled or cold finished.



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## Table A.3.4M
## MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS

| ALLOY | TEMPER | PRODUCT | THICKNESS mm | $F_{tu}$ MPa | $F_{ty}$ MPa | $F_{cy}$ MPa | $F_{su}$ MPa | $E$ MPa |
|---|---|---|---|---|---|---|---|---|
| 1100 | -H12 | Sheet, Plate, Drawn Tube, | All | 95 | 75 | 70 | 62 | 69,600 |
| | -H14 | Rod & Bar | All | 110 | 95 | 90 | 70 | 69,600 |
| 2014 | -T6 | Sheet | 1.00 to 6.30 | 455 | 400 | 405 | 275 | 75,200 |
| | -T651 | Plate | 6.30 to 50.00 | 460 | 405 | 400 | 275 | 75,200 |
| | -T6, T6510, T6511 | Extrusions | All | 415 | 365 | 360 | 240 | 75,200 |
| | -T6, T651 | Rod & Bar, Drawn Tube | All | 450 | 380 | 365 | 260 | 75,200 |
| Alclad 2014 | -T6 | Sheet | 0.63 to 1.00 | 435 | 380 | 385 | 260 | 74,500 |
| | -T6 | Sheet | 1.00 to 6.30 | 440 | 395 | 400 | 270 | 74,500 |
| | -T651 | Plate | 6.30 to 12.50 | 440 | 395 | 385 | 270 | 74,500 |
| 3003 | -H12 | Sheet & Plate | 0.40 to 50.00 | 120 | 85 | 70 | 75 | 69,600 |
| | -H14 | Sheet & Plate | 0.20 to 25.00 | 140 | 115 | 95 | 85 | 69,600 |
| | -H16 | Sheet | 0.15 to 4.00 | 165 | 145 | 125 | 95 | 69,600 |
| | -H18 | Sheet | 0.15 to 3.20 | 185 | 165 | 140 | 105 | 69,600 |
| | -H12 | Drawn Tube | All | 120 | 85 | 75 | 75 | 69,600 |
| | -H14 | Drawn Tube | All | 140 | 115 | 110 | 85 | 69,600 |
| | -H16 | Drawn Tube | All | 165 | 145 | 130 | 95 | 69,600 |
| | -H18 | Drawn Tube | All | 185 | 165 | 145 | 105 | 69,600 |
| Alclad 3003 | -H12 | Sheet & Plate | 0.40 to 50.00 | 115 | 80 | 62 | 70 | 69,600 |
| | -H14 | Sheet & Plate | 0.20 to 25.00 | 135 | 110 | 90 | 85 | 69,600 |
| | -H16 | Sheet | 0.15 to 4.00 | 160 | 140 | 115 | 95 | 69,600 |
| | -H18 | Sheet | 0.15 to 3.20 | 180 | 160 | 130 | 105 | 69,600 |
| | -H14 | Drawn Tube | 0.63 to 6.30 | 135 | 110 | 105 | 85 | 69,600 |
| | -H18 | Drawn Tube | 0.25 to 12.50 | 180 | 160 | 140 | 105 | 69,600 |
| 3004 | -H32 | Sheet & Plate | 0.40 to 50.00 | 190 | 145 | 125 | 115 | 69,600 |
| | -H34 | Sheet & Plate | 0.20 to 25.00 | 220 | 170 | 150 | 130 | 69,600 |
| | -H36 | Sheet | 0.15 to 4.00 | 240 | 190 | 170 | 140 | 69,600 |
| | -H38 | Sheet | 0.15 to 3.20 | 260 | 215 | 200 | 145 | 69,600 |
| | -H34 | Drawn Tube | 0.45 to 11.50 | 220 | 170 | 165 | 130 | 69,600 |
| | -H36 | Drawn Tube | 0.45 to 11.50 | 240 | 190 | 185 | 140 | 69,600 |
| Alclad 3004 | -H32 | Sheet | 0.40 to 6.30 | 185 | 140 | 115 | 110 | 69,600 |
| | -H34 | Sheet | 0.20 to 6.30 | 215 | 165 | 145 | 125 | 69,600 |
| | -H36 | Sheet | 0.15 to 4.00 | 235 | 185 | 165 | 130 | 69,600 |
| | -H38 | Sheet | 0.15 to 3.20 | 255 | 205 | 195 | 145 | 69,600 |
| | -H131, H241, H341 | Sheet | 0.60 to 1.20 | 215 | 180 | 150 | 125 | 69,600 |
| | -H151, H261, H361 | Sheet | 0.60 to 1.20 | 235 | 205 | 195 | 130 | 69,600 |
| 3005 | -H25 | Sheet | 0.32 to 1.20 | 180 | 150 | 140 | 105 | 69,600 |
| | -H28 | Sheet | 0.15 to 2.00 | 215 | 185 | 170 | 115 | 69,600 |
| 3105 | -H25 | Sheet | 0.32 to 2.00 | 160 | 130 | 115 | 95 | 69,600 |
| 5005 | -H12 | Sheet & Plate | 0.40 to 50.00 | 125 | 95 | 90 | 75 | 69,600 |
| | -H14 | Sheet & Plate | 0.20 to 25.00 | 145 | 115 | 105 | 85 | 69,600 |
| | -H16 | Sheet | 0.15 to 4.00 | 165 | 135 | 125 | 95 | 69,600 |
| | -H32 | Sheet & Plate | 0.40 to 50.00 | 120 | 85 | 75 | 75 | 69,600 |
| | -H34 | Sheet & Plate | 0.20 to 25.00 | 140 | 105 | 95 | 85 | 69,600 |
| | -H36 | Sheet | 0.15 to 4.00 | 160 | 125 | 110 | 90 | 69,600 |
| 5050 | -H32 | Sheet | 0.40 to 6.30 | 150 | 110 | 95 | 95 | 69,600 |
| | -H34 | Sheet | 0.20 to 6.30 | 170 | 140 | 125 | 105 | 69,600 |
| | -H32 | Rod & Bar, Drawn Tube | All | 150 | 110 | 105 | 90 | 69,600 |
| | -H34 | Rod & Bar, Drawn Tube | All | 170 | 140 | 130 | 105 | 69,600 |
| 5052 | -O | Sheet & Plate | 0.15 to 80.00 | 170 | 65 | 65 | 110 | 70,300 |
| | -H32 | Sheet & Plate, Rod & Bar, | All | 215 | 160 | 145 | 130 | 70,300 |
| | -H34 | Drawn Tube | All | 235 | 180 | 165 | 140 | 70,300 |
| | -H36 | Sheet | 0.15 to 4.00 | 255 | 200 | 180 | 150 | 70,300 |



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## Table A.3.4M
## MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS (Continued)

