SECTION 7: ALUMINUM STRUCTURES

TABLE OF CONTENTS

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SECTION 7

ALUMINUM STRUCTURES

Commentary is opposite the text it annotates.

7.1—SCOPE

This Section covers the design of aluminum components and connections for beam and girder structures, and metal deck systems. Horizontally curved girders and non-redundant structures are not addressed.

C7.1

In highway bridges, aluminum is usually used in conjunction with other materials such as steel or concrete. This Section addresses the design of the aluminum components; the Designer should use other Sections for the design of components of other materials.

Many of the provisions in this Section are based on the *Specification for Aluminum Structures*, published by the Aluminum Association as Part I of the 2015 *Aluminum Design Manual* (AA, 2015).

7.2—DEFINITIONS

The provisions of Article 6.2 apply to terms used in this Section that are not defined below.

Beam—A structural member whose primary function is to transmit loads to the support primarily through flexure and shear.

Clear Distance of Bolts—The distance between the edges of adjacent bolt holes.

Closed Shape—A hollow shape that resists lateral–torsional buckling primarily by torsional resistance rather than warping resistance.

Column—A structural member that has the primary function of resisting a compressive axial force.

Element—A part of a shape's cross-section that is rectangular in cross-section or of constant curvature and thickness. Elements are connected to other elements only along their longitudinal edges. An I-beam, for example, consists of five elements, which include a web element and two elements in each flange.

Longitudinal Weld—A weld whose axis is parallel to the member's length axis.

Plate—A flat, rolled product whose thickness equals or exceeds 0.250 in.

Transverse Weld—A weld whose axis is perpendicular to the member's length axis.

Weld-Affected Zone—Material within 1.0 in. of the centerline of a weld.

7.3—NOTATION

$(ADTT)_{SL}$ = single lane ADTT as specified in Article 3.6.1.4.2 (7.6.2.5)
A_e = effective net area of the member (in.^{2}) (7.8.2.1)
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 (in.^{2}) (7.10.4)
A_g = gross cross-sectional area (in.^{2}) (7.5.4.4.1)
A_{gc} = gross area of the element in compression (in.^{2}) (7.5.4.5.1)
A_{gt} = gross area in tension (in.^{2}) (7.12.4)
A_{gv} = gross area in shear (in.^{2}); gross area of the connection element subject to shear (in.^{2}) (7.12.4) (7.12.5.3)
A_i = area of element i (in.^{2}) (7.9.2.2.2)
A_L = cross-sectional area of the longitudinal stiffener (in.^{2}) (7.5.4.5.4)
A_n = net area of the web (in.^{2}); net area of the pipe or tube (in.^{2}); net area of the member at the connection (in.^{2}) (7.5.4.6.2) (7.5.4.6.4) (7.8.2.2)
A_{nt} = net area in tension (in.^{2}) (7.12.4)
A_{nv} = net area in shear (in.^{2}); net area of the connection element subject to shear (in.^{2}) (7.12.4) (7.12.5.3)
A_s = area of the stiffener (in.^{2}) (7.5.4.4.5)
A_v = shear area (in.^{2}) (7.5.4.6.1)
A_w = area of the web (in.^{2}) (7.5.4.6.2)

A_{wz} = cross-sectional area of the weld-affected zone (in.^{2}); weld-affected area of the web (in.^{2}); weld-affected area of the pipe or tube (in.^{2}); weld-affected 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 (in.^{2}) (7.5.4.4.1) (7.5.4.6.2) (7.5.4.6.4) (7.10.4)

A_{wzc} = cross-sectional area of the weld-affected zone in compression (in.^{2}) (7.5.4.5.1)

a_1 = the lesser of the clear height of the web and the distance between stiffeners (in.) (7.5.4.6.2)

a_2 = the greater of the clear height of the web and the distance between stiffeners (in.) (7.5.4.6.2)

B = buckling constant intercept (ksi) (7.5.4.3)

b = clear height of web (in.); clear height of the web for webs without transverse stiffeners (in.); distance from the unsupported edge to the mid-thickness of the supporting element (in.) (7.5.4.5.4) (7.5.4.6.2) (7.5.4.6.3)

C = buckling constant intersection (7.5.4.3)

C_b = bending coefficient (7.10.4.1)

C_f = constant taken from Table 7.6.2.5-1 (ksi) (7.6.2.5)

C_w = warping constant (in.^{6}) (7.9.2.1.3)

C_{wa} = web crippling parameter (7.11.2.1)

C_{wb} = web crippling parameter (7.11.2.1)

c = distance from the neutral axis to the extreme compression fiber (in.) (7.10.4)

c_c = distance from neutral axis to the element extreme fiber with the greatest compressive stress (in.) (7.5.4.5.2)

c_{cf} = distance from the centerline of a uniform compression element to the cross-section's neutral axis (in.) (7.10.3.1)

c_{cs} = distance from the cross-section's neutral axis to the extreme fiber of uniform compression element (in.) (7.10.3.1)

c_{cw} = distance from a flexural compression element's extreme compression fiber to the cross-section's neutral axis (in.) (7.10.3.1)

c_o = distance from neutral axis to other extreme fiber of the element (in.) (7.5.4.5.2)

D = buckling constant slope (ksi); nominal diameter of the bolt (in.); nominal diameter of the pin (in.) (7.5.4.3) (7.12.2.9) (7.12.7.4)

D_S = clear length of the stiffener (in.) (7.5.4.4.4)

d = full depth of the section (in.); depth of the beam (in.); dimension of the bar in the plane of flexure (in.); member depth (in.) (7.5.4.6.2) (7.10.4.2.1) (7.10.4.2.4) (7.11.2.1)

d_e = distance from the center of the bolt to the edge of the part in the direction of force (in.); distance from the center of the pin to the edge of the part in the direction of force (in.) (7.12.2.9) (7.12.7.6)

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 (in.) (7.10.4.2.5)

d_s = the stiffener's flat width (in.) (7.5.4.4.4)

d_1 = distance from the neutral axis to the compression flange (in.) (7.5.4.5.4)

E = modulus of elasticity (ksi) (7.4.1)

F_b = stress corresponding to the resistance of an element in flexural compression (ksi) (7.10.3.1)

F_c = compressive buckling stress (ksi); stress corresponding to the resistance of an element in uniform compression (ksi) (7.9.2.1.1) (7.10.3.1)

F_{cy} = compressive yield strength (ksi) (7.4.1)

F_e = elastic local buckling stress of the cross-section determined by rational analysis (ksi); elastic buckling stress (ksi) (7.5.4.4.7) (7.5.4.7)

F_{nb} = stress corresponding to the flexural resistance of elements (ksi) (7.5.4.5.1)

F_{nbo} = stress corresponding to the flexural compressive resistance calculated using Articles 7.5.4.5.2 through 7.5.4.5.4 for an element if no part of the cross-section is weld-affected (ksi) (7.5.4.5.1)

F_{nbw} = stress corresponding to the flexural compressive resistance calculated using Articles 7.5.4.5.2 through 7.5.4.5.4 for an element if the entire cross-section is weld-affected (ksi) (7.5.4.5.1)

F_{nc} = stress corresponding to the uniform compression resistance of elements (ksi) (7.5.4.4.1)

F_{nci} = nominal local buckling resistance of element i computed per Articles 7.5.4.4.1 through 7.5.4.4.6 (ksi) (7.9.2.2.2)

F_{nco} = stress corresponding to the uniform compression resistance calculated using Articles 7.5.4.4.2 through 7.5.4.4.6 for an element if no part of the cross-section is weld-affected (ksi) (7.5.4.4.1)

F_{ncw} = stress corresponding to the uniform compression resistance calculated using Articles 7.5.4.4.2 through 7.5.4.4.6 for an element if the entire cross-section is weld-affected (ksi) (7.5.4.4.1)

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F_{nso} = shear stress corresponding to the shear resistance for an element if no part of the cross-section is weld-affected (ksi) (7.5.4.6.1)
F_{nST} = stress corresponding to the uniform compression resistance calculated in Article 7.5.4.4.4 (ksi) (7.5.4.4.4)
F_{nsw} = shear stress corresponding to the shear resistance for an element if the entire cross-section is weld-affected (ksi) (7.5.4.6.1)
F_{nUT} = stress corresponding to the uniform compression resistance calculated using Article 7.5.4.4.2 (ksi) (7.5.4.4.4)
F_{su} = shear ultimate strength (ksi); shear ultimate strength of the connection element (ksi) (7.4.1) (7.12.5.3) (7.12.7.4)
F_{suw} = shear ultimate strength in the weld-affected zone (ksi); lesser of the welded shear ultimate strengths of the base metals and the filler (ksi); shear ultimate strength of the filler taken as $0.5F_{tuw}$ (ksi); welded shear ultimate strength of the base metal (ksi) (7.5.4.6.1) (7.12.3.2.2b) (7.12.3.2.3b)
F_{sw} = fillet weld strength (kips/in.) (7.12.3.2.4)
F_{sy} = shear yield strength (ksi); shear yield strength of the connection element; shear yield strength of the pin (7.4.1) (7.12.5.3) (7.12.7.4)
F_{syw} = shear yield strength in the weld-affected zone (ksi) (7.12.5.3)
F_{tu} = specified minimum tensile ultimate strength (ksi); tensile ultimate strength of the connected part (ksi); tensile ultimate strength of the pin (7.4.1) (7.12.2.9) (7.12.7.5)
F_{tuw} = tensile ultimate strength in the weld-affected zone (ksi); lesser of the welded tensile strengths of the base metals and the filler (ksi); tensile ultimate strength of the filler (ksi) (7.4.1) (7.12.3.2.2a) (7.12.3.2.3a)
F_{ty} = specified minimum tensile yield strength (ksi) (7.4.1)
F_{tyw} = tensile yield strength in the weld-affected zone (ksi) (7.4.1)
$F_{tyw6061}$ = tensile yield strength in the weld-affected zone of 6061 (ksi) (7.4.1)
f = compressive stress at the toe of the flange (ksi) (7.5.4.5.4)
G = shear modulus of elasticity (ksi) (7.4.1)
g = transverse center-to-center distance (gauge) between two holes (in.) (7.8.3)
g_0 = distance from the shear center to the point of application of the load (7.10.4.2.5)
I_f = moment of inertia of the uniform stress elements about the cross-section's neutral axis (7.10.3.1)
I_L = moment of inertia of the longitudinal stiffener about the web of the beam (in.^{4}) (7.5.4.5.4)
I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent subelements and the transition corners between them taken about the centroidal axis of the section parallel to the stiffened element (in.^{4}) (7.5.4.4.5)
I_s = moment of inertia of transverse stiffener (in.^{4}) (7.5.4.6.2)
I_w = moment of inertia of the flexural compression elements about the cross-section's neutral axis (in.^{4}) (7.10.3.1)
I_x = moment of inertia about the strong axis (in.^{4}) (7.9.2.1.3)
I_y = moment of inertia about the weak axis (in.^{4}); moment of inertia about the *y*-axis (in.^{4}) (7.9.2.1.3) (7.10.4.2.1)
I_{yc} = moment of inertia of the compression flange about the *y*-axis (in.^{3}) (7.10.4.2.5)
J = torsion constant (in.^{4}) (7.10.4.2)
K = effective length factor specified in Article 4.6.2.5 (7.9.2.1.1)
k_1 = postbuckling constant (7.5.4.3)
k_2 = postbuckling constant (7.5.4.3)
L = member length (in.) (7.9.2.1.1)
L_b = unbraced length (in.) (7.10.4.2.1)
L_v = length of tube from maximum to zero shear force (in.) (7.5.4.6.4)
l = unbraced length (in.) (7.8.4)
M_A = absolute value of the moment at the quarter point of the unbraced segment (kip-in.) (7.10.4.1.1)
M_B = absolute value of the moment at the midpoint of the unbraced segment (kip-in.) (7.10.4.1.1)
M_C = absolute value of the moment at the three-quarter point of the unbraced segment (kip-in.) (7.10.4.1.1)
M_e = elastic lateral–torsional buckling moment determined by analysis (7.10.4.2.5)
M_{max} = absolute value of the maximum moment in the unbraced segment (kip-in.) (7.10.4.1.1)
M_n = nominal flexural resistance of the pin (7.12.7.1)
M_{rx} = factored flexural resistance about the major principal axis (kip-in.) (7.8.2.3)
M_{ry} = factored flexural resistance about the minor principal axis (kip-in.) (7.8.2.3)
M_u = moment in the member at the location of the concentrated force resulting from factored loads (kip-in.); moment on the pin due to the factored loads (k-in) (7.11.2.3) (7.12.7.7)