| ALLOY | TEMPER | PRODUCT | THICKNESS mm | $F_{tu}$ MPa | $F_{ty}$ MPa | $F_{cy}$ MPa | $F_{su}$ MPa | $E$ MPa |
|---|---|---|---|---|---|---|---|---|
| 5083 | -O | Extrusions | up thru 13.00 | 270 | 110 | 110 | 165 | 71,700 |
| | -H111 | Extrusions | up thru 12.70 | 275 | 165 | 145 | 165 | 71,700 |
| | -H111 | Extrusions | 12.70 to 130.00 | 275 | 165 | 145 | 160 | 71,700 |
| | -O | Sheet & Plate | 1.20 to 6.30 | 275 | 125 | 125 | 170 | 71,700 |
| | -H116, H32, H321 | Sheet & Plate | 4.00 to 40.00 | 305 | 215 | 180 | 180 | 71,700 |
| | -H116, H32, H321 | Plate | 40.00 to 80.00 | 285 | 200 | 165 | 165 | 71,700 |
| 5086 | -O | Extrusions | up thru 130.00 | 240 | 95 | 95 | 145 | 71,700 |
| | -H111 | Extrusions | up thru 130.00 | 250 | 145 | 125 | 145 | 71,700 |
| | -O | Sheet & Plate | 0.50 to 50.00 | 240 | 95 | 95 | 145 | 71,700 |
| | -H112 | Sheet & Plate | 4.00 to 12.50 | 250 | 125 | 115 | 150 | 71,700 |
| | -H112 | Plate | 12.50 to 40.00 | 240 | 105 | 110 | 145 | 71,700 |
| | -H112 | Plate | 40.00 to 80.00 | 235 | 95 | 105 | 145 | 71,700 |
| | -H116 | Sheet & Plate | 1.60 to 50.00 | 275 | 195 | 180 | 165 | 71,700 |
| | -H32 | Sheet & Plate, Drawn Tube | All | 275 | 195 | 180 | 165 | 71,700 |
| | -H34 | Sheet & Plate, Drawn Tube | All | 300 | 235 | 220 | 180 | 71,700 |
| 5154 | -H38 | Sheet | 0.15 to 3.20 | 310 | 240 | 230 | 165 | 71,700 |
| 5454 | -O | Extrusions | up thru 130.00 | 215 | 85 | 85 | 130 | 71,700 |
| | -H111 | Extrusions | up thru 12.70 | 230 | 130 | 110 | 140 | 71,700 |
| | -H111 | Extrusions | 12.70 to 130.00 | 230 | 130 | 110 | 130 | 71,700 |
| | -H112 | Extrusions | up thru 130.00 | 215 | 85 | 90 | 130 | 71,700 |
| | -O | Sheet & Plate | 0.50 to 80.00 | 215 | 85 | 85 | 130 | 71,700 |
| | -H32 | Sheet & Plate | 0.50 to 50.00 | 250 | 180 | 165 | 145 | 71,700 |
| | -H34 | Sheet & Plate | 0.50 to 25.00 | 270 | 200 | 185 | 160 | 71,700 |
| 5456 | -O | Sheet & Plate | 1.20 to 6.30 | 290 | 130 | 130 | 180 | 71,700 |
| | -H116, H32, H321 | Sheet & Plate | 4.00 to 12.50 | 315 | 230 | 185 | 185 | 71,700 |
| | -H116, H32, H321 | Plate | 12.50 to 40.00 | 305 | 215 | 170 | 170 | 71,700 |
| | -H116, H32, H321 | Plate | 40.00 to 80.00 | 285 | 200 | 170 | 170 | 71,700 |
| 6005 | -T5 | Extrusions | up thru 25.00 | 260 | 240 | 240 | 165 | 69,600 |
| 6005A | -T61 | Extrusions | up thru 25.00 | 260 | 240 | 240 | 165 | 69,600 |
| 6061 | -T6, T651 | Sheet & Plate | 0.25 to 100.00 | 290 | 240 | 240 | 185 | 69,600 |
| | -T6, T6510, T6511 | Extrusions | All | 260 | 240 | 240 | 165 | 69,600 |
| | -T6, T651 | Rod & Bar | up thru 200 | 290 | 240 | 240 | 170 | 69,600 |
| | -T6 | Drawn Tube | 0.63 to 12.50 | 290 | 240 | 240 | 185 | 69,600 |
| | -T6 | Pipe | All | 260 | 240 | 240 | 165 | 69,600 |
| 6063 | -T5 | Extrusions | up thru 12.50 | 150 | 110 | 110 | 90 | 69,600 |
| | -T52 | Extrusions | up thru 25.00 | 150 | 110 | 110 | 90 | 69,600 |
| | -T5 | Extrusions | 12.50 to 25.00 | 145 | 105 | 105 | 85 | 69,600 |
| | -T6 | Extrusions & Pipe | All | 205 | 170 | 170 | 130 | 69,600 |
| 6066 | -T6, T6510, T6511 | Extrusions | All | 345 | 310 | 310 | 185 | 69,600 |
| 6070 | -T6, T62 | Extrusions | up thru 80.00 | 330 | 310 | 310 | 200 | 69,600 |
| 6082 | -T6, T6511 | Extrusions | 5.00 thru 150.00 | 310 | 260 | 260 | 170 | 69,600 |
| 6105 | -T5 | Extrusions | up thru 12.50 | 260 | 240 | 240 | 165 | 69,600 |
| 6351 | -T5 | Extrusions | up thru 25.00 | 260 | 240 | 240 | 165 | 69,600 |
| 6351 | -T6 | Extrusions | up thru 20.00 | 290 | 255 | 255 | 185 | 69,600 |
| 6463 | -T6 | Extrusions | up thru 12.50 | 205 | 170 | 170 | 130 | 69,600 |
| 7005 | -T53 | Extrusions | up thru 20.00 | 345 | 305 | 295 | 195 | 72,400 |

Note: Rod & Bar is rolled or cold finished



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# Table A.3.5
# MECHANICAL PROPERTIES FOR WELD-AFFECTED ZONES IN WROUGHT ALUMINUM PRODUCTS

| ALLOY | TEMPER | PRODUCT | THICKNESS in. | $F_{tuw}$ ksi | $F_{tyw}$ ksi | $F_{cyw}$ ksi | $F_{suw}$ ksi | $E$ ksi |
|---|---|---|---|---|---|---|---|---|
| 1100 | All | Sheet & Plate, Drawn Tube | | 11 | 3.5 | 3.5 | 8 | 10,100 |
| 1100 | All | Rod & Bar | | 11 | 3.0 | 3.0 | 8 | 10,100 |
| 3003 | All | Sheet & Plate, Drawn Tube | | 14 | 5 | 5 | 10 | 10,100 |
| Alclad 3003 | All | Sheet & Plate, Drawn Tube | | 13 | 4.5 | 4.5 | 10 | 10,100 |
| 3004 | All | Sheet & Plate | | 22 | 8.5 | 8.5 | 14 | 10,100 |
| 3004 | All | Drawn Tube | | 23 | 8.5 | 8.5 | 14 | 10,100 |
| Alclad 3004 | All | Sheet | | 21 | 8 | 8 | 13 | 10,100 |
| 3005 | All | Sheet | | 17 | 6.5 | 6.5 | 12 | 10,100 |
| 5005 | All | Sheet & Plate | | 15 | 5 | 5 | 9 | 10,100 |
| 5050 | All | Sheet & Plate, Drawn Tube, Rod & Bar | | 18 | 6 | 6 | 12 | 10,100 |
| 5052 | All | Sheet & Plate, Rod & Bar | | 25 | 9.5 | 9.5 | 16 | 10,200 |
| 5052 | All | Drawn Tube | | 25 | 10 | 10 | 16 | 10,200 |
| 5083 | All | Extrusions | | 39 | 16 | 16 | 24 | 10,400 |
| 5083 | All | Sheet & Plate | 0.188 to 1.500 | 40 | 18 | 18 | 24 | 10,400 |
| 5083 | All | Plate | 1.501 to 3.000 | 39 | 17 | 17 | 24 | 10,400 |
| 5086 | All | Sheet & Plate, Extrusions, Drawn Tube | | 35 | 14 | 14 | 21 | 10,400 |
| 5154 | All | Sheet | | 30 | 11 | 11 | 19 | 10,300 |
| 5454 | All | Sheet & Plate, Extrusions | | 31 | 12 | 12 | 19 | 10,400 |
| 5456 | All | Sheet & Plate | 0.188–1.500 | 42 | 19 | 19 | 26 | 10,400 |
| 5456 | All | Plate | 1.501–3.000 | 41 | 18 | 17 | 25 | 10,400 |
| 6005 | T5 | Extrusions | up thru 1.000 | 24 | 13 | 13 | 15 | 10,100 |
| 6005A | T61 | Extrusions | up thru 1.000 | 24 | 13 | 13 | 15 | 10,100 |
| 6061 | T6, T651, T6510, T6511[1] | All | | 24 | 15 | 15 | 15 | 10,100 |
| 6061 | T6, T651, T6510, T6511[2] | All | over 0.375 | 24 | 11 | 11 | 15 | 10,100 |
| 6063 | T5, T52, T6 | All | | 17 | 8 | 8 | 11 | 10,100 |
| 6082 | T6, T6511 | Extrusions | 0.200 to 6.000 | 28 | 16 | 16 | 15 | 10,100 |
| 6105 | T5 | Extrusions | up thru 0.500 | 24 | 13 | 13 | 15 | 10,100 |
| 6351 | T5, T6[1] | Extrusions | | 24 | 15 | 15 | 15 | 10,100 |
| 6351 | T5, T6[2] | Extrusions | over 0.375 | 24 | 11 | 11 | 15 | 10,100 |
| 6463 | T6 | Extrusions | up thru 0.500 | 17 | 8 | 8 | 11 | 10,100 |
| 7005 | T53 | Extrusions | up thru 0.750 | 40 | 24 | 24 | 22 | 10,500 |

Notes
1. 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..
2. When welded with 4043, 5554, or 5654 alloy filler.



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# Table A.3.5M
# MECHANICAL PROPERTIES FOR WELD-AFFECTED ZONES IN WROUGHT ALUMINUM PRODUCTS

| ALLOY | TEMPER | PRODUCT | THICKNESS mm | $F_{tuw}$ MPa | $F_{tyw}$ MPa | $F_{cyw}$ MPa | $F_{suw}$ MPa | $E$ MPa |
|---|---|---|---|---|---|---|---|---|
| 1100 | All | Sheet & Plate, Drawn Tube | | 75 | 25 | 25 | 55 | 69,600 |
| 1100 | All | Rod & Bar | | 75 | 20 | 20 | 55 | 69,600 |
| 3003 | All | Sheet & Plate, Drawn Tube | | 95 | 35 | 35 | 70 | 69,600 |
| Alclad 3003 | All | Sheet & Plate, Drawn Tube | | 90 | 30 | 30 | 70 | 69,600 |
| 3004 | All | Sheet & Plate | | 150 | 60 | 60 | 95 | 69,600 |
| 3004 | All | Drawn Tube | | 160 | 60 | 60 | 95 | 69,600 |
| Alclad 3004 | All | Sheet | | 145 | 55 | 55 | 90 | 69,600 |
| 3005 | All | Sheet | | 115 | 45 | 45 | 85 | 69,600 |
| 5005 | All | Sheet & Plate | | 105 | 35 | 35 | 62 | 69,600 |
| 5050 | All | Sheet & Plate, Drawn Tube, Rod & Bar | | 125 | 40 | 40 | 85 | 69,600 |
| 5052 | All | Sheet & Plate, Rod & Bar | | 170 | 65 | 65 | 110 | 70,300 |
| 5052 | All | Drawn Tube | | 170 | 70 | 70 | 110 | 70,300 |
| 5083 | All | Extrusions | | 270 | 110 | 110 | 165 | 71,700 |
| 5083 | All | Plate | 6.30 to 80.00 | 270 | 115 | 115 | 165 | 71,700 |
| 5086 | All | Sheet & Plate, Drawn Tube, Extrusions | | 240 | 95 | 95 | 145 | 71,700 |
| 5154 | All | Sheet | | 205 | 75 | 75 | 130 | 71,700 |
| 5454 | All | Sheet & Plate, Extrusions | | 215 | 85 | 85 | 130 | 71,700 |
| 5456 | All | Plate | 6.30 to 38.00 | 285 | 125 | 125 | 170 | 71,700 |
| 5456 | All | Plate | 38.00 to 80.00 | 285 | 125 | 120 | 170 | |
| 6005 | T5 | Extrusions | up thru 25.00 | 165 | 90 | 90 | 105 | 69,600 |
| 6005A | T61 | Extrusions | up thru 25.00 | 165 | 90 | 90 | 105 | 69,600 |
| 6061 | T6, T651, T6510, T6511[1] | All | | 165 | 105 | 105 | 105 | 69,600 |
| 6061 | T6, T651, T6510, T6511[2] | All | over 9.50 | 165 | 80 | 80 | 105 | 69,600 |
| 6063 | T5, T52, T6 | All | | 115 | 55 | 55 | 75 | 69,600 |
| 6082 | T6, T6511 | Extrusions | 5.00 to 150.00 | 190 | 110 | 110 | 105 | 69,600 |
| 6105 | T5 | Extrusions | up thru 12.50 | 165 | 90 | 90 | 105 | 69,600 |
| 6351 | T5, T6[1] | Extrusions | | 165 | 105 | 105 | 105 | 69,600 |
| 6351 | T5, T6[2] | Extrusions | over 9.50 | 165 | 80 | 80 | 105 | 69,600 |
| 6463 | T6 | Extrusions | up thru 12.50 | 115 | 55 | 55 | 75 | 69,600 |
| 7005 | T53 | Extrusions | up thru 20.00 | 275 | 165 | 165 | 155 | 72,400 |

Notes
1. 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.
2. When welded with 4043, 5554, or 5654 alloy filler.



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## Table A.3.6
## STRENGTHS OF ALUMINUM CASTINGS

| Alloy | Temper | Casting Type | $F_{tu}$ ksi | $F_{ty}$ ksi | Note |
|---|---|---|---|---|---|
| 356.0 | T6 | sand | 22.5 | 15 | |
| A356.0 | T6 | sand | 25.5 | 18 | |
| 354.0 | T61 | permanent mold | 36 | 27.7 | (1) |
| | | | 47 | 36 | (2) |
| | | | 43 | 33 | (3) |
| C355.0 | T61 | permanent mold | 30 | 22.5 | (1) |
| | | | 40 | 30 | (2) |
| | | | 37 | 30 | (3) |
| 356.0 | T6 | permanent mold | 33 | 22 | (1) |
| A356.0 | T61 | permanent mold | 28.5 | 19.5 | (1) |
| | | | 33 | 26 | (2) |
| | | | 28 | 26 | (3) |
| A357.0 | T61 | permanent mold | 33.7 | 27 | (1) |
| | | | 46 | 36 | (2) |
| | | | 41 | 31 | (3) |
| 359.0 | T61 | permanent mold | 33.7 | 25.5 | (1) |
| | | | 45 | 34 | (2) |
| | | | 40 | 30 | (3) |
| 359.0 | T62 | permanent mold | 35.2 | 28.5 | (1) |
| | | | 47 | 38 | (2) |
| | | | 40 | 30 | (3) |
| 535.0 | F | permanent mold | 26.2 | 13.5 | (1) |

See Table A.3.6M

## Table A.3.6M
## STRENGTHS OF ALUMINUM CASTINGS

| Alloy | Temper | Casting Type | $F_{tu}$ MPa | $F_{ty}$ MPa | Note |
|---|---|---|---|---|---|
| 356.0 | T6 | sand | 154 | 105 | |
| A356.0 | T6 | sand | 176 | 124 | |
| 354.0 | T61 | permanent mold | 248 | 191 | (1) |
| | | | 324 | 248 | (2) |
| | | | 297 | 228 | (3) |
| C355.0 | T61 | permanent mold | 207 | 155 | (1) |
| | | | 276 | 207 | (2) |
| | | | 255 | 207 | (3) |
| 356.0 | T6 | permanent mold | 228 | 152 | (1) |
| A356.0 | T61 | permanent mold | 196 | 134 | (1) |
| | | | 228 | 179 | (2) |
| | | | 193 | 179 | (3) |
| A357.0 | T61 | permanent mold | 232 | 186 | (1) |
| | | | 317 | 248 | (2) |
| | | | 283 | 214 | (3) |
| 359.0 | T61 | permanent mold | 232 | 175 | (1) |
| | | | 310 | 234 | (2) |
| | | | 276 | 207 | (3) |
| 359.0 | T62 | permanent mold | 243 | 196 | (1) |
| | | | 324 | 262 | (2) |
| | | | 276 | 207 | (3) |
| 535.0 | F | permanent mold | 180 | 93 | (1) |

Notes

1. These strengths apply at any location in the casting if the purchaser does not specify that test specimens be cut from castings.
2. These strengths apply in the locations specified by the purchaser if the purchaser specifies such locations. At other locations, the strengths in (1) apply.
3. These strengths apply anywhere in the casting if the purchaser specifies that these strengths shall be met in specimens cut from the casting without designating a location.