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M_{ux} = moment about the major principal axis resulting from the factored loads (kip-in.) (7.8.2.3)
M_{uy} = moment about the minor principal axis resulting from the factored loads (kip-in.) (7.8.2.3)
m = factor for determining the flexural compressive resistance of flat elements; constant taken from Table 7.6.2.5-1 (7.5.4.5.2) (7.6.2.5)
N = length of the bearing surface at the concentrated force (in.) (7.11.2.1)
n = number of stress range cycles per truck taken from Table 6.6.1.2.5-2 (7.6.2.5)
P_n = nominal axial compressive resistance (kip) (7.9.2)
P_{no} = nominal member buckling resistance if no part of the cross-section is weld-affected (kip) (7.9.2.1.1)
P_{nu} = nominal resistance for tensile rupture (kip) (7.8.2.1)
P_{nw} = nominal member buckling resistance if the entire cross-section is weld-affected (kip) (7.9.2.1.1)
P_{ny} = nominal resistance for tensile yield (kip) (7.8.2.1)
P_{rc} = factored axial compression resistance (kip) (7.9.2)
P_{rt} = factored axial tension resistance (kip) (7.8.2.1)
P_u = shear force on the pin due to the factored loads (kip) (7.12.7.7)
P_{uc} = axial compression resulting from the factored loads (kip) (7.9.4)
P_{ut} = axial tension resulting from the factored loads (kip) (7.8.2.3)
R = transition radius of an attachment (in.) (7.6.2.3)
R_b = mid-thickness radius of a round tube or maximum mid-thickness radius of oval tube (in.) (7.5.4.4.6)
R_i = for extruded shapes, $R_i = 0$; for all other shapes, R_i = inside bend radius at the juncture of the flange and web (in.) (7.11.2.1)
R_n = nominal resistance to a concentrated force (kip); nominal resistance of a bolt, connection, or connected material (kip); nominal shear resistance of the pin (kip) (7.11.2.1) (7.12.2.2) (7.12.7.7)
R_r = factored resistance to a concentrated force (kip); factored resistance of a bolt, connection, or connected material (kip); nominal shear resistance of the pin or connected material (7.11.2.1) (7.12.3.2.2a) (7.12.7.1)
R_S = ratio of minimum stress to maximum stress (7.6.2.3)
R_u = concentrated force resulting from factored loads (kip) (7.11.2.3)
r = radius of gyration (in.) (7.8.4)
r_s = the stiffener's radius of gyration about the stiffened element's mid-thickness (in.) (7.5.4.4.4)
r_x = major axis radius of gyration (in.) (7.9.2.1.3)
r_y = minor axis radius of gyration (in.) (7.9.2.1.3)
r_{ye} = effective minor axis radius of gyration (in.) (7.10.4.2.1)
r_0 = polar radius of gyration about the shear center (in.) (7.9.2.1.3)
S_c = section modulus on the compression side of the neutral axis (in.^{3}) (7.10.2)
S_t = section modulus on the tension side of the neutral axis (in.^{3}) (7.10.2)
S_w = fillet weld size (in.) (7.12.3.2.4)
S_x = section modulus about the x-axis (in.^{3}) (7.10.4.2.1)
s = distance between transverse stiffeners (in.); longitudinal center-to-center distance (pitch) between two holes (in.) (7.5.4.5.4) (7.8.3)
T_n = nominal tensile resistance of bolt (kip) (7.12.2.2)
T_r = factored tensile resistance of bolt (kip) (7.12.2.2)
t = thickness of web, tube, or pin-connected part (in.); dimension of the bar perpendicular to the plane of flexure (in.); for plain holes, thickness of the connected part; for countersunk holes, thickness of the connected part less ½ the countersink depth (in.) (7.4.1) (7.10.4.2.4) (7.12.2.9)
U = reduction factor to account for shear lag taken as given in Article 6.8.2.1 (7.8.2.2)
V = shear force on the web at the transverse stiffener (kip) (7.5.4.6.2)
V_n = nominal shear resistance (kip) (7.5.4.6.1)
x_0 = x-coordinate of the shear center with respect to the centroid (in.) (7.9.2.1.3)
y_0 = y-coordinate of the shear center with respect to the centroid (in.); the shear center's y-coordinate (in.) (7.9.2.1.3) (7.10.4.2.5)
Z = plastic modulus (in.^{3}) (7.10.2)
α = thermal coefficient of expansion (in./in./°F) (7.4.1)
α_s = factor for a longitudinal web stiffener (7.5.4.5.4)
γ = load factor specified in Table 3.4.1-1 for the fatigue load combination (7.6.2.2)
$(\Delta F)_n$ = nominal fatigue resistance as specified in Article 7.6.2.5 (ksi) (7.6.2.2)
$(\Delta F)_{TH}$ = constant amplitude threshold taken from Table 7.6.2.5-1 (ksi) (7.6.2.5)

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(Δf)	=	force effect, live load stress range due to the passage of the fatigue load as specified in Article 3.6.1.4 (ksi) (7.6.2.2)
θ_s	=	angle between the stiffener and the stiffened element (7.5.4.4.4)
θ_w	=	angle between the plane of web and the plane of the bearing surface ($\theta_w \leq 90°$) (7.11.2.1)
λ	=	axial slenderness ratio; lateral torsional buckling slenderness (7.9.2.1.1) (7.10.4)
λ_e	=	slenderness boundary for the effectiveness of edge stiffeners (7.5.4.4.4)
λ_{eq}	=	slenderness ratio of a shape corresponding to the elastic local buckling stress (7.5.4.4.7)

7.4—MATERIALS

7.4.1—Aluminum Alloys

Aluminum extrusions shall conform to the requirements of Table 7.4.1-1. Aluminum sheet and plate shall conform to the requirements of Table 7.4.1-2. Design shall be based on the strength and stiffness properties given in Tables 7.4.1-1, 7.4.1-2, and 7.4.1-3. For 6061 parts of any thickness welded with 5183, 5356, or 5556 filler and parts 0.375 in. thick or less when welded with 4043 filler, $F_{tyw6061}$ shall be taken as 15 ksi; for 6061 parts thicker than 0.375 in. when welded with 4043 filler, $F_{tyw6061}$ shall be taken as 11 ksi.

C7.4.1

The strengths given in Tables 7.4.1-1 and 7.4.1-2 are:

- The specified minimum tensile ultimate strength, F_{tu}, and the tensile yield strength, F_{ty}, are the minimum strengths specified in ASTM B209, B221, and B928.
- The welded minimum tensile ultimate strength F_{tuw}, is the qualification strength required by AWS D1.2/D1.2M, *Structural Welding Code—Aluminum* (AWS, 2014), hereafter referred to as "AWS D1.2/D1.2M."
- The welded tensile yield strength, F_{tyw}, is taken from the *Aluminum Design Manual* (AA, 2015).

The modulus of elasticity and coefficient of thermal expansion vary slightly among aluminum alloys; the values given here are conservative. The relationship between shear yield strength and tensile yield strength and between shear ultimate strength and tensile ultimate strength are based on the von Mises yield criterion.

Some aluminum alloys are notch-sensitive, and in the *Aluminum Design Manual* (AA, 2015) their tensile rupture strengths are divided by a tension coefficient, k_t, which is greater than one. The aluminum alloys included in Tables 7.4.1-1 and 7.4.1-2 are not notch-sensitive, and therefore, for these alloys, k_t is 1, and thus the k_t factor is not included in the expressions for tensile strength given in this Specification. Aluminum castings are not included in this Specification because their fatigue strengths have not been established and their use in highway bridges is rare.

The properties given in Article 7.4.1 apply to material held at temperatures of 200°F or less for any period of time. Aluminum's strength and modulus of elasticity decrease at temperatures above 200°F, and the decrease in strength remains after returning to ambient temperature after heating above 200°F.

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Table 7.4.1-1—Minimum Mechanical Properties of Aluminum Extrusions

ASTM Specification	B221	B221	B221	B221	B221	B221
Alloy-Temper	6005A-T61	6061-T6, T6510, T6511	6063-T5	6063-T5	6063-T6	6082-T6, T6511
Thickness t (in.)	$t \le 1.000$	All	$t \le 0.500$	$0.500 < t \le 1.000$	All	$0.200 \le t \le 6.000$
F_{tu} (ksi)	38	38	22	21	30	45
F_{ty} (ksi)	35	35	16	15	25	38
F_{tuw} (ksi)	24	24	17	17	17	28
F_{tyw} (ksi)	13	$F_{tyw6061}$	8	8	8	16
Unwelded C_t	141	141	275	290	189	131
Welded C_t	446	389	715	715	715	366

Table 7.4.1-2—Minimum Mechanical Properties of Aluminum Sheet and Plate

ASTM Specification	B209	B209	B928	B928	B928	B209
Alloy-Temper	5052-H32	5052-H34	5083-H116, H321	5083-H116, H321	5086-H116	6061-T6, T651
Thickness t (in.)	$t \le 2.000$	$t \le 1.000$	$t \le 1.500$	$1.500 < t \le 3.000$	$t \le 2.000$	$t \le 6.000$
F_{tu} (ksi)	31	34	44	41	40	42
F_{ty} (ksi)	23	26	31	29	28	35
F_{tuw} (ksi)	25	25	40	39	35	24
F_{tyw} (ksi)	9.5	9.5	18	17	14	$F_{tyw6061}$
Unwelded C_t	284	250	235	254	235	141
Welded C_t	608	608	336	532	427	389

Table 7.4.1-3—Aluminum Properties

Modulus of elasticity	E	10,100 ksi
Shear modulus of elasticity	G	3800 ksi
Poisson's ratio	υ	0.33
Thermal coefficient of expansion	α	13×10^{-6} in./in./°F
Compressive yield strength for unwelded tempers beginning with H	F_{cy}	$0.9F_{ty}$
Compressive yield strength for all other material	F_{cy}	F_{ty}
Shear yield strength	F_{sy}	$0.6F_{ty}$
Shear ultimate strength	F_{su}	$0.6F_{tu}$

7.4.2—Pins, Rollers, and Rockers

Pins, rollers, and expansion rockers shall conform to one of the following:

- Steel pins, rollers, and expansion rockers shall conform to Article 6.4.2 and shall be galvanized.
  Aluminum pins, rollers, and expansion rockers shall conform to Article 7.4.1.

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7.4.3—Bolts, Nuts, and Washers

7.4.3.1—Bolts

High-strength bolts used as structural fasteners shall conform to ASTM F3125. The specified minimum tensile strengths of ASTM F3125 bolts shall be taken as specified in Table 6.4.3.1.1-1.

Corrosion-resistant coatings may be applied to Grade A325, F1852, and A490 bolts, as specified in ASTM F3125.

Anchor bolts shall conform to ASTM F1554. Anchor bolts and nuts shall conform to Article 6.4.3.3.

7.4.3.2—Nuts Used with ASTM F3125 Bolts

Nuts used with ASTM F3125 bolts shall be as listed in ASTM F3125 as recommended or suitable for the bolt.

7.4.3.3—Washers Used with ASTM F3125 Bolts

Hardened washers used with ASTM F3125 bolts shall be as listed in ASTM F3125 as recommended or suitable for the bolts.

7.4.3.4—Direct Tension Indicators

Direct tension indicators (DTIs) conforming to the requirements of ASTM F959 may be used in conjunction with bolts, nuts, and washers. DTIs shall conform to Article 6.4.3.1.4.

7.4.4—Shear Connectors

Shear connectors shall conform to Article 7.4.1 or 7.4.3.

C7.4.4

Headed aluminum shear studs are not a standard commercial product. Extruded shapes or bolts are typically used to transfer shear instead of studs.

7.4.5—Weld Metal

Weld metal shall meet the requirements of AWS D1.2/D1.2M.

C7.4.5

AWS D1.2/D1.2M requires that weld metal (fillers) meet the requirements of AWS A5.10/A5.10M, *Welding Consumables—Wire Electrodes, Wires, and Rods for Welding Aluminum and Aluminum-Alloys—Classification* (AWS, 2017g).

7.5—LIMIT STATES

7.5.1—General

The structural behavior of components made of aluminum, or aluminum in combination with other materials, shall be investigated for each stage that may be critical during construction, handling, transportation, and erection as well as during the service life of the structure of which they are part.

Structural components shall be proportioned to satisfy the requirements at strength, extreme event, service, and fatigue limit states.