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## Table A.3.7
## 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 |

## Table A.3.8
## STRENGTHS OF ALUMINUM BOLTS

| Alloy and Temper | Shear Ultimate Strength[1] $F_{su}$ (ksi) | Tensile Ultimate Strength[1] $F_{tu}$ (ksi) |
|---|---|---|
| 2024-T4 | 37 | 62 |
| 6061-T6 | 25 | 42 |
| 7075-T73 | 41 | 68 |

Note: 1. From ASTM B 316/B 316M and F 468

## Table A.3.8M
## STRENGTHS OF ALUMINUM BOLTS

| Alloy and Temper | Shear Ultimate Strength[1] $F_{su}$ (MPa) | Tensile Ultimate Strength[1] $F_{tu}$ (MPa) |
|---|---|---|
| 2024-T4 | 255 | 425 |
| 6061-T6 | 170 | 290 |
| 7075-T73 | 280 | 470 |

Note: 1. From ASTM B 316/B 316M

## Table A.3.9
## STRENGTHS OF ALUMINUM RIVETS

| Designation Before Driving | Shear Ultimate Strength $F_{su}$ (ksi) (note 1) |
|---|---|
| 2017-T4 | 33 |
| 2024-T42 | 37 |
| 2117-T4 | 26 |
| 2219-T6 | 30 |
| 6053-T61 | 20 |
| 6061-T6 | 25 |
| 7050-T7 | 39 |
| 7075-T6 | 42 |
| 7075-T73 | 41 |
| 7178-T6 | 46 |

Note: 1. From ASTM B 316/B 316M

## Table A.3.9M
## STRENGTHS OF ALUMINUM RIVETS

| Designation Before Driving | Shear Ultimate Strength $F_{su}$ (MPa) (note 1) |
|---|---|
| 2017-T4 | 225 |
| 2024-T42 | 255 |
| 2117-T4 | 180 |
| 2219-T6 | 205 |
| 6053-T61 | 135 |
| 6061-T6 | 170 |
| 7050-T7 | 270 |
| 7075-T6 | 290 |
| 7075-T73 | 280 |
| 7178-T6 | 315 |

Note: 1. From ASTM B 316/B 316M



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# Chapter B Design Requirements

## 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, moments, and deflections 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
$R_n$ = nominal strength
$\phi$ = resistance factor
$\phi R_n$ = 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
$R_n$ = nominal strength
$\Omega$ = safety factor
$R_n/\Omega$ = allowable strength

Safety factors for building-type structures and bridge-type structures shall be as given in this *Specification.*

### 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.



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### 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 |
|---|---|---|---|
| Compression in Columns and Beam Flanges | $B_c = F_{cy}\left(1 + \left(\frac{F_{cy}}{1000\kappa}\right)^{1/2}\right)$ | $D_c = \frac{B_c}{20}\left(\frac{6B_c}{E}\right)^{1/2}$ | $C_c = \frac{2B_c}{3D_c}$ |
| Axial Compression in Flat Elements | $B_p = F_{cy}\left(1 + \left(\frac{F_{cy}}{440\kappa}\right)^{1/3}\right)$ | $D_p = \frac{B_p}{20}\left(\frac{6B_p}{E}\right)^{1/2}$ | $C_p = \frac{2B_p}{3D_p}$ |
| Axial Compression in Curved Elements | $B_t = F_{cy}\left(1 + \left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$ | $D_t = \frac{B_t}{3.7}\left(\frac{B_t}{E}\right)^{1/3}$ | $C_t$ see note 2 |
| Bending Compression in Flat Elements | $B_{br} = 1.3F_{cy}\left(1 + \left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$ | $D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$ | $C_{br} = \frac{2B_{br}}{3D_{br}}$ |
| Bending 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 | $B_s = F_{sy}\left(1 + \left(\frac{F_{sy}}{240\kappa}\right)^{1/3}\right)$ | $D_s = \frac{B_s}{20}\left(\frac{6B_s}{E}\right)^{1/2}$ | $C_s = \frac{2B_s}{3D_s}$ |

Notes
1. $\kappa$ = 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.4.2
### BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH T5, T6, T7, T8, OR T9

| Type of Stress and Member | Intercept | Slope | Intersection |
|---|---|---|---|
| Compression in Columns and Beam Flanges | $B_c = F_{cy}\left(1 + \left(\frac{F_{cy}}{2250\kappa}\right)^{1/2}\right)$ | $D_c = \frac{B_c}{10}\left(\frac{B_c}{E}\right)^{1/2}$ | $C_c = 0.41\frac{B_c}{D_c}$ |
| Axial Compression in Flat Elements | $B_p = F_{cy}\left(1 + \left(\frac{F_{cy}}{1500\kappa}\right)^{1/3}\right)$ | $D_p = \frac{B_p}{10}\left(\frac{B_p}{E}\right)^{1/2}$ | $C_p = 0.41\frac{B_p}{D_p}$ |
| Axial Compression in Curved Elements | $B_t = F_{cy}\left(1 + \left(\frac{F_{cy}}{50{,}000\kappa}\right)^{1/5}\right)$ | $D_t = \frac{B_t}{4.5}\left(\frac{B_t}{E}\right)^{1/3}$ | $C_t$ see note 2 |
| Bending Compression in Flat Elements | $B_{br} = 1.3F_{cy}\left(1 + \left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$ | $D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$ | $C_{br} = \frac{2B_{br}}{3D_{br}}$ |
| Bending 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 | $B_s = F_{sy}\left(1 + \left(\frac{F_{sy}}{800\kappa}\right)^{1/3}\right)$ | $D_s = \frac{B_s}{10}\left(\frac{B_s}{E}\right)^{1/2}$ | $C_s = 0.41\frac{B_s}{D_s}$ |

Notes
1. $\kappa$ = 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.4.3
## 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:

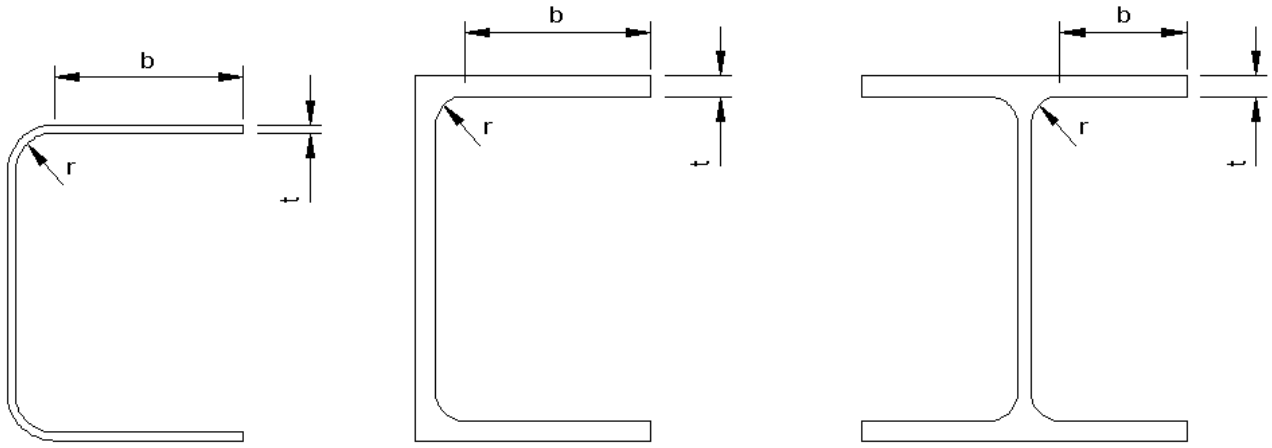
a) supported on one edge, the element width $b$ is the distance from the element's unsupported edge to the toe of the fillet or bend at the element's supported edge (Figure B.5.1)
b) supported on both edges and flat elements supported on one edge and with a stiffener on the other edge, the element width $b$ 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.

### B.5.2 Radius of Curved Elements

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

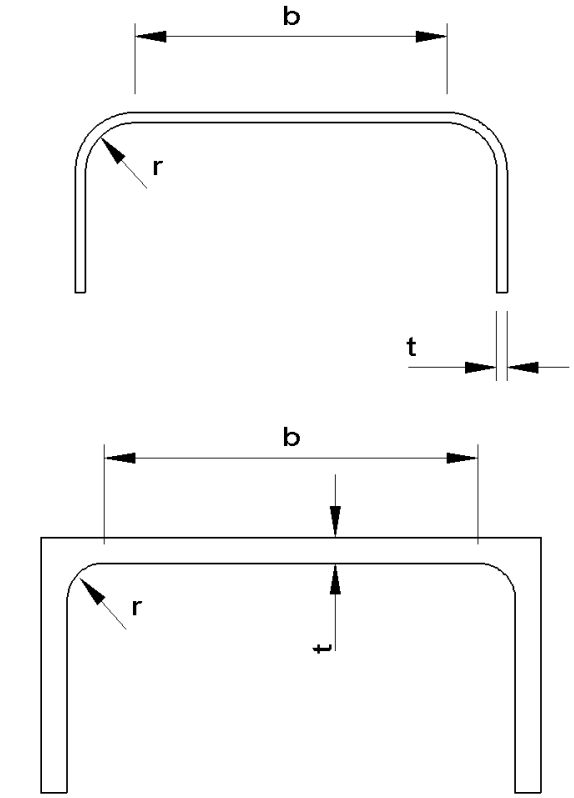



If $r > 4t$, use $r = 4t$ to calculate $b$.

**Figure B.5.1**
**FLAT ELEMENTS SUPPORTED ON ONE EDGE**



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If $r > 4t$, use $r = 4t$ to calculate $b$.

**Figure B.5.2**
**FLAT ELEMENTS SUPPORTED ON BOTH EDGES**

### B.5.3 Thickness of Elements

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

a) For tapered thickness elements with the thick edge supported and the thin edge free, the slenderness ratio 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 ratio is $(b/t_{avg})$
c) For tapered thickness elements supported on both edges, the slenderness ratio 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

For elements in uniform compression, the stress corresponding to the uniform compression strength is

For unwelded members:

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

For welded members:

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

where

$F_{co}$ = stress corresponding to the uniform compression 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 strengths from Table A.3.4 or Table A.3.4M.
$F_{cw}$ = stress corresponding to the uniform compression 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 strengths from Table A.3.5 or Table A.3.5M. For transversely welded elements with $b/t \le S_1$, $F_c = F_{co}$.
$A_{wz}$ = cross sectional area of the weld-affected zone
$A_g$ = gross cross sectional area of the element.

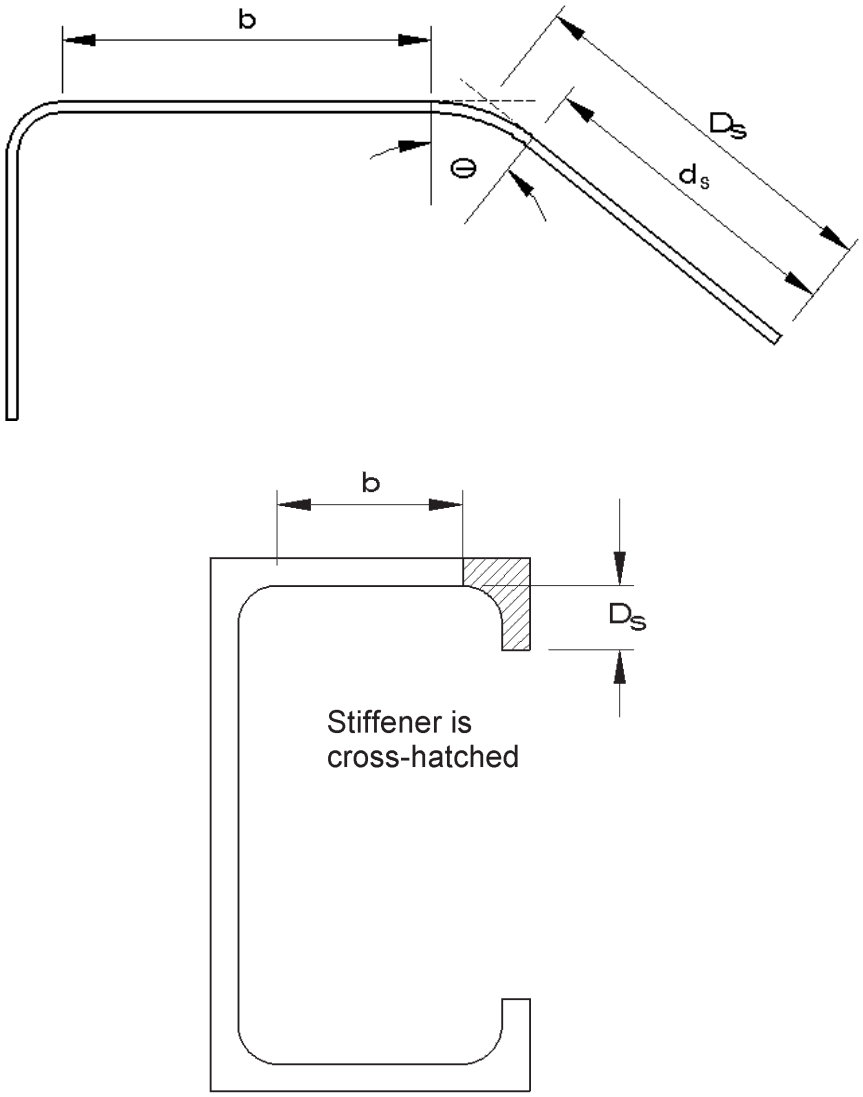
#### B.5.4.1 Flat Elements Supported On One Edge

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

| Limit State | $F_c$ | $b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $F_{cy}$ | $b/t \le S_1$ | $S_1 = \frac{B_p - F_{cy}}{5.0D_p}$ |
| inelastic buckling | $B_p - 5.0D_p\, b/t$ | $S_1 < b/t < S_2$ | |
| in columns whose buckling axis is not an axis of symmetry: | | | |
| elastic buckling | $\frac{\pi^2 E}{(5.0b/t)^2}$ | $b/t \ge S_2$ | $S_2 = \frac{C_p}{5.0}$ |
| in all other columns and all beams: | | | |
| post-buckling | $\frac{k_2\sqrt{B_p E}}{5.0b/t}$ | $b/t \ge S_2$ | $S_2 = \frac{k_1 B_p}{5.0D_p}$ |



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If $r > 4t$, use $r = 4t$ to calculate $b$.

**Figure B.5.3**
**EDGE STIFFENED ELEMENTS**

### B.5.4.2 Flat Elements Supported on Both Edges

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

| Limit State | $F_c$ | $b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $F_{cy}$ | $b/t \le S_1$ | $S_1 = \dfrac{B_p - F_{cy}}{1.6D_p}$ |
| inelastic buckling | $B_p - 1.6D_p\, b/t$ | $S_1 < b/t < S_2$ | |
| post-buckling | $\dfrac{k_2\sqrt{B_p E}}{1.6b/t}$ | $b/t \ge S_2$ | $S_2 = \dfrac{k_1 B_p}{1.6D_p}$ |