7.5.2—Service Limit State

The provisions of Article 2.5.2.6 shall apply.

7.5.3—Fatigue Limit State

Components shall be investigated for fatigue as specified in Article 7.6.

The fatigue load combinations specified in Table 3.4.1-1 and the fatigue live load specified in Article 3.6.1.4 shall apply.

7.5.4—Strength Limit State

7.5.4.1—General

Strength and stability shall be considered using the applicable strength load combinations specified in Table 3.4.1-1.

7.5.4.2—Resistance Factors

Resistance factors, ϕ, for the strength limit state shall be taken as follows:

- For flexure: tensile rupture $\phi_{ft} = 0.75$
- For flexure: limit states other than rupture $\phi_f = 0.90$
- For shear or torsion rupture $\phi_{vu} = 0.75$
- For shear or torsion: limit states other than rupture $\phi_v = 0.90$
- For axial compression $\phi_c = 0.90$
- For axial tension: rupture $\phi_u = 0.75$
- For axial tension: yield $\phi_y = 0.90$
- For pins bearing on connected parts $\phi_b = 0.75$
- For bolts bearing on connected parts $\phi_{bb} = 0.75$
- For block shear rupture $\phi_{bs} = 0.75$
- For web crippling $\phi_w = 0.80$
- For weld metal and base metal at welds $\phi_e = 0.75$

7.5.4.3—Buckling Constants

Buckling constants B, D, and C shall be determined from Tables 7.5.4.3-1 and 7.5.4.3-2. Postbuckling constants k_1 and k_2 shall be determined from Table 7.5.4.3-3.

C7.5.4.3

Buckling constants are used to determine inelastic buckling strengths of aluminum structural components. Table 7.5.4.3-1 matches Table B.4.1; Table 7.5.4.3-2 matches Table B.4.2; and Table 7.5.4.3-3 matches Table B.4.3 of the *Aluminum Design Manual* (AA, 2015).

T5 and T6 are artificially aged tempers.

Table 7.5.4.3-1—Buckling Constants for Tempers Beginning with H and Weld-Affected Zones of All Tempers

Type of Stress and Member	Intercept B (ksi)	Slope D (ksi)	Intersection C
Member Buckling	$B_c = F_{cy}\left(1+\left(\frac{F_{cy}}{1000}\right)^{1/2}\right)$	$D_c = \frac{B_c}{20}\left(\frac{6B_c}{E}\right)^{1/2}$	$C_c = \frac{2B_c}{3D_c}$
Axial Compression in Flat Elements	$B_p = F_{cy}\left(1+\left(\frac{F_{cy}}{440}\right)^{1/3}\right)$	$D_p = \frac{B_p}{20}\left(\frac{6B_p}{E}\right)^{1/2}$	$C_p = \frac{2B_p}{3D_p}$
Axial Compression in Curved Elements	$B_t = F_{cy}\left(1+\left(\frac{F_{cy}}{6500}\right)^{1/5}\right)$	$D_t = \frac{B_t}{3.7}\left(\frac{B_t}{E}\right)^{1/3}$	C_t; see Tables 7.4.1-1 and 7.4.1-2
Flexural Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1+\left(\frac{F_{cy}}{340}\right)^{1/3}\right)$	$D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \frac{2B_{br}}{3D_{br}}$
Flexural Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1+\left(\frac{F_{cy}}{6500}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb}-B_t}{D_{tb}-D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\frac{F_{sy}}{240}\right)^{1/3}\right)$	$D_s = \frac{B_s}{20}\left(\frac{6B_s}{E}\right)^{1/2}$	$C_s = \frac{2B_s}{3D_s}$

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Table 7.5.4.3-2—Buckling Constants for Tempers Beginning with T5 or T6

Type of Stress and Member	Intercept B (ksi)	Slope D (ksi)	Intersection C
Member Buckling	$B_c = F_{cy}\left(1+\left(\dfrac{F_{cy}}{2250}\right)^{1/2}\right)$	$D_c = \dfrac{B_c}{10}\left(\dfrac{B_c}{E}\right)^{1/2}$	$C_c = 0.41\dfrac{B_c}{D_c}$
Axial Compression in Flat Elements	$B_p = F_{cy}\left(1+\left(\dfrac{F_{cy}}{1500}\right)^{1/3}\right)$	$D_p = \dfrac{B_p}{10}\left(\dfrac{B_p}{E}\right)^{1/2}$	$C_p = 0.41\dfrac{B_p}{D_p}$
Axial Compression in Curved Elements	$B_t = F_{cy}\left(1+\left(\dfrac{F_{cy}}{50{,}000}\right)^{1/5}\right)$	$D_t = \dfrac{B_t}{4.5}\left(\dfrac{B_t}{E}\right)^{1/3}$	C_t; see Tables 7.4.1-1 and 7.4.1-2
Flexural Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1+\left(\dfrac{F_{cy}}{340}\right)^{1/3}\right)$	$D_{br} = \dfrac{B_{br}}{20}\left(\dfrac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \dfrac{2B_{br}}{3D_{br}}$
Flexural Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1+\left(\dfrac{F_{cy}}{50{,}000}\right)^{1/5}\right)$	$D_{tb} = \dfrac{B_{tb}}{2.7}\left(\dfrac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\dfrac{B_{tb}-B_t}{D_{tb}-D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1+\left(\dfrac{F_{sy}}{800}\right)^{1/3}\right)$	$D_s = \dfrac{B_s}{10}\left(\dfrac{B_s}{E}\right)^{1/2}$	$C_s = 0.41\dfrac{B_s}{D_s}$

Table 7.5.4.3-3—Postbuckling Constants for Flat Elements

Type of Element	k_1	k_2
Flat Elements in Axial Compression for Temper Designations Beginning with H, and Weld-Affected Zones of All Tempers	0.50	2.04
Flat Elements in Axial Compression for Temper Designations Beginning with T5 or T6	0.35	2.27
Flat Elements in Flexure	0.50	2.04

7.5.4.4—Nominal Resistance of Elements in Uniform Compression

7.5.4.4.1—General

The nominal resistance of elements in uniform compression shall be taken as:

- For unwelded elements:
  $F_{nc} = F_{nco}$ (7.5.4.4.1-1)

- For welded elements:
  $F_{nc} = F_{nco}(1 - A_{wz}/A_g) + F_{ncw}\,A_{wz}/A_g$ (7.5.4.4.1-2)

where:

F_{nco} = stress corresponding to the uniform compression resistance calculated using Articles 7.5.4.4.2 through 7.5.4.4.6 for an element if no part of the cross-section is

C7.5.4.4.1

This Article matches Section B.5.4 of the *Aluminum Design Manual* (AA, 2015).

weld-affected using buckling constants for unwelded metal and unwelded strengths (ksi)

F_{ncw} = stress corresponding to the uniform compression resistance calculated using Articles 7.5.4.4.2 through 7.5.4.4.6 for an element if the entire cross-section is weld-affected using buckling constants for weld-affected zones and welded strengths (ksi). For transversely welded elements with $b/t \leq \lambda_1$, $F_{ncw} = F_{nco}$

A_{wz} = cross-sectional area of the weld-affected zone (in.^{2})

A_g = gross cross-sectional area of the element (in.^{2})

λ_1 = slenderness at the intersection of yielding and inelastic buckling

7.5.4.4.2—Flat Elements Supported on One Edge

The nominal resistance, F_{nc}, of flat elements supported on one edge shall be taken as:

- If $b/t \leq \dfrac{B_p - F_{cy}}{5.0D_p} = \lambda_1$, then

$$F_{nc} = F_{cy} \qquad (7.5.4.4.2\text{-}1)$$

- If $\dfrac{B_p - F_{cy}}{5.0D_p} < b/t < \dfrac{C_p}{5.0}$, then

$$F_{nc} = B_p - 5.0D_p\, b/t \qquad (7.5.4.4.2\text{-}2)$$

- If $b/t \geq \dfrac{C_p}{5.0}$, then

$$F_{nc} = \frac{\pi^2 E}{(5.0b/t)^2} \qquad (7.5.4.4.2\text{-}3)$$

where:

B_p, D_p, and C_p = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

C7.5.4.4.2

This Article matches Section B.5.4.1 of the *Aluminum Design Manual* (AA, 2015).

7.5.4.4.3—Flat Elements Supported on Both Edges

The stress, F_{nc}, corresponding to the uniform compression resistance of flat elements supported on both edges shall be taken as:

- If $b/t \leq \dfrac{B_p - F_{cy}}{1.6D_p} = \lambda_1$, then

$$F_{nc} = F_{cy} \qquad (7.5.4.4.3\text{-}1)$$

- If $\dfrac{B_p - F_{cy}}{1.6D_p} < b/t < \dfrac{k_1 B_p}{1.6D_p}$, then

$$F_{nc} = B_p - 1.6D_p\, b/t \qquad (7.5.4.4.3\text{-}2)$$

C7.5.4.4.3

This Article matches Section B.5.4.2 of the *Aluminum Design Manual* (AA, 2015).

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- If $b/t \geq \frac{k_1 B_p}{1.6 D_p}$, then

$$F_{nc} = \frac{k_2 \sqrt{B_p E}}{1.6b/t} \quad (7.5.4.4.3\text{-}3)$$

7.5.4.4.4—Flat Elements Supported on One Edge and with a Stiffener on the Other Edge

For flat elements satisfying all of the following criteria:

- supported on one edge and with a stiffener on the other edge,
- with a stiffener of depth $D_S \leq 0.8b$, where D_S is the clear length of the stiffener, and
- with a thickness no greater than the stiffener's thickness,

the nominal resistance shall be taken as:

$$F_{nc} = F_{nUT} + (F_{nST} - F_{nUT})\,\rho_{ST} \quad (7.5.4.4.4\text{-}1)$$

where:

F_{nUT} is F_{nc} determined using Article 7.5.4.4.2 and neglecting the stiffener.

F_{nST} is F_{nc} determined using Article 7.5.4.4.3.

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

- If $b/t \leq \lambda_e/3$, then

$$\rho_{ST} = 1.0 \quad (7.5.4.4.4\text{-}2)$$

- If $\lambda_e/3 < b/t \leq \lambda_e$, then

$$\rho_{ST} = \frac{r_s}{9t\left(\frac{b/t}{\lambda_e} - \frac{1}{3}\right)} \leq 1.0 \quad (7.5.4.4.4\text{-}3)$$

- If $\lambda_e < b/t \leq 2\lambda_e$, then

$$\rho_{ST} = \frac{r_s}{1.5t\left(\frac{b/t}{\lambda_e} + 3\right)} \leq 1.0 \quad (7.5.4.4.4\text{-}4)$$

in which:

$$\lambda_e = 1.28\sqrt{E/F_{cy}} \quad (7.5.4.4.4\text{-}5)$$

where:

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

C7.5.4.4.4

This Article matches Section B.5.4.3 of the *Aluminum Design Manual* (AA, 2015).

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For straight stiffeners of constant thicknesses, r_s may be taken as:

$$r_s = \frac{(d_s \sin\theta_s)}{\sqrt{3}} \quad (7.5.4.4.4\text{-}6)$$

where:

d_s = the stiffener's flat width (in.)
θ_s = the angle between the stiffener and the stiffened element (deg)

F_{nc} for the stiffened element determined using Article 7.5.4.4.4 shall not exceed F_{nc} for the stiffener alone determined using Article 7.5.4.4.2.

For flat elements:

- supported on one edge and with a stiffener on the other edge, and
- with a stiffener of depth D_S > 0.8b, where D_S is the clear length of the stiffener, or
- with a thickness greater than the stiffener's thickness,

the nominal resistance shall be taken as:

$$F_{nc} = F_{nUT} \quad (7.5.4.4.4\text{-}7)$$

7.5.4.4.5—Flat Elements Supported on Both Edges and with an Intermediate Stiffener

The nominal resistance of flat elements supported on both edges and with an intermediate stiffener shall be taken as:

- If $\lambda_s \leq \frac{B_c - F_{cy}}{D_c} = \lambda_1$, then

$$F_{nc} = F_{cy} \quad (7.5.4.4.5\text{-}1)$$

- If $\frac{B_c - F_{cy}}{D_c} < \lambda_s < C_c$, then

$$F_{nc} = B_c - D_c\lambda_s \quad (7.5.4.4.5\text{-}2)$$

- If $\lambda_s \geq C_c$, then

$$F_{nc} = \frac{\pi^2 E}{\lambda_s{}^2} \quad (7.5.4.4.5\text{-}3)$$

in which:

$$\lambda_s = 4.62\left(\frac{b}{t}\right)\sqrt{\frac{1 + A_s/(bt)}{1+\sqrt{1+\frac{10.67 I_o}{bt^3}}}} \quad (7.5.4.4.5\text{-}4)$$

where:

C7.5.4.4.5

This Article matches Section B.5.4.4 of the *Aluminum Design Manual* (AA, 2015).