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

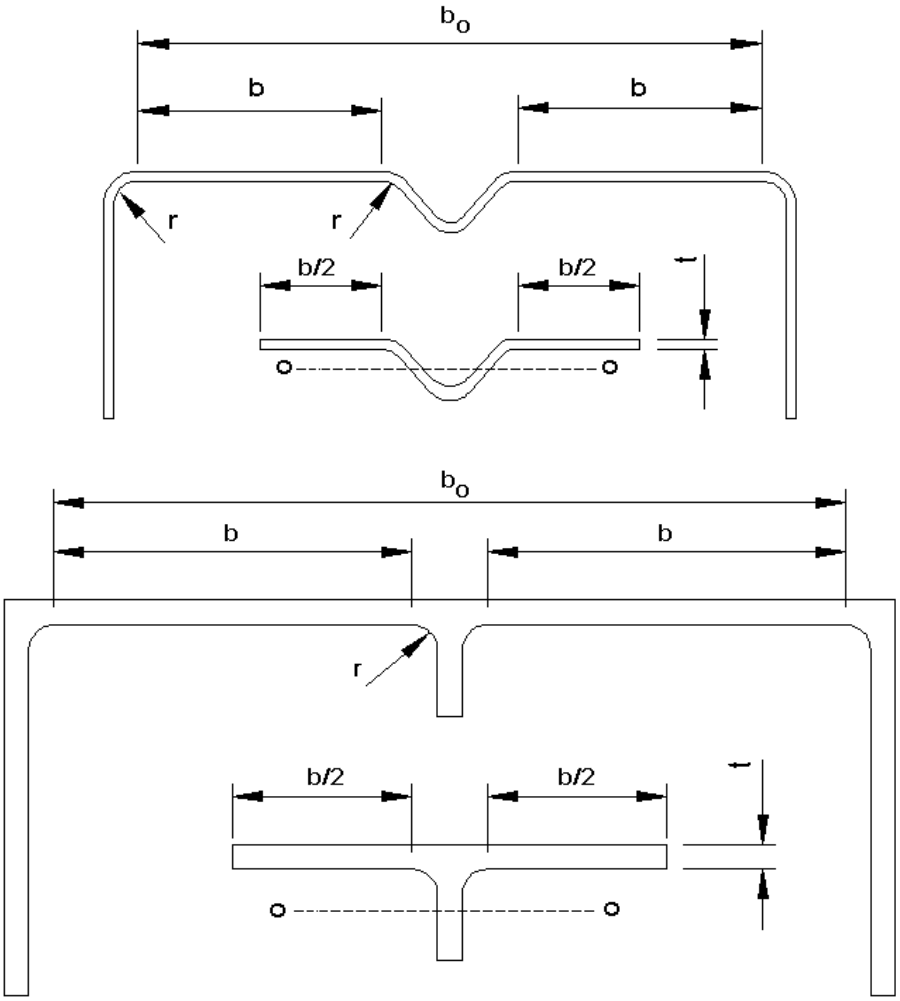
For flat elements

a) supported on one edge and with a stiffener on the other edge,
b) with a stiffener of depth $D_S \le 0.8b$, where $D_S$ is defined in Figure B.5.3, and
c) with a thickness no greater than the stiffener's thickness, the stress corresponding to the uniform compression strength is

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



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Line o-o is the neutral axis of the stiffener and element of width $b/2$ on each side of the stiffener. $I_o$ is the moment of inertia of the portion shown in the partial section.

If $r > 4t$, use $r = 4t$ to calculate $b$.

**Figure B.5.4**
**FLAT ELEMENTS WITH AN INTERMEDIATE STIFFENER**

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

$\rho_{ST}$ = stiffener effectiveness ratio determined as follows:

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

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

c) $\rho_{ST} = \dfrac{r_s}{1.5t\left(\dfrac{b/t}{S_e} + 3\right)} \le 1.0$ for $S_e < b/t < 2S_e$ (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) $r_s = d_s(\sin\theta)/\sqrt{3}$ where $d_s$ = the stiffener's flat width and $\theta$ = the angle between the stiffener and the stiffened element.

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

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

For flat elements

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



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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 corresponding to the uniform compression 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 compression strength of flat elements supported on both edges and with an intermediate stiffener is:

| Limit State | $F_c$ | $\lambda_s$ | Slenderness Limits |
|---|---|---|---|
| yielding | $F_{cy}$ | $\lambda_s \le S_1$ | $S_1 = \dfrac{B_c - F_{cy}}{D_c}$ |
| inelastic buckling | $B_c - D_c \lambda_s$ | $S_1 < \lambda_s < S_2$ | |
| elastic buckling | $\dfrac{\pi^2 E}{\lambda_s^2}$ | $\lambda_s \ge S_2$ | $S_2 = C_c$ |

where

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

$A_s$ = 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 Curved Elements Supported on Both Edges

The stress $F_c$ corresponding to the uniform compression strength of curved elements supported on both edges is:

| Limit State | $F_c$ | $R_b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $F_{cy}$ | $R_b/t \le S_1$ | $S_1 = \left(\dfrac{B_t - F_{cy}}{D_t}\right)^2$ |
| inelastic buckling | $B_t - D_t \sqrt{\dfrac{R_b}{t}}$ | $S_1 < R_b/t < S_2$ | |
| elastic buckling | $\dfrac{\pi^2 E}{16\left(\dfrac{R_b}{t}\right)\left(1 + \dfrac{\sqrt{R_b/t}}{35}\right)^2}$ | $R_b/t \ge S_2$ | $S_2 = C_t$ |

For tubes with circumferential welds, use of Section B.5.4.5 is limited by Sections E.6.1 and F.9.1.

### B.5.4.6 Flat Elements Alternate Method

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

| Limit State | $F_c$ | $\lambda_{eq}$ | Slenderness Limits |
|---|---|---|---|
| yielding | $F_{cy}$ | $\lambda_{eq} \le S_1$ | $S_1 = \dfrac{B_p - F_{cy}}{D_p}$ |
| inelastic buckling | $B_p - D_p \lambda_{eq}$ | $S_1 < \lambda_{eq} < S_2$ | |
| post-buckling | $\dfrac{k_2 \sqrt{B_p E}}{\lambda_{eq}}$ | $\lambda_{eq} \ge S_2$ | $S_2 = \dfrac{k_1 B_p}{D_p}$ |

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

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

## B.5.5 Strength of Elements in Flexure

For elements in flexure, the stress corresponding to the flexural compression strength is

For unwelded members:

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

For welded members:

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

where

$F_{bo}$ = stress corresponding to the flexural compression 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 mechanical properties from Table A.3.4 or Table A.3.4M.

$F_{bw}$ = stress corresponding to the flexural compression 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 mechanical properties from Table A.3.5 or Table A.3.5M. For transversely welded elements with $b/t \le S_1$, $F_b = F_{bo}$.

$A_{wzc}$ = 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 compression strength of flat elements supported on both edges and flat



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elements supported on the compression edge with the tension edge free is:

| Limit State | $F_b$ | $b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $1.3F_{cy}$ | $b/t \le S_1$ | $S_1 = \dfrac{B_{br} - 1.3F_{cy}}{mD_{br}}$ |
| inelastic buckling | $B_{br} - mD_{br}\, b/t$ | $S_1 < b/t < S_2$ | |
| post-buckling | $\dfrac{k_2\sqrt{B_{br}E}}{(mb/t)}$ | $b/t \ge S_2$ | $S_2 = \dfrac{k_1 B_{br}}{mD_{br}}$ |

$m = 1.15 + c_o/(2c_c)$ for $-1 < c_o/c_c < 1$
$m = 1.3/(1 - c_o/c_c)$ for $c_o/c_c \le -1$
$m = 0.65$ for $c_c = -c_o$
$c_c$ = distance from neutral axis to the element extreme fiber with the greatest compression stress
$c_o$ = distance from neutral axis 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 compression strength of flat elements supported on the tension edge with the compression edge free is:

| Limit State | $F_b$ | $b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $1.3F_{cy}$ | $b/t \le S_1$ | $S_1 = \dfrac{B_{br} - 1.3F_{cy}}{3.5D_{br}}$ |
| inelastic buckling | $B_{br} - 3.5D_{br}\, b/t$ | $S_1 < b/t < S_2$ | |
| elastic buckling | $\dfrac{\pi^2 E}{(3.5b/t)^2}$ | $b/t \ge S_2$ | $S_2 = \dfrac{C_{br}}{3.5}$ |

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

The stress $F_b$ corresponding to the flexural compression strength of 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 | $F_b$ | $b/t$ | Slenderness Limits |
|---|---|---|---|
| yielding | $1.3F_{cy}$ | $b/t \le S_1$ | $S_1 = \dfrac{B_{br} - 1.3F_{cy}}{0.29D_{br}}$ |
| inelastic buckling | $B_{br} - 0.29D_{br}\, b/t$ | $S_1 < b/t < S_2$ | |
| post-buckling | $\dfrac{k_2\sqrt{B_{br}E}}{(0.29b/t)}$ | $b/t \ge S_2$ | $S_2 = \dfrac{k_1 B_{br}}{0.29D_{br}}$ |