A_s = area of the stiffener (in.^{2})

I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent subelements and the transition corners between them taken about the centroidal axis of the section parallel to the stiffened element (in.^{4})

B_c, D_c, and C_c = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

F_{nc} shall not exceed F_{nc} determined using Article 7.5.4.4.3 for the sub-elements of the stiffened element.

F_{nc} need not be less than F_{nc} determined using Article 7.5.4.4.3 and neglecting the stiffener.

7.5.4.4.6—Round Hollow Elements and Curved Elements Supported on Both Edges

The nominal resistance of round hollow elements and curved elements supported on both edges shall be taken as:

- If $R_b / t \le \left(\frac{B_t - F_{cy}}{D_t}\right)^2 = \lambda_1$, then

$$F_{nc} = F_{cy} \tag{7.5.4.4.6-1}$$

- If $\left(\frac{B_t - F_{cy}}{D_t}\right)^2 < R_b / t < C_t$, then

$$F_{nc} = B_t - D_t\sqrt{\frac{R_b}{t}} \tag{7.5.4.4.6-2}$$

- If $R_b / t \ge C_t$, then

$$F_{nc} = \frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1 + \frac{\sqrt{R_b / t}}{35}\right)^2} \tag{7.5.4.4.6-3}$$

F_{nc} need not be less than that determined using Article 7.5.4.4.3, where b is the length of the curved element.

For tubes with circumferential welds, use of Article 7.5.4.4.6 shall be limited to tubes with $R_b/t \le 20$.

where:

R_b = mid-thickness radius of a round tube or maximum mid-thickness radius of oval tube (in.)

B_t, D_t, and C_t = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

C7.5.4.4.6

This Article matches Section B.5.4.5 of the *Aluminum Design Manual* (AA, 2015), but also permits the strength of curved elements to be no less than the strength of flat elements of the same length.

7.5.4.4.7—Alternative Method for Flat Elements

As an alternative to Articles 7.5.4.4.2 through 7.5.4.4.5, the nominal resistance of flat elements without welds in uniform compression may be determined as:

- If $\lambda_{eq} \leq \frac{B_p - F_{cy}}{D_p} = \lambda_1$, then

$$F_{nc} = F_{cy} \tag{7.5.4.4.7-1}$$

- If $\frac{B_p - F_{cy}}{D_p} < \lambda_{eq} < \frac{k_1 B_p}{D_p}$, then

$$F_{nc} = B_p - D_p \lambda_{eq} \tag{7.5.4.4.7-2}$$

- If $\lambda_{eq} \geq \frac{k_1 B_p}{D_p}$, then

$$F_{nc} = \frac{k_2 \sqrt{B_p E}}{\lambda_{eq}} \tag{7.5.4.4.7-3}$$

in which:

$$\lambda_{eq} = \pi \sqrt{\frac{E}{F_e}} \tag{7.5.4.4.7-4}$$

where:

F_e = the elastic local buckling stress of the cross-section determined by rational analysis (ksi)

B_p, D_p = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

C7.5.4.4.7

This Article matches Section B.5.4.6 of the *Aluminum Design Manual* (AA, 2015).

7.5.4.5—Nominal Resistance of Elements in Flexural Compression

7.5.4.5.1—General

The nominal resistance of elements in flexural compression shall be taken as:

- For unwelded elements:

$$F_{nb} = F_{nbo} \tag{7.5.4.5.1-1}$$

- For welded elements:

$$F_{nb} = F_{nbo}(1 - A_{wzc}/A_{gc}) + F_{nbw} A_{wzc}/A_{gc} \tag{7.5.4.5.1-2}$$

where:

F_{nbo} = stress corresponding to the flexural compressive resistance calculated using Articles 7.5.4.5.2 through 7.5.4.5.4 for an

C7.5.4.5.1

This Article matches Section B.5.5 of the *Aluminum Design Manual* (AA, 2015).

element if no part of the cross-section is weld-affected using buckling constants for unwelded metal and unwelded strengths (ksi)

F_{nbw} = stress corresponding to the flexural compressive resistance calculated using Articles 7.5.4.5.2 through 7.5.4.5.4 for an element if the entire cross-section is weld-affected. Use buckling constants for weld-affected zones and welded strengths (ksi).

A_{wzc} = cross-sectional area of the weld-affected zone in compression (in.^{2})

A_{gc} = gross cross-sectional area of the element in compression (in.^{2})

7.5.4.5.2—Flat Elements Supported on Both Edges

The nominal resistance of flat elements supported on both edges and flat elements supported on the compression edge with the tension edge free shall be taken as:

- If $b/t \le \dfrac{B_{br} - 1.5F_{cy}}{mD_{br}} = \lambda_1$, then

$$F_{nb} = 1.5F_{cy} \tag{7.5.4.5.2-1}$$

- If $\dfrac{B_{br} - 1.5F_{cy}}{mD_{br}} < b/t < \dfrac{k_1 B_{br}}{mD_{br}}$, then

$$F_{nb} = B_{br} - mD_{br} b/t \tag{7.5.4.5.2-2}$$

- If $b/t \ge \dfrac{k_1 B_{br}}{mD_{br}}$, then

$$F_{nb} = \frac{k_2\sqrt{B_{br}E}}{(mb/t)} \tag{7.5.4.5.2-3}$$

in which:

m = factor for determining the flexural compressive resistance of flat elements

m = $1.15 + c_o/(2c_c)$ for $-1 < c_o/c_c < 1$ (7.5.4.5.2-4)

m = $1.3/(1 - c_o/c_c)$ for $c_o/c_c \le -1$ (7.5.4.5.2-5)

m = 0.65 for $c_c = -c_o$ (7.5.4.5.2-6)

where:

c_c = distance from neutral axis to the element extreme fiber with the greatest compressive stress (in.)

c_o = distance from neutral axis to other extreme fiber of the element (in.)

B_{br}, D_{br} = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

C7.5.4.5.2

This Article matches Section B.5.5.1 of the *Aluminum Design Manual* (AA, 2015).

Distances to compressive fibers shall be taken as negative and distances to tensile fibers shall be taken as positive.

7.5.4.5.3—Flat Elements Supported on Tension Edge, Compression Edge Free

The nominal flexural compressive resistance of flat elements supported on one edge with the compression edge free shall be taken as:

- If $b/t \le \dfrac{B_{br} - 1.5F_{cy}}{3.5D_{br}} = \lambda_1$, then

$$F_{nb} = 1.5F_{cy} \quad (7.5.4.5.3\text{-}1)$$

- If $\dfrac{B_{br} - 1.5F_{cy}}{3.5D_{br}} < b/t < \dfrac{C_{br}}{3.5}$, then

$$F_{nb} = B_{br} - 3.5D_{br} b/t \quad (7.5.4.5.3\text{-}2)$$

- If $b/t \ge \dfrac{C_{br}}{3.5}$, then

$$F_{nb} = \frac{\pi^2 E}{(3.5b/t)^2} \quad (7.5.4.5.3\text{-}3)$$

C7.5.4.5.3

This Article matches Section B.5.5.2 of the *Aluminum Design Manual* (AA, 2015).

7.5.4.5.4—Flat Elements Supported on Both Edges and with a Longitudinal Stiffener

The nominal resistance of flat elements supported on both edges and with a longitudinal stiffener located $0.4d_1$ from the supported edge that is in compression shall be taken as:

- If $b/t \le \dfrac{B_{br} - 1.5F_{cy}}{0.29D_{br}} = \lambda_1$, then

$$F_{nb} = 1.5F_{cy} \quad (7.5.4.5.4\text{-}1)$$

- If $\dfrac{B_{br} - 1.5F_{cy}}{0.29D_{br}} < b/t < \dfrac{k_1 B_{br}}{0.29D_{br}}$, then

$$F_{nb} = B_{br} - 0.29D_{br}\, b/t \quad (7.5.4.5.4\text{-}2)$$

- If $b/t \ge \dfrac{k_1 B_{br}}{0.29D_{br}}$, then

$$F_{nb} = \frac{k_2\sqrt{B_{br}E}}{(0.29b/t)} \quad (7.5.4.5.4\text{-}3)$$

The moment of inertia of the longitudinal stiffener, I_L, about the web of the beam shall satisfy:

$$I_L \ge \frac{0.02\alpha_s f t b^3}{E}\left[\left(1+\frac{6A_L}{bt}\right)\left(\frac{s}{b}\right)^2 + 0.4\right] \quad (7.5.4.5.4\text{-}4)$$

C7.5.4.5.4

This Article matches Section B.5.5.3 of the *Aluminum Design Manual* (AA, 2015).

where:

A_L = cross-sectional area of the longitudinal stiffener (in.^{2})
d_1 = distance from the neutral axis to the compression flange (in.)
f = compressive stress at the toe of the flange (ksi)
b = clear height of the web (in.)
s = distance between transverse stiffeners (in.)
t = web thickness (in.)
α_s = 1 for a stiffener consisting of equal members on both sides of the web
= 3.5 for a stiffener consisting of a member on only one side of the web

For a stiffener consisting of equal members on both sides of the web, the moment of inertia, I_L, shall be the sum of the moments of inertia about the centerline of the web.

For a stiffener consisting of a member on one side of the web only, the moment of inertia, I_L, shall be taken about the face of the web in contact with the stiffener.

7.5.4.5.5—Pipes and Round Tubes

The nominal resistance of round hollow elements and curved elements supported on both edges shall be taken as:

- If $R_b / t \leq C_{tb}$, then

$$F_{nb} = B_{tb} - D_{tb}\sqrt{R_b / t} \tag{7.5.4.5.5-1}$$

- If $C_{tb} < R_b / t < C_t$, then

$$F_{nb} = B_t - D_t\sqrt{R_b / t} \tag{7.5.4.5.5-2}$$

- If $R_b / t \geq C_t$, then

$$F_{nb} = \frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1 + \frac{\sqrt{R_b / t}}{35}\right)^2} \tag{7.5.4.5.5-3}$$

C7.5.4.5.5

This Article matches Section B.5.5.4 of the *Aluminum Design Manual* (AA, 2015).

7.5.4.5.6—Alternative Method for Flat Elements

As an alternative to Articles 7.5.4.5.2 through 7.5.4.5.4 for flat elements in flexure without welds, the stress, F_{nb}, may be determined as:

- If $\lambda_{eq} \leq \frac{B_P - F_{cy}}{D_p} = \lambda_1$, then

$$F_{nb} = M_{np}/S_{xc} \tag{7.5.4.5.6-1}$$

- If $\frac{B_p - F_{cy}}{D_p} < \lambda_{eq} < C_p$, then

C7.5.4.5.6

This Article matches Section B.5.5.4 of the *Aluminum Design Manual* (AA, 2015).

$$F_{nb} = \frac{M_{np}}{S_{xc}} - \left(\frac{M_{np}}{S_{xc}} - \frac{\pi^2 E}{C_p{}^2}\right)\left(\frac{\lambda_{eq} - \lambda_1}{C_p - \lambda_1}\right) \quad (7.5.4.5.6\text{-}2)$$

- If $\lambda_{eq} \geq C_p$, then

$$F_{nb} = \frac{k_2\sqrt{B_p E}}{\lambda_{eq}} \quad (7.5.4.5.6\text{-}3)$$

in which:

$$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}} \quad (7.5.4.5.6\text{-}4)$$

where:

F_e = the elastic local buckling stress of the cross-section determined by rational analysis (ksi)

7.5.4.6—Nominal Resistance of Elements in Shear

7.5.4.6.1—General

For the limit states of shear yielding and shear buckling, the nominal shear resistance shall be taken as:

- For unwelded members:

$$V_n = F_{nso} A_v \quad (7.5.4.6.1\text{-}1)$$

- For welded members:

$$V_n = F_{nso}\left(A_v - A_{wz}\right) + F_{nsw} A_{wz} \quad (7.5.4.6.1\text{-}2)$$

where:

F_{nso} = shear stress corresponding to the shear resistance for an element if no part of the cross-section is weld-affected (ksi). Use buckling constants for unwelded metal and unwelded strengths.

F_{nsw} = shear stress corresponding to the shear resistance for an element if the entire cross-section is weld-affected (ksi). Use buckling constants for weld-affected zones and welded strengths.

A_{wz} = cross-sectional area of the weld-affected zone (in.^{2})

A_v = shear area defined in Articles 7.5.4.6.2, 7.5.4.6.3, and 7.5.4.6.4 (in.^{2})

C7.5.4.6.1

This Article matches Section G.1 of the *Aluminum Design Manual* (AA, 2015).

7.5.4.6.2—Flat Elements Supported on Both Edges

For the limit state of shear rupture:

C7.5.4.6.2

This Article matches Section G.2 of the *Aluminum Design Manual* (AA, 2015).

- For unwelded members:
  $V_n = F_{su} A_n$ (7.5.4.6.2-1)

- For welded members:
  $V_n = F_{su} (A_n - A_{wz}) + F_{suw} A_{wz}$ (7.5.4.6.2-2)

where:

A_n = net area of the web (in.^{2})
F_{suw} = shear ultimate strength in the weld-affected zone (ksi)
A_{wz} = weld-affected area of the web (in.^{2})

For the limit states of shear yielding and shear buckling, V_n is as defined in Article 7.5.4.6.1 with $A_v = dt$ and F_{ns} determined from:

- If $b/t \leq \dfrac{B_s - F_{sy}}{1.25D_s} = \lambda_1$, then

  $$F_{ns} = F_{sy} \quad (7.5.4.6.2\text{-}3)$$

- If $\dfrac{B_s - F_{sy}}{1.25D_s} < b/t < \dfrac{C_s}{1.25}$, then

  $$F_{ns} = B_s - 1.25D_s b/t \quad (7.5.4.6.2\text{-}4)$$

- If $b/t \geq \dfrac{C_s}{1.25}$, then

  $$F_{ns} = \frac{\pi^2 E}{(1.25b/t)^2} \quad (7.5.4.6.2\text{-}$$

For webs without transverse stiffeners, b shall be taken as the clear height of the web; for webs with transverse stiffeners, b shall be determined as:

$$b = \frac{a_1}{\sqrt{1 + 0.7\left(\frac{a_1}{a_2}\right)^2}} \quad (7.5.4.6.2\text{-}6)$$

where:

a_1 = the lesser of the clear height of the web and the distance between stiffeners (in.)
a_2 = the greater of the clear height of the web and the distance between stiffeners (in.)
t = web thickness (in.)
A_w = area of the web (in.^{2}) = dt
d = full depth of the section (in.)
B_s, D_s, and C_s = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

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

- If $\frac{s}{b} \le 0.4$, then

$$I_s = \frac{0.55Vb^2}{E}\left(\frac{s}{b}\right) \qquad (7.5.4.6.2\text{-}7)$$

- If $\frac{s}{b} > 0.4$, then

$$I_s = \frac{0.088Vb^2}{E}\left(\frac{b}{s}\right) \qquad (7.5.4.6.2\text{-}8)$$

where:

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

I_s = moment of inertia of the transverse stiffener (in.^{4}). For a stiffener composed of members of equal size on each side of the web, the moment of inertia of the stiffener shall be computed about the centerline of the web. For a stiffener composed of a member on only one side of the web, the moment of inertia of the stiffener shall be computed about the face of the web in contact with the stiffener.

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

V = shear force on the web at the transverse stiffener (kip)

Transverse stiffeners shall consist of plates or angles welded or bolted to either one or both sides of the web. Stiffeners in straight girders not used as connection plates shall be tight fit or attached at the compression flange, but need not be in bearing with the tension flange.

7.5.4.6.3—Flat Elements Supported on One Edge

For the limit state of shear rupture:

- For unwelded members:
$$V_n = F_{su} A_n \qquad (7.5.4.6.3\text{-}1)$$
- For welded members:
$$V_n = F_{su} (A_n - A_{wz}) + F_{suw} A_{wz} \qquad (7.5.4.6.3\text{-}2)$$

where:

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

C7.5.4.6.3

This Article matches Section G.3 of the *Aluminum Design Manual* (AA, 2015).

For the limit states of shear yielding and shear buckling, V_n is as defined in Article 7.5.4.6.1 with $A_v = bt$ and F_{ns} determined from the nominal shear resistance of flat elements supported on one edge shall be taken as:

- If $b/t \leq \dfrac{B_s - F_{sy}}{3.0D_s} = \lambda_1$, then

$$F_{ns} = F_{sy} \tag{7.5.4.6.3-3}$$

- If $\dfrac{B_s - F_{sy}}{3.0D_s} < b/t < \dfrac{C_s}{3.0}$, then

$$F_{ns} = B_s - 3.0D_s b/t \tag{7.5.4.6.3-4}$$

- If $b/t \geq \dfrac{C_s}{3.0}$, then

$$F_{ns} = \frac{\pi^2 E}{(3.0b/t)^2} \tag{7.5.4.6.3-5}$$

where:

b = distance from the unsupported edge to the mid-thickness of the supporting element (in.)
t = web thickness (in.)
A_w = area of the web (in.^{2}) = bt

7.5.4.6.4—Pipes and Round or Oval Tubes

C7.5.4.6.4

This Article matches Section G.4 of the *Aluminum Design Manual* (AA, 2015).

For the limit state of shear rupture:

- For unwelded members:
$$V_n = F_{su} A_n/2 \tag{7.5.4.6.4-1}$$
- For welded members:
$$V_n = F_{su}(A_n - A_{wz})/2 + F_{suw} A_{wz}/2 \tag{7.5.4.6.4-2}$$

where:

A_n = net area of the pipe or tube (in.^{2})
A_{wz} = weld-affected area of the pipe or tube (in.^{2})

For the limit states of shear yielding and shear buckling, V_n is as defined in Article 7.5.4.6.1 with $A_v = \pi(D_o^2 - D_i^2)/8$, where D_o = outside diameter of the pipe or tube, D_i = inside diameter of the pipe or tube, and F_{ns} is determined as:

- If $\lambda_t \leq \dfrac{1.3B_s - F_{sy}}{1.63D_s} = \lambda_1$, then

$$F_{ns} = F_{sy} \tag{7.5.4.6.4-3}$$

- If $\dfrac{1.3B_s - F_{sy}}{1.63D_s} < \lambda_t < \dfrac{C_s}{1.25}$, then

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$$F_{ns} = 1.3B_s - 1.63D_s\lambda_t \quad (7.5.4.6.4\text{-}4)$$

- If $\lambda_t \geq \frac{C_s}{1.25}$, then

$$F_{ns} = \frac{1.3\pi^2 E}{(1.25\lambda_t)^2} \quad (7.5.4.6.4\text{-}5)$$

in which:

$$\lambda_t = 2.9\left(\frac{R_b}{t}\right)^{5/8}\left(\frac{L_v}{R_b}\right)^{1/4} \quad (7.5.4.6.4\text{-}6)$$

where:

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

7.5.4.7—Elastic Buckling Stress of Elements

The elastic buckling stress, F_e, of elements shall be determined using Table 7.5.4.7-1.

C7.5.4.7

This Article matches Sections B.5.5.2 and B.5.6 of the *Aluminum Design Manual* (AA, 2015).

Table 7.5.4.7-1—Elastic Buckling Stress, F_e, of Elements

Element Type	Element Stress	Element Support	F_e (ksi)
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	$\frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1+\frac{\sqrt{R_b/t}}{35}\right)^2}$
Flat	Flexural Compression	Supported on one edge, compression edge free	$\frac{\pi^2 E}{(3.5b/t)^2}$

7.5.5—Extreme Event Limit State

All applicable extreme event load combinations in Table 3.4.1-1 shall be investigated. All resistance factors for the extreme limit state shall be taken as 1.0.

Bolted joints not protected by capacity design or structural fuses may be assumed to behave as bearing-type connections at the extreme event limit state, and the resistance factors given in Article 7.5.4.2 shall apply.

7.6—FATIGUE

7.6.1—General

Fatigue shall be categorized as load- or distortion-induced fatigue.

7.6.2—Load-Induced Fatigue

7.6.2.1—Application

The force effect considered for the fatigue design of an aluminum bridge detail shall be the live load stress range. Residual stresses shall not be included in investigating fatigue.

These provisions shall be applied only to details subjected to a net applied tensile stress. In regions where the unfactored permanent loads produce compression, fatigue shall be considered only if the compressive stress is less than that resulting from the Fatigue I load combination specified in Table 3.4.1-1.

7.6.2.2—Design Criteria

For load-induced fatigue considerations, each detail shall satisfy:

$$\gamma(\Delta f) < (\Delta F)_n \qquad (7.6.2.2\text{-}1)$$

where:

γ = load factor specified in Table 3.4.1-1 for the fatigue load combination

(Δf) = force effect, live load stress range due to the passage of the fatigue load as specified in Article 3.6.1.4 (ksi)

$(\Delta F)_n$ = nominal fatigue resistance as specified in Article 7.6.2.5 (ksi)

7.6.2.3—Detail Categories

Components and details shall be designed to satisfy the requirements of their respective detail categories summarized in Table 7.6.2.3-1 and illustrated in Figure 7.6.2.3-1 which provides examples as guidelines and is not intended to exclude other similar details. Tensile stresses shall be considered to be positive and compressive stresses shall be considered to be negative.

C7.6.2.3

Table 7.6.2.3-1 matches Table 3.1 of the *Aluminum Design Manual* (AA, 2015).

The values in Table 7.6.2.3-2 were determined by equating infinite and finite life resistances with due regard to the difference in load factors used with the infinite (1.5 for Fatigue I) and finite life (0.75 for Fatigue II) load combinations. The values were computed using the values for C_f, m, and $(\Delta F)_{TH}$ given in Table 7.6.2.5-1

Bolt fabrication shall conform to the provisions of Article 11.4.8.5 of the *AASHTO LRFD Bridge Construction Specifications*. Where permitted for use, unless specific information is available to the contrary, bolt holes in cross-frame, diaphragm, and lateral bracing members and their connection plates shall be assumed for design to be punched full size.

Except as specified herein for fracture-critical members where the projected 75-year single lane Average Daily Truck Traffic $(ADTT)_{SL}$ is less than or equal to that specified in Table 7.6.2.3-2 for the component or detail under consideration, that component or detail should be designed for finite life using the Fatigue II load combination specified in Table 3.4.1-1. Otherwise, the component or detail shall be designed for infinite life using the Fatigue I load combination. A single-lane Average Daily Truck Traffic $(ADTT)_{SL}$ shall be computed as specified in Article 3.6.1.4.2. and a number of stress range cycles per truck passage, n, equal to one, and rounded up to the nearest five trucks per day.