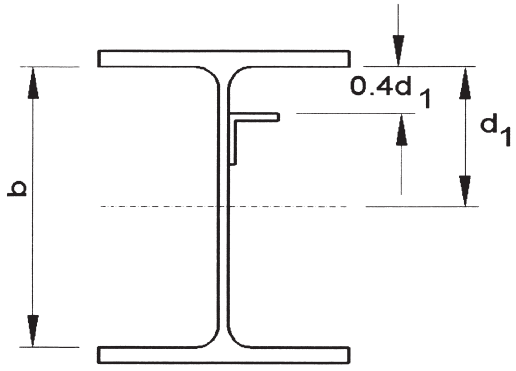



**Figure B.5.5**
**FLAT ELEMENT WITH A LONGITUDINAL STIFFENER**

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

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

where (see Figure B.5.5)

$A_L$ = cross-sectional area of the longitudinal stiffener
$d_1$ = distance from the neutral axis to the compression flange
$f$ = compressive stress at the toe of the flange
$b$ = clear height of the web
$s$ = distance between transverse stiffeners
$t$ = web thickness
$\alpha_s$ = 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 Flat Elements Alternate 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 strength may be determined as:

| Limit State | $F_b$ | $\lambda_{eq}$ | Slenderness Limits |
|---|---|---|---|
| yielding | $1.3F_{cy}$ | $\lambda_{eq} \le S_1$ | $S_1 = \dfrac{B_{br} - 1.3F_{cy}}{D_{br}}$ |
| inelastic buckling | $B_{br} - D_{br}\lambda_{eq}$ | $S_1 < \lambda_{eq} < S_2$ | |
| post-buckling | $\dfrac{k_2\sqrt{B_{br}E}}{\lambda_{eq}}$ | $\lambda_{eq} \ge S_2$ | $S_2 = \dfrac{k_1 B_{br}}{D_{br}}$ |



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

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

Note: $\lambda_s$ is determined from equation B.5-10



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# Chapter C Design for Stability

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

## C.1 General Stability Requirements

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

## C.2 Calculation of Required Strengths

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

1) Flexural, shear, and axial deformations, including all member and connection deformations that contribute to displacements of the structure;
2) Second-order effects including $P$-$\Delta$ effects (the effect of loads acting on the displaced location of joints or nodes in a structure) and $P$-$\delta$ 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 $\tau_b$ 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 $\alpha P_r/P_y \le 0.5$

   $\tau_b = 4(\alpha P_r/P_y)(1 - \alpha P_r/P_y)$ 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 gravity loads, including loads on elements that are not part of the lateral load-resisting system. 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 shall be taken as 1.

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



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# Chapter D Design of Members for Tension

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

## D.1 General Provisions

The design tensile strength $\phi_t P_n$ and the allowable tensile strength $P_n/\Omega_t$ of tension members shall be determined in accordance with chapter D where

| Limit State | $\phi_t$ building-type structures | $\Omega_t$ building-type structures | $\Omega_t$ 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 $P_n$ of tension members shall be determined as follows.

a) For tensile yielding in the gross section:

For unwelded members and members with transverse welds

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

For members with longitudinal welds

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

b) For tensile rupture in the net section:

For unwelded members

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

For welded members

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

Block shear rupture strength for the end connections of tension members is given in Section J.6.3.

## 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 $\frac{1}{32}$ 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, 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 net effective 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



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

## E.1 General Provisions

The design compressive strength $\phi_c P_n$ and the allowable compressive strength $P_n/\Omega_c$ are the least value for the limit states of member buckling (E.3), local buckling (E.4), and the interaction between member buckling and local buckling (E.5), where

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

Buckling constants are given in Tables B.4.1, B.4.2, and B.4.3. For weld-affected members see Section E.6.

## E.2 Effective Length

The effective length factor $k$ for calculating column slenderness $kL/r$ shall be determined in accordance with Section C.3.

## E.3 Member Buckling

The nominal member buckling strength $P_n$ is

$$P_n = F_c A_g \qquad \text{(E.3-1)}$$

where

$$\text{for } kL/r < S_2,\ F_c = 0.85(B_c - D_c\, kL/r) \le F_{cy} \qquad \text{(E.3-2)}$$

$$\text{for } kL/r \ge S_2,\ F_c = \frac{0.85\,\pi^2 E}{\left(\frac{kL}{r}\right)^2} \qquad \text{(E.3-3)}$$

$kL/r$ = greatest column slenderness determined from Sections E.3.1 and E.3.2.

$$S_2 = C_c \qquad \text{(E.3-4)}$$

### E.3.1 Flexural Buckling

For flexural buckling, $kL/r$ is the largest slenderness ratio of the column.

### E.3.2 Torsional and Flexural-Torsional Buckling

For torsional or flexural-torsional buckling, $kL/r$ is the larger of the slenderness ratio for flexural buckling and the equivalent slenderness ratio determined as follows:

$$\left(\frac{kL}{r}\right)_e = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(E.3-5)}$$

where $F_e$ is the elastic buckling stress determined as follows:

a) For doubly symmetric members:

$$F_e = \left(\frac{\pi^2 E C_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y} \qquad \text{(E.3-6)}$$

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

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H}\right)\left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}}\right] \qquad \text{(E.3-7)}$$

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

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0 \qquad \text{(E.3-8)}$$

where

$$r_o^2 = x_o^2 + y_o^2 + \frac{I_x + I_y}{A_g} \qquad \text{(E.3-9)}$$

$$H = 1 - \frac{x_o^2 + y_o^2}{r_o^2} \qquad \text{(E.3-10)}$$

$$F_{ex} = \frac{\pi^2 E}{\left(\frac{k_x L_x}{r_x}\right)^2} \qquad \text{(E.3-11)}$$

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_y}{r_y}\right)^2} \qquad \text{(E.3-12)}$$

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) \qquad \text{(E.3-13)}$$

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

## E.4 Local Buckling

For members without welds, the local buckling strength shall be determined in accordance with either Section E.4.1 or E.4.2. For members with welds, the local buckling strength shall be determined in accordance with Section E.4.1.



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### E.4.1 Weighted Average Local Buckling Strength

The weighted average local buckling strength is

$$P_n = \sum_{i=1}^{n} F_{ci} A_i + F_{cy}\left(A_g - \sum_{i=1}^{n} A_i\right) \qquad \text{(E.4-1)}$$

where

$F_{ci}$ = local buckling stress of element $i$ computed per Sections B.5.4.1 through B.5.4.5.
$A_i$ = area of element $i$

### E.4.2 Alternate Local Buckling Strength

As an alternate to Section E.4.1, the local buckling strength of a shape composed of flat elements may be determined as:

$$P_n = F_c A_g \qquad \text{(E.4-2)}$$

where $F_c$ is determined in accordance with Section B.5.4.6.

## E.5 Interaction Between Member Buckling and Local Buckling

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

$$P_n = \left[\frac{0.85\pi^2 E}{(kL/r)^2}\right]^{1/3} F_e^{2/3} A_g \qquad \text{(E.5-1)}$$

If the local buckling strength is determined from Section E.4.1, $F_e$ is the smallest elastic local buckling stress for all elements of the cross section according to Table B.5.1.

If the local buckling strength is determined from Section E.4.2, $F_e$ is the elastic local buckling stress of the cross section determined by analysis.

## E.6 Welded Compression Members

### E.6.1 Compression Members with Transverse Welds

The nominal member buckling strength of a member supported at both ends with no transverse weld farther than $0.05L$ from the member ends shall be calculated as if there were no welds.

The nominal member buckling strength of a member supported at both ends with a transverse weld farther than $0.05L$ from the member ends and a member supported at only one end with a transverse weld shall be calculated as if the entire cross sectional area were weld-affected.

For tubes with circumferential welds, Section B.5.4.5 only applies if $R_b/t \le 20$.

### E.6.2 Compression Members with Longitudinal Welds

The nominal member buckling strength $P_n$ of members with longitudinal welds is

$$P_n = P_{no}\,(1 - A_{wz}/A_g) + P_{nw}\,(A_{wz}/A_g) \qquad \text{(E.6-1)}$$

where

$P_{no}$ = nominal member buckling strength 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 mechanical properties from Table A.3.4 or Table A.3.4M.
$P_{nw}$ = nominal member buckling strength if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and mechanical properties from Table A.3.5 or Table A.3.5M.



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This chapter addresses members subjected to bending that are either

a) loaded in a plane parallel to a principal axis that passes through the shear center, or
b) restrained against rotation about their longitudinal axis at load points and supports.

## F.1 General Provisions

The design flexural strength $\phi_b M_n$ and allowable flexural strength $M_n/\Omega_b$ shall be determined in accordance with Chapter F, where $M_n$ = nominal flexural strength, and

| Limit State | $\phi_b$ building-type structures | $\Omega_b$ building-type structures | $\Omega_b$ bridge-type structures |
|---|---|---|---|
| tensile rupture | 0.75 | 1.95 | 2.20 |
| other flexural limit states | 0.90 | 1.65 | 1.85 |

Buckling constants are given in Tables B.4.1, B.4.2, and B.4.3. For weld-affected members see Section F.9.

### F.1.1 Bending Coefficient $C_b$

a) Members supported on both ends: For members subjected to uniform bending moment, the bending coefficient $C_b = 1$. For other members, $C_b$ shall be taken as 1 or determined in accordance with Section F.1.1.1 or F.1.1.2.
b) Cantilevers: $C_b$ shall be determined in accordance with Section F.1.1.1.

#### F.1.1.1 Doubly Symmetric Shapes

For doubly symmetric shapes between brace points

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C} \qquad \text{(F.1-1)}$$

where

$M_{\max}$ = absolute value of the maximum moment in the unbraced segment
$M_A$ = absolute value of the moment at the quarter point of the unbraced segment
$M_B$ = absolute value of the moment at the midpoint of the unbraced segment
$M_C$ = absolute value of the moment at the three-quarter point of the unbraced segment

For doubly symmetric shape cantilevers unbraced at the free end, $C_b$ shall be determined as follows:

| Loading | $C_b$ |
|---|---|
| Concentrated load applied at the centroid at the free end | 1.3 |
| Uniform transverse load applied at the centroid | 2.1 |

#### F.1.1.2 Singly Symmetric Shapes

For singly symmetric shapes between brace points

a) If $I_{cy}/I_y \le 0.1$ or $I_{cy}/I_y \ge 0.9$, $C_b = 1.0$
b) If $0.1 < I_{cy}/I_y < 0.9$, $C_b$ shall be determined using Equation F.1-1.

If $M_{\max}$ produces compression on the larger flange and the smaller flange is also subjected to compression in the unbraced length, the member shall be checked at the location of $M_{\max}$ using $C_b$ determined using Equation F.1-1 and at the location where the smaller flange is subjected to its maximum compression using $C_b = 1.67$.

## F.2 Open Shapes

For open shapes subject to lateral-torsional buckling, the nominal flexural strength shall be determined using Sections F.2.1, F.2.3, and F.8. For open shapes not subject to lateral-torsional buckling, the nominal flexural strength shall be determined using Section F.8. For single angles, the nominal flexural strength shall be determined using Section F.5.

### F.2.1 Lateral-Torsional Buckling

For the limit state of lateral-torsional buckling, the nominal flexural strength is $M_n = F_b S_c$ where the lateral-torsional buckling stress $F_b$ is:

| Limit State | $F_b$ | $\frac{L_b}{r_{ye}\sqrt{C_b}}$ | Slenderness Limits |
|---|---|---|---|
| inelastic buckling | $B_c - \frac{D_c L_b}{1.2 r_{ye}\sqrt{C_b}}$ | $\frac{L_b}{r_{ye}\sqrt{C_b}} < S_2$ | $S_2 = 1.2C_c$ |
| elastic buckling | $\frac{\pi^2 E}{\left(\frac{L_b}{1.2 r_{ye}\sqrt{C_b}}\right)^2}$ | $\frac{L_b}{r_{ye}\sqrt{C_b}} \ge S_2$ | |

$r_{ye}$ shall be $r_y$ or determined from Section F.2.2.

### F.2.2 Effective Radius of Gyration $r_{ye}$

#### F.2.2.1 Shapes Symmetric About the Bending Axis

For shapes symmetric about the bending axis:

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

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{I_y d}{S_c}}\sqrt{1 + 0.152\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2} \qquad \text{(F.2-1)}$$

b) Between brace points of beams subjected to transverse loads applied on the top or bottom flange (where the



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load is free to move laterally with the beam if the beam buckles):

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{I_y d}{S_c}\left[\pm 0.5 + \sqrt{1.25 + 0.152\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right]} \qquad \text{(F.2-2)}$$

0.5 is negative when the load acts toward the shear center and positive when the load acts away from the shear center.

where

The $y$-axis is the centroidal symmetry or principal axis that is parallel to the web.

$I_y$ = moment of inertia about the $y$-axis
$S_c$ = section modulus, compression side
$d$ = depth of the beam

### F.2.2.2 Singly Symmetric Shapes Unsymmetric about the Bending Axis

For singly symmetric shapes unsymmetric about the bending axis, calculate $r_{ye}$ by either:

a) using Section F.2.2.1 with $I_y$, $S_c$ and $J$ determined as though both flanges were the same as the compression flange with the overall depth $d$ remaining the same, or
b) using Section F.2.2.3.

### F.2.2.3 Shapes Unsymmetric about the Bending Axis

For shapes unsymmetric about the bending axis and with:

a) braces on both ends, and
b) loading that does not cause torsion or lateral bending (if the loading causes torsion or lateral bending, apply Section H.3):

$$r_{ye} = \frac{L_b}{1.2\pi}\sqrt{\frac{M_e}{ES_c}} \qquad \text{(F.2-3)}$$

where

$$M_e = A_g F_{ey}\left[U + \sqrt{U^2 + r_o^2\left(\frac{F_{ez}}{F_{ey}}\right)}\right] \qquad \text{(F.2-4)}$$

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

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_b}{r_y}\right)^2} \qquad \text{(F.2-5)}$$

$k_y$ = effective length factor for the compression flange about the $y$-axis. $k_y$ shall not be less than 1.0.

$$U = C_1 g_0 - C_2 j \qquad \text{(F.2-6)}$$

$C_1$ and $C_2$: if the moment varies linearly between the ends of the unbraced segment $C_1 = 0$ and $C_2 = 1$. For simply supported singly symmetric shapes with $0.1 < I_{cy}/I_y < 0.9$:

a) For a uniformly distributed load over the entire span, $C_b = 1.13$, $C_1 = 0.41C_b$, and $C_2 = 0.47C_b$.
b) For a concentrated load at a distance $aL$ from one end of the span,
   $C_b = 1.75 - 1.6a(1 - a)$
   $C_1 = C_b \sin^2\pi a/[a(1 - a)\pi^2]$
   $C_2 = (C_b - C_1)/2$
c) For two symmetric concentrated loads at a distance $aL$ from each end of the span,
   $C_b = 1 + 2.8a^3$
   $C_1 = 2C_b \sin^2\pi a/(a\pi^2)$
   $C_2 = (1 - a)C_b - C_1/2$

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

$$j = \frac{1}{2I_x}\left(\int_A y^3 dA + \int_A yx^2 dA\right) - y_0 \qquad \text{(F.2-7)}$$

For singly symmetric I shapes, as an alternative to Equation F.2-7,

$$j = 0.45 d_f\left(\frac{2I_{cy}}{I_y} - 1\right)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right] \qquad \text{(F.2-8)}$$

where

$I_{cy}$ = moment of inertia of the compression flange about the $y$-axis
$d_f$ = the distance between the flange centroids; for tees $d_f$ is the distance between the flange centroid and the tip of the stem.

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

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) \qquad \text{(F.2-9)}$$

$L_z$ = unbraced length for twisting
$k_z$ = effective length factor for torsional buckling

$$r_o = \sqrt{r_x^2 + r_y^2 + x_o^2 + y_o^2} \qquad \text{(F.2-10)}$$

= polar radius of gyration of the cross section about the shear center
$r_x$, $r_y$ = radii of gyration of the cross section about the centroidal principal axes
$x_o$ = the shear center's $x$-coordinate
$y_o$ = the shear center's $y$-coordinate



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