Table 7.6.2.3-1—Detail Categories for Load-Induced Fatigue

General Condition	Detail	Detail Category	Fatigue Design Details (Note 1)
Plain Material	Base metal with rolled, extruded, drawn, or cold finished surfaces; cut or sheared surfaces with ANSI/ASME B46.1 surface roughness ≤ 1,000 µin.	A	1, 2
Built-up Members	Base metal and weld metal in members without attachments and built up of plates or shapes connected by continuous full- or partial-penetration groove welds or continuous fillet welds parallel to the direction of applied stress.	B	3, 4, 5
	Flexural stress in base metal at the toe of welds on girder webs or flanges adjacent to welded transverse stiffeners.	C	6, 21
	Base metal at the end of partial-length welded cover plates with square or tapered ends, with or without welds across the ends.	E	5
Mechanically Fastened Connections	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration does not result in out-of-plane bending in the connected material and the stress ratio (the ratio of minimum stress to maximum stress), R_S, is (Note 2):		
	$R_S \leq 0$	B	7
	$0 < R_S < 0.5$	D	7
	$R_S \geq 0.5$	E	7

(continued on next page)

Table 7.6.2.3-1 (continued)—Detail Categories for Load-Induced Fatigue

General Condition	Detail	Detail Category	Fatigue Design Details (Note 1)
Mechanically Fastened Connections (cont'd)	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration results in out-of-plane bending in connected material.	E	8
Fillet Welds	Base metal at intermittent fillet welds	E	
	Base metal at the junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the members so as to balance weld stresses.	E	15, 17
	Shear stress in weld metal of continuous or intermittent longitudinal or transverse fillet welds.	F	5, 15, 18
Groove Welds	Base metal and weld metal at full-penetration groove welded splices of parts of similar cross-section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection.	B	9, 10
	Base metal and weld metal at full-penetration groove welded splices at transitions in width or thickness, with welds ground to slopes $\leq$ 1: 2.5, with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection.	B	11, 12
	Base metal and weld metal at full-penetration groove welded splices with or without transitions with slopes $\leq$ 1:2.5, when reinforcement is not removed or weld soundness is not established by radiographic or ultrasonic inspection; or both.	C	9, 10, 11, 12
	Base metal and weld metal at full-penetration groove welds with permanent backing.	E	22
Attachments	Base metal detail of any length attached by groove welds subject to transverse or longitudinal loading, or both; with a transition radius $R \geq 2$ in., and with the weld termination ground smooth:		
	$R \geq 24$ in.	B	13
	24 in. $> R \geq 6$ in.	C	13
	6 in. $> R \geq 2$ in.	D	13
	Base metal at a detail attached by groove welds or fillet welds with a detail dimension parallel to the direction of stress $a < 2$ in.	C	19

(continued on next page)

Table 7.6.2.3-1 (continued)—Detail Categories for Load-Induced Fatigue

General Condition	Detail	Detail Category	Fatigue Design Details (Note 1)
Attachments (cont'd)	Base metal at a detail attached by groove welds or fillet welds with a detail dimension parallel to the direction of stress $a < 2$ in.	C	19
	Base metal at a detail attached by groove welds or fillet welds subject to longitudinal loading, with a transition radius, if any, < 2 in.:		
	2 in. $\leq a \leq 12b$ or 4 in.	D	14
	Base metal at a detail attached by groove welds or fillet welds with a detail dimension parallel to the direction of stress $a < 2$ in.:	C	19
	2 in. $\leq a \leq 12b$ or 4 in.	D	14
	$a > 12b$ or 4 in.	E	14, 19, 20
	Base metal at a detail of any length attached by fillet welds or partial-penetration groove welds in the direction parallel to the stress, with a transition radius $R \geq 2$ in., and the weld termination is ground smooth:		
	$R \geq 24$ in.	B	16
	24 in. $> R \geq 6$ in.	C	16
	6 in. $> R \geq 2$ in.	D	16

Notes:
1. See Figure 7.6.2.3-1. These examples are provided as guidelines and are not intended to exclude other similar details.
2. Tensile stresses are considered to be positive and compressive stresses are considered to be negative.

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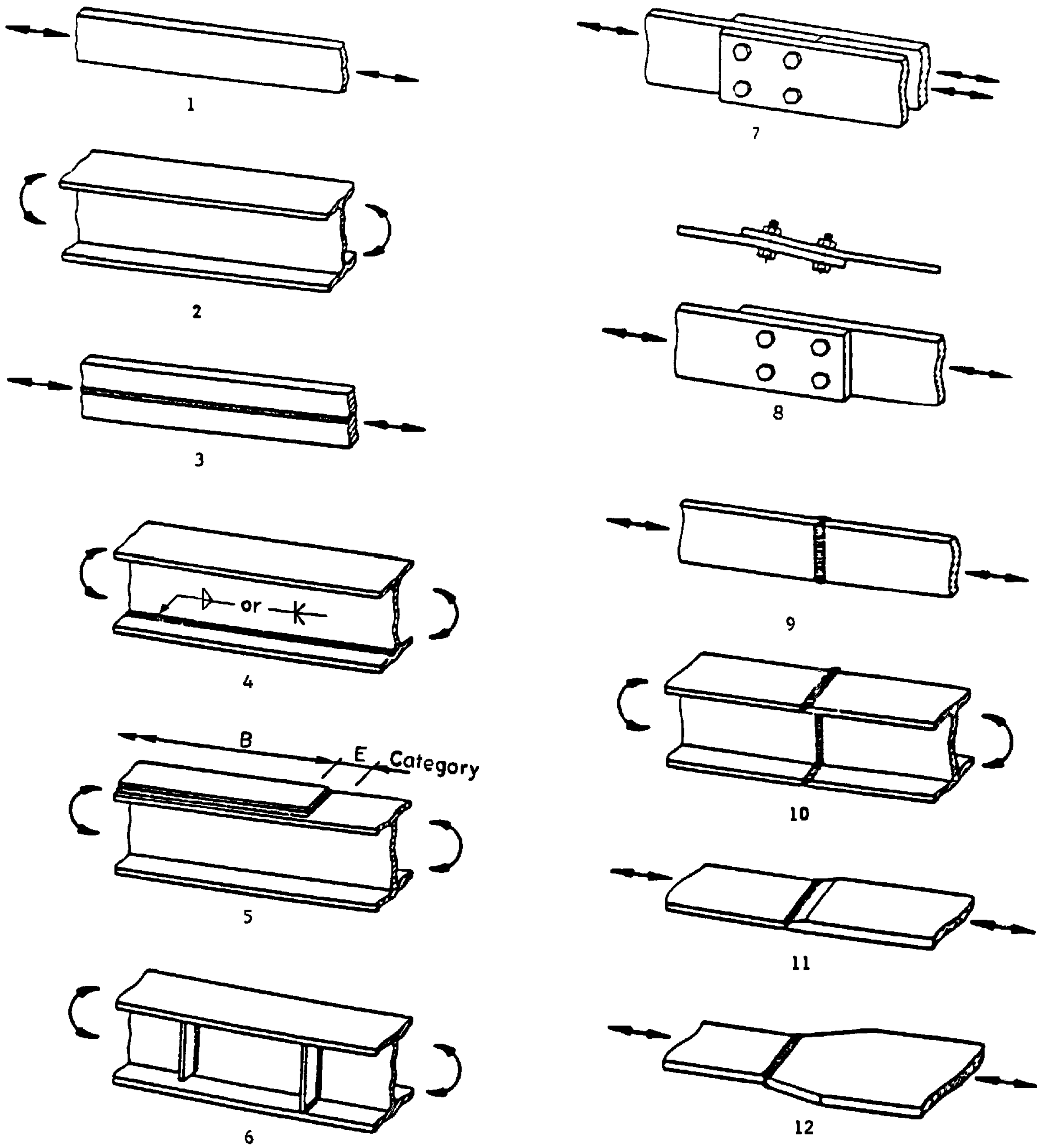

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Figure 7.6.2.3-1—Illustrative Examples

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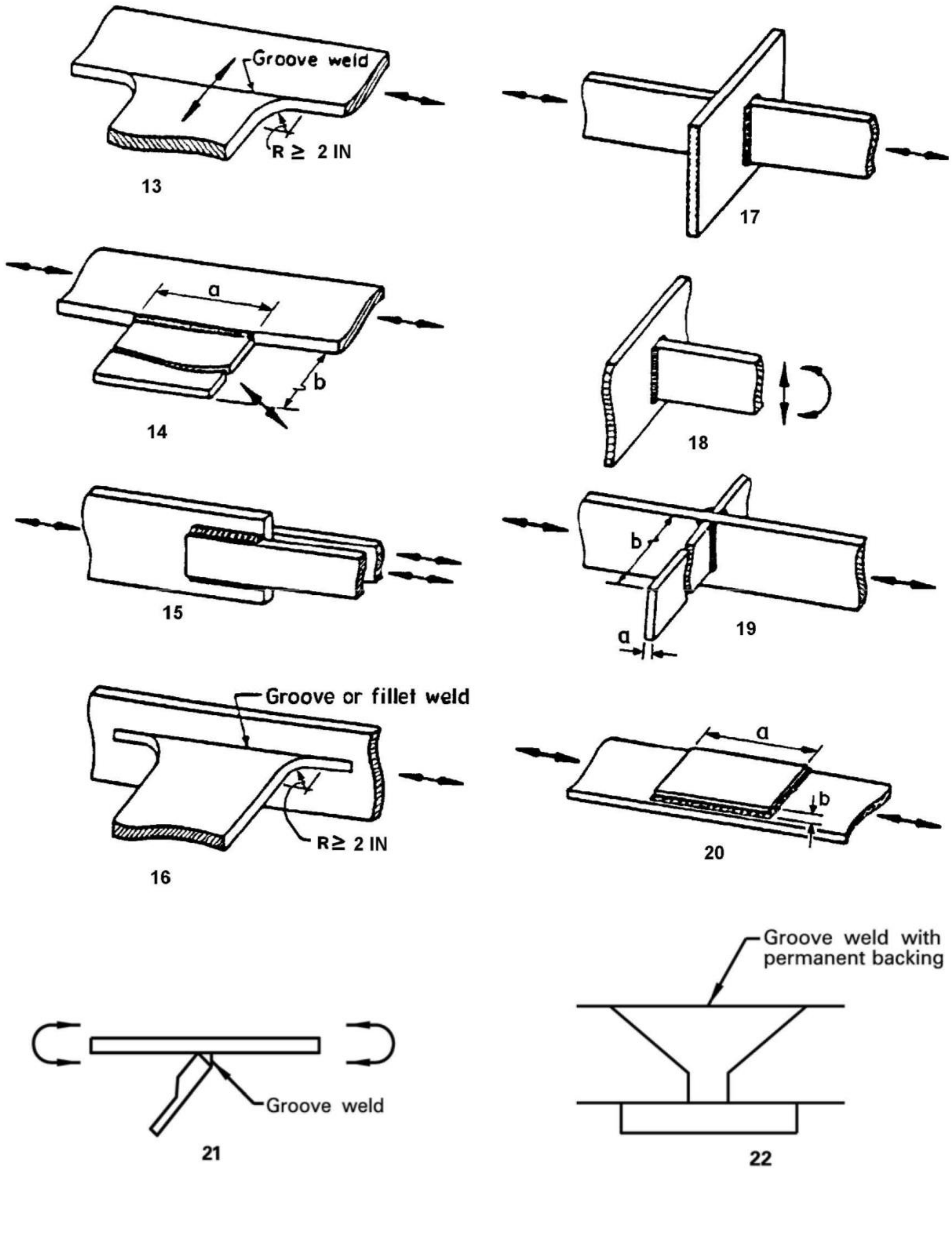

Figure 7.6.2.3-1 (continued)—Illustrative Examples

Table 7.6.2.3-2—75-year $(ADTT)_{SL}$ Equivalent to Infinite Life

Detail Category	75-year $(ADTT)_{SL}$ Equivalent to Infinite Life (Trucks/Day)
A	20,410
B	5,085
C	2,310
D	2,465
E	2,115
F	2,005

7.6.2.4—Detailing to Reduce Constraint

To the extent practical, welded structures shall be detailed to avoid conditions that create highly constrained joints and crack-like geometric discontinuities that are susceptible to constraint-induced fracture. Welds that are parallel to the primary stress but interrupted by intersecting members shall be detailed to allow a minimum gap of 1.0 in. between weld toes.

7.6.2.5—Fatigue Resistance

Nominal fatigue resistance, $(\Delta F)_n$, shall be taken as:

- For the Fatigue I load combination and infinite life:
  $$(\Delta F)_n = (\Delta F)_{TH} \quad (7.6.2.5\text{-}1)$$
- For the Fatigue II load combination and finite life:
  $$(\Delta F)_n = C_f / N^{1/m} \quad (7.6.2.5\text{-}2)$$

in which:

$$N = (365)(75)n\,(ADTT)_{SL} \quad (7.6.2.5\text{-}3)$$

where:

C_f = constant taken from Table 7.6.2.5-1 (ksi)
m = constant taken from Table 7.6.2.5-1
n = number of stress range cycles per truck taken from Table 6.6.1.2.5-2
$(ADTT)_{SL}$ = single-lane ADTT as specified in Article 3.6.1.4
$(\Delta F)_{TH}$ = constant amplitude threshold taken from Table 7.6.2.5-1

C7.6.2.5

Table 7.6.2.5-1 matches Table 3.2 of the *Aluminum Design Manual* and Eq. 7.6.2.5-2 matches the equation for fatigue strength given in Section 3.2 of the *Aluminum Design Manual* (AA, 2015). While the *S-N* curves of different fatigue categories for steel are parallel, the curves for aluminum are not. When the curves were derived, the best fits were used. The *S-N* curves for detail Classes C through F could be made parallel without significant loss of accuracy. However, this was not done in part to maintain some consistency with fatigue provisions developed in conjunction with European partners. From a fracture mechanics perspective, the relationship between incremental crack growth and applied stress intensity factor range is more complex than for steel, particularly in the slow growth regime, and is reflective of aluminum's microstructural barriers to crack growth extension, like sub-grain structures. Further, it seems clear that Class A details, like plain extruded sections, would be expected to have a different fatigue response than other classes with residual stresses caused by welds, and perhaps a significantly different *S-N* curve slope.

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Table 7.6.2.5-1—Detail Category Constant and Constant Amplitude Fatigue Threshold

Detail Category	C_f (ksi)	m	$(\Delta F)_{TH}$ (ksi)
A	96.5	6.85	10.2
B	130	4.84	5.4
C	278	3.64	4.0
D	157	3.73	2.5
E	160	3.45	1.8
F	174	3.42	1.9

7.6.3—Distortion-Induced Fatigue

Load paths that are sufficient to transmit all intended and unintended forces shall be provided by connecting all transverse members to appropriate components of the cross-section of longitudinal members. The load paths shall be provided by attaching the various components by either welding or bolting.

7.6.3.1—Transverse Connection Plates

The provisions of Article 6.6.1.3.1 shall apply.

7.6.3.2—Lateral Connection Plates

The provisions of Article 6.6.1.3.2 shall apply.

7.7—GENERAL DIMENSION AND DETAIL REQUIREMENTS

7.7.1—Effective Length of Span

Span lengths shall be taken as the distance between centers of bearings or other points of support.

7.7.2—Dead Load Camber

Aluminum structures should be cambered during fabrication to compensate for dead load deflection and vertical alignment.

Deflection due to aluminum weight, steel weight, concrete weight, wearing surface weight, and loads not applied at the time of construction shall be reported separately.

Vertical camber shall be specified to account for the computed dead load deflection.

When staged construction is specified, the sequence of load application should be considered when determining the cambers.

7.7.3—Minimum Thickness

The nominal thickness of aluminum components shall not be less than 0.187 in.

C7.7.3

The minimum thickness of aluminum components depends primarily on resistance to damage during fabrication and handling rather than a need for corrosion allowance.

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7.7.4—Diaphragms and Cross-Frames

Diaphragms and cross-frames shall conform to the intent of Articles 6.7.4.1, 6.7.4.2, 6.7.4.3, and 6.7.4.4, except the provisions for horizontally-curved girders.

7.7.5—Lateral Bracing

Lateral bracing shall conform to the intent of Article 6.7.5.

7.8—TENSION MEMBERS

7.8.1—General

Members and splices subjected to axial tension shall be investigated for:

- yield on the gross section, and
- fracture on the net section.

Holes larger than those typically used for connectors such as bolts shall be deducted in determining the gross section area, A_g.

The determination of the net section, A_n, requires consideration of:

- The gross area from which deductions will be made or reduction factors applied, as appropriate;
- Deductions for all holes in the design cross-section;
- Correction of the bolt hole deductions for the stagger rule specified in Article 7.8.3;
- Application of the reduction factor specified in Article 7.8.2.2 to account for shear lag.

Tension members shall satisfy the slenderness requirements specified in Article 7.8.4 and the fatigue requirements of Article 7.6. Block shear resistance shall be investigated at end connections as specified in Article 7.12.4.

7.8.2—Tensile Resistance

7.8.2.1—General

The factored tensile resistance, P_{rt}, shall be taken as the lesser of the values for tensile yielding on the gross section and tensile rupture on the net section.

- For tensile yielding on the gross section:

$$P_{rt} = \phi_y P_{ny} \tag{7.8.2.1-1}$$

in which:

- For unwelded members and members with transverse welds:

$$P_{ny} = F_{ty} A_g \tag{7.8.2.1-2}$$

C7.8.2.1

This Article matches Section D.2 of the *Aluminum Design Manual* (AA, 2015).

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- For members with longitudinal welds:

$$P_{ny} = F_{ty}(A_g - A_{wz}) + F_{tyw} A_{wz} \quad (7.8.2.1\text{-}3)$$

- For tensile rupture on the net section:

$$P_{rt} = \phi_u P_{nu} \quad (7.8.2.1\text{-}4)$$

in which:

- For unwelded members:

$$P_{nu} = F_{tu} A_e \quad (7.8.2.1\text{-}5)$$

- For welded members:

$$P_{nu} = F_{tu}(A_e - A_{wz}) + F_{tuw} A_{wz} \quad (7.8.2.1\text{-}6)$$

7.8.2.2—Effective Net Area

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

- 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, shall be taken as the net area, A_n.
- 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, shall be taken as:

$$A_e = UA_n \quad (7.8.2.2\text{-}1)$$

where:

A_n = net area of the member at the connection (in.^{2})
U = reduction factor to account for shear lag taken as given in Article 6.8.2.1

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

C7.8.2.2

This Article is similar to Section D.3.2 of the *Aluminum Design Manual* (AA, 2015), except for the reduction factor that accounts for shear lag.

7.8.2.3—Combined Tension and Flexure

A component subjected to tension and flexure shall satisfy Eq. 7.8.2.3-1.

$$\frac{P_{ut}}{P_{rt}} + \frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1.0 \quad (7.8.2.3\text{-}1)$$

where:

C7.8.2.3

This Article matches Section H.1 of the *Aluminum Design Manual* (AA, 2015).

P_{ut} = axial tension resulting from the factored loads (kip)
P_{rt} = factored tensile resistance (kip)
M_{ux} = moment about the major principal axis resulting from the factored loads (kip-in.)
M_{rx} = factored flexural resistance about the major principal axis (kip-in.)
M_{uy} = moment about the minor principal axis resulting from the factored loads (kip-in.)
M_{ry} = factored flexural resistance about the minor principal axis (kip-in.)

7.8.3—Net Area

The net area, A_n, of an element is the product of the thickness of the element and its smallest net width. The width of each drilled hole shall be taken as the nominal diameter of the hole and the width of each punched hole shall be taken as the nominal diameter of the hole plus 0.0313 in. The net width shall be determined for each chain of holes extending across the member or along any transverse, diagonal, or zigzag line.

The net width for each chain shall be determined by subtracting from the width of the element the sum of the widths of all holes in the chain and adding the quantity $s^2/4g$ for each space between consecutive holes in the chain.

where:

s = longitudinal center-to-center distance (pitch) between two holes (in.)
g = transverse center-to-center distance (gauge) between two holes (in.)

7.8.4—Limiting Slenderness Ratio

Tension members other than rods, eyebars, and plates shall satisfy the slenderness requirements specified below:

- For primary members subject to stress reversals, $l/r \leq 140$
- For primary members not subject to stress reversals, $l/r \leq 200$
- For secondary members, $l/r \leq 240$

where:

l = unbraced length (in.)
r = radius of gyration (in.)

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7.8.5—Built-Up Members

The main elements of built-up tension members shall be connected by continuous plates with or without perforations, or by tie plates with or without lacing. Welded connections between shapes and plates shall be continuous. Bolted connections between shapes and plates shall conform to Articles 7.12.2 and 7.12.5.

7.9—COMPRESSION MEMBERS

7.9.1—General

The provisions of this Article shall apply to prismatic aluminum members subjected to either axial compression, or combined axial compression and flexure.

7.9.2—Axial Compression Resistance

The factored resistance, P_{rc}, of components in axial compression shall be taken as:

$$P_{rc} = \phi_c P_n \quad (7.9.2\text{-}1)$$

where:

P_n = least of the nominal compressive resistance for member buckling specified in Article 7.9.2.1, the nominal compressive resistance for local buckling specified in Article 7.9.2.2, and the nominal compressive resistance for the interaction between member buckling and local buckling specified in Article 7.9.2.3 (kip)

ϕ_c = resistance factor for compression specified in Article 7.5.4.2

C7.9.2

The Article matches Section E.1 of the *Aluminum Design Manual* (AA, 2015).

7.9.2.1—Member Buckling

7.9.2.1.1—General

The nominal compressive resistance, P_n, for member buckling is:

$$P_n = F_c A_g \quad (7.9.2.1.1\text{-}1)$$

in which the compressive buckling stress, F_c, shall be taken as:

- If $\frac{Kl}{r} \le \lambda_1$, then $F_c = F_{cy}$ (7.9.2.1.1-2)

- If $\lambda_1 < \frac{Kl}{r} < C_c$, then

$$F_c = \left(B_c - D_c\lambda\right)\left(0.85 + 0.15\frac{C_c - \lambda}{C_c - \lambda_1}\right) \quad (7.9.2.1.1\text{-}3)$$

C7.9.2.1.1

This Article matches Section E.2 of the *Aluminum Design Manual* (AA, 2015).

- If $\frac{Kl}{r} \geq C_c$, then

$$F_c = \frac{0.85\pi^2 E}{\left(\frac{Kl}{r}\right)^2} \quad (7.9.2.1.1\text{-}4)$$

$$\lambda_1 = \frac{B_c - F_{cy}}{D_c} \quad (7.9.2.1.1\text{-}5)$$

where:

Kl/r = largest column effective slenderness determined from Articles 7.9.2.1.2 and 7.9.2.1.3

λ = axial slenderness ratio, KL/r

B_c, D_c, and C_c = parameters specified in Table 7.5.4.3-1 or 7.5.4.3-2

The effective length factor, K, shall be determined in accordance with Article 4.6.2.5. For members without welds, B_c, D_c, C_c, and F_{cy} shall be determined using unwelded material properties. For members whose cross-section is fully weld-affected over the entire length of the member, B_c, D_c, C_c, and F_{cy} shall be determined using welded material properties. For other members:

- For members supported at both ends and with no transverse weld farther than $0.05L$ from the member ends, B_c, D_c, C_c, and F_{cy} shall be determined using unwelded material properties.
- For members supported at both ends with a transverse weld farther than $0.05L$ from the member ends and for members supported at only one end with a transverse weld, B_c, D_c, C_c, and F_{cy} shall be determined using welded material properties.
- For members with longitudinal welds:

  The nominal member buckling resistance, P_n, is

$$P_n = P_{no}\left(1 - \frac{A_{wz}}{A_g}\right) + P_{nw}\left(\frac{A_{wz}}{A_g}\right) \quad (7.9.2.1.1\text{-}6)$$

where:

P_{no} = nominal member buckling resistance if no part of the cross-section is weld-affected (kip)

P_{nw} = nominal member buckling resistance if the entire cross-section is weld-affected (kip)

7.9.2.1.2—Flexural Buckling

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

C7.9.2.1.2

This Article matches Section E.2.1 of the *Aluminum Design Manual* (AA, 2015).

7.9.2.1.3—Torsional and Flexural–Torsional Buckling

For torsional or flexural–torsional buckling, Kl/r shall be taken as the larger of the slenderness ratio for flexural buckling and the equivalent slenderness ratio, which shall be determined as:

$$\left(\frac{Kl}{r}\right)_e = \pi\sqrt{\frac{E}{F_e}} \qquad (7.9.2.1.3\text{-}1)$$

The elastic buckling stress, F_e, (ksi) shall be determined by rational analysis or as follows:

- For doubly symmetric members:

$$F_e = \left(\frac{\pi^2 E C_w}{(K_z l_z)^2} + GJ\right)\frac{1}{I_x + I_y} \qquad (7.9.2.1.3\text{-}2)$$

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

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H}\right)\left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}}\right] \qquad (7.9.2.1.3\text{-}3)$$

- For asymmetric members, F_e is the lowest root of the cubic equation:

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_0/r_0)^2 - F_e^2(F_e - F_{ex})(y_0/r_0)^2 = 0 \qquad (7.9.2.1.3\text{-}4)$$

in which:

$$r_0^2 = x_0^2 + y_0^2 + \frac{I_x + I_y}{A_g} \qquad (7.9.2.1.3\text{-}5)$$

$$H = 1 - \frac{x_0^2 + y_0^2}{r_0^2} \qquad (7.9.2.1.3\text{-}6)$$

$$F_{ex} = \frac{\pi^2 E}{\left(\frac{K_x l_x}{r_x}\right)^2} \qquad (7.9.2.1.3\text{-}7)$$

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{K_y l_y}{r_y}\right)^2} \qquad (7.9.2.1.3\text{-}8)$$

$$F_{ez} = \frac{1}{A_g r_0^2}\left(GJ + \frac{\pi^2 E C_w}{(K_z l_z)^2}\right) \qquad (7.9.2.1.3\text{-}9)$$

C7.9.2.1.3

This Article matches Section E.2.2 of the *Aluminum Design Manual* (AA, 2015).

where:

r_0 = polar radius of gyration about the shear center (in.)
x_0, y_0 = coordinates of the shear center with respect to the centroid (in.)
I_x, I_y = moments of inertia about the principal axes (in.^{4})
r_x, r_y = radii of gyration about the centroidal principal axes (in.)

7.9.2.2—Local Buckling

7.9.2.2.1—General

For members without welds, the nominal compressive resistance, P_n, for local buckling shall be determined in accordance with either Article 7.9.2.2.2 or 7.9.2.2.3. For members with welds, the local buckling resistance shall be determined in accordance with Article 7.9.2.2.2.

C7.9.2.2.1

This Article matches Section E.3 of the *Aluminum Design Manual* (AA, 2015).

7.9.2.2.2—Weighted Average Local Buckling Resistance

The weighted average local buckling resistance may be determined as:

$$P_n = \sum_{i=1}^{n} F_{nci} A_i + F_{cy}\left(A_g - \sum_{i=1}^{n} A_i\right) \qquad (7.9.2.2.2\text{-}1)$$

where:

F_{nci} = nominal local buckling resistance of element i computed per Articles 7.5.4.4.1 through 7.5.4.4.6 (ksi)
A_i = area of element i (in.^{2})

C7.9.2.2.2

This Article matches Section E.3.1 of the *Aluminum Design Manual* (AA, 2015).

7.9.2.2.3—Alternative Local Buckling Resistance

As an alternative to Article 7.9.2.2.2, the local buckling resistance of a shape composed of flat elements may be determined as:

$$P_n = F_{nc} A_g \qquad (7.9.2.2.3\text{-}1)$$

where F_{nc} is determined in accordance with Article 7.5.4.4.7.

C7.9.2.2.3

This Article matches Section E.3.2 of the *Aluminum Design Manual* (AA, 2015). Article 7.9.2.2.3 may be used for shapes not addressed by Article 7.5.4.4, or for a more accurate determination of local buckling resistance of any shape.

7.9.2.3—Interaction between Member Buckling and Local Buckling

If the elastic local buckling stress, F_e, is less than the member buckling stress given by Eq. 7.9.2.1.1-2 or 7.9.2.1.1-3 as appropriate, the nominal compressive resistance of the member shall not exceed:

C7.9.2.3

This Article matches Section E.4 of the *Aluminum Design Manual* (AA, 2015).

$$P_n = \left[\frac{0.85\pi^2 E}{(Kl/r)^2}\right]^{1/3} F_e^{2/3} A_g \qquad (7.9.2.3\text{-}1)$$

If the local buckling resistance is determined from Article 7.9.2.2.2, F_e is the smallest elastic local buckling stress for all elements of the cross-section determined from Table 7.5.4.7-1.

If the local buckling resistance is determined from Article 7.9.2.2.3, F_e is the elastic local buckling stress of the cross-section determined by rational analysis.

7.9.3—Limiting Slenderness Ratio

Compression members shall satisfy the slenderness requirements specified below:

- For primary members, $Kl/r \leq 120$
- For secondary members, $Kl/r \leq 140$

where:

K = effective length factor specified in Article 4.6.2.5
l = unbraced length (in.)
r = radius of gyration (in.)

7.9.4—Combined Axial Compression and Flexure

A component subjected to axial compression and flexure shall satisfy:

$$\frac{P_{uc}}{P_{rc}} + \frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1.0 \qquad (7.9.4\text{-}1)$$

where:

P_{uc} = axial compression resulting from the factored loads (kip)
P_{rc} = factored axial compression resistance (kip)
M_{ux} = moment about the major principal axis resulting from the factored loads (kip-in.)
M_{rx} = factored flexural resistance about the major principal axis (kip-in.)
M_{uy} = moment about the minor principal axis resulting from the factored loads (kip-in.)
M_{ry} = factored flexural resistance about the minor principal axis (kip-in.)
M_{ux}, M_{uy} = moments about axes of symmetry, may be determined by:

- A second-order elastic analysis that accounts for the magnification of moment caused by the factored axial load, or

C7.9.4

This Article matches Section H.1 of the *Aluminum Design Manual* (AA, 2015).

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- The approximate single-step adjustment in Article 4.5.3.2.2b.

7.10—FLEXURAL MEMBERS

C7.10

This Article matches Chapter F of the *Aluminum Design Manual* (AA, 2015).

7.10.1—General

This Article addresses members subjected to flexure that are either:

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

The factored flexural resistance, M_r, shall be taken as:

$$M_r = \phi M_n \quad (7.10.1\text{-}1)$$

where:

ϕ = resistance factor for flexure specified in Article 7.5.4.2, taken as:
- ϕ_{ft} for flexural tensile rupture, or
- ϕ_f for all other flexural limit states

M_r shall be taken as the factored flexural resistance (kip-in.) which is the least of the factored flexural resistances for yielding and rupture specified in Article 7.10.2, local buckling specified in Article 7.10.3, and lateral–torsional buckling specified in Article 7.10.4.

7.10.2—Yielding and Rupture

For the limit state of yielding, the flexural resistance, M_{np}, is the least of Z, F_{cy}, $1.5S_tF_{ty}$, and $1.5S_cF_{cy}$.

For the limit state of rupture, the flexural resistance is:

$$M_{nu} = \frac{ZF_{tu}}{k_t} \quad (7.10.2\text{-}1)$$

where:

Z = plastic modulus (in.^{3})
S_t = section modulus on the tension side of the neutral axis (in.^{3})
S_c = section modulus on the compression side of the neutral axis (in.^{3})

7.10.3—Local Buckling

For shapes composed of flat or curved elements, the flexural resistance for the limit state of local buckling, M_{nlb}, shall be determined by Article 7.10.3.1, 7.10.3.2, or 7.10.3.3. Local buckling is not a limit state for wire, rod, or bar.

7.10.3.1—Weighted Average Method

$$M_{nlb} = \frac{F_c I_f}{c_{cf}} + \frac{F_b I_w}{c_{cw}} \tag{7.10.3.1-1}$$

where:

F_c = stress corresponding to the resistance of an element in uniform compression determined using Articles 7.5.4.4.2 through 7.5.4.4.6. The resistance of stiffened elements shall not exceed the resistance of an intermediate stiffener or an edge stiffener. (ksi)

I_f = moment of inertia of the uniform stress elements about the cross-section's neutral axis. These elements include the elements in uniform compression and the elements in uniform tension and their edge or intermediate stiffeners. (in.^{4})

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

F_b = stress corresponding to the resistance of an element in flexural compression determined using Articles 7.5.4.5.2 through 7.5.4.5.5 (ksi)

I_w = moment of inertia of the flexural compression elements about the cross-section's neutral axis. (in.^{4}) These elements include the elements in flexure and their intermediate stiffeners.

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

If there are stiffeners located farther than the compression flange from the cross-section's neutral axis, the compressive flexural resistance shall not exceed $F_{cy} I_f / c_{cs} + F_b I_w / c_{cw}$.

where:

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

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7.10.3.2—Direct Strength Method

$$M_{nlb} = F_b S_{xc} \tag{7.10.3.2-1}$$

where F_b is determined in accordance with Article 7.5.4.5.6.

7.10.3.3—Limiting Element Method

The flexural resistance for local buckling, M_{nlb}, is determined by limiting the stress in any element to the local buckling stress of that element, determined in accordance with Articles 7.5.4.4.2 through 7.5.4.4.6 and 7.5.4.5.2 through 7.5.4.5.5.

7.10.4—Lateral–Torsional Buckling

For the limit state of lateral–torsional buckling, the flexural resistance is M_{nmb} where:

Limit State	M_{nmb}	Slenderness Limits
Inelastic Buckling	$M_{np}\left(1-\dfrac{\lambda}{C_c}\right)+\dfrac{\pi^2 E\lambda S_{xc}}{C_c^3}$	$\lambda \le C_c$
Elastic Buckling	$\dfrac{\pi^2 E S_{xc}}{\lambda^2}$	$\lambda > C_c$

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

To determine the lateral–torsional buckling slenderness, λ, use Articles 7.10.4.2.1 through 7.10.4.2.5. If more than one Article applies, any applicable Article shall be used.

For members without welds, determine the lateral–torsional buckling resistance, $M_{nmb} = M_{nmbo}$, using C_c for unwelded material using Table 7.5.4.3-1 or Table 7.5.4.3-2 and F_{cy}.

For members that are fully weld-affected, determine the lateral–torsional buckling resistance, $M_{nmb} = M_{nmbw}$, using C_c for welded material using Table 7.5.4.3-1 and F_{cyw}.

For members with transverse welds and:

- supported at both ends with no transverse weld farther than $0.05L$ from the member ends, $M_{nmb} = M_{nmbo}$
- supported at both ends with a transverse weld farther than $0.05L$ from the member ends, or supported at only one end with a transverse weld, $M_{nmb} = M_{nmbw}$

For members with longitudinal welds, the lateral–torsional buckling resistance, M_{nmb}, is:

$$M_{nmb} = M_{nmbo}\left(1 - \frac{A_{wz}}{A_f}\right) + M_{nmbw}\left(\frac{A_{wz}}{A_f}\right) \qquad (7.10.4\text{-}1)$$

where:

λ = lateral–torsional buckling slenderness

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 (in.^{2})

A_{wz} = weld-affected 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 (in.^{2})

7.10.4.1—Bending Coefficient, C_b

- 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 using Article 7.10.4.1.1 or 7.10.4.1.2.
- Cantilevers: 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

7.10.4.1.1—Doubly Symmetric Shapes

For doubly symmetric shapes between brace points:

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C} \qquad (7.10.4.1.1\text{-}1)$$

where:

$M_{\max}$ = absolute value of the maximum moment in the unbraced segment (kip-in.)

M_A = absolute value of the moment at the quarter point of the unbraced segment (kip-in.)

M_B = absolute value of the moment at the midpoint of the unbraced segment (kip-in.)

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

7.10.4.1.2—Singly Symmetric Shapes

For singly symmetric shapes between brace points:

- If $I_{yc}/I_y < 0.1$ or $I_{yc}/I_y > 0.9$, $C_b = 1.0$
- If $0.1 < I_{yc}/I_y < 0.9$, C_b shall be determined using Article 7.10.4.1.1

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 Article 7.10.4.1.1, and at the location where the smaller flange is subjected to its maximum compression using $C_b = 1.67$.

7.10.4.2—Slenderness for Lateral–Torsional Buckling

7.10.4.2.1—Shapes Symmetric about the Bending Axis

The slenderness for shapes symmetric about the bending axis is:

$$\lambda = \frac{L_b}{r_{ye}\sqrt{C_b}} \qquad (7.10.4.2.1\text{-}1)$$

where:

L_b = unbraced length (in.)

r_{ye} is:

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

$$r_{ye} = \sqrt{\frac{\sqrt{I_y}}{S_x}\sqrt{C_w + 0.038JL_b^{\,2}}} \qquad (7.10.4.2.1\text{-}2)$$

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

$$r_{ye} = \sqrt{\frac{I_y}{S_x}\left[\pm\frac{d}{4} + \sqrt{\frac{d^2}{16} + \frac{C_w}{I_y} + \frac{0.038JL_b^{\,2}}{I_y}}\right]} \qquad (7.10.4.2.1\text{-}3)$$

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

where:

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

I_y = moment of inertia about the y-axis (in.^{4})
S_x = section modulus about the x-axis (in.^{3})
d = depth of the beam (in.)

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

7.10.4.2.2—Singly Symmetric Open Shapes Asymmetric about the Bending Axis

For singly symmetric open shapes asymmetric about the bending axis and with $I_{yc} < I_{yt}$, determine the slenderness using Article 7.10.4.2.1 where r_{ye} is calculated with I_y, S_x, and J determined as though both flanges were the same as the compression flange with the overall depth, d, remaining the same.

7.10.4.2.3—Closed Shapes

For closed shapes, the slenderness is:

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} \qquad (7.10.4.2.3\text{-}1)$$

7.10.4.2.4—Rectangular Bars

For rectangular bars, the slenderness is:

$$\lambda = \frac{2.3}{t}\sqrt{\frac{dL_b}{C_b}} \qquad (7.10.4.2.4\text{-}1)$$

where:

d = dimension of the bar in the plane of flexure (in.)
t = dimension of the bar perpendicular to the plane of flexure (in.)

7.10.4.2.5—Any Shape

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

$$\lambda = \pi\sqrt{\frac{ES_{xc}}{M_e}} \qquad (7.10.4.2.5\text{-}1)$$

where M_e is the elastic lateral–torsional buckling moment determined by analysis or as:

$$M_e = \frac{C_b \pi^2 E I_y}{L_b^2}\left[U + \sqrt{U^2 + \frac{0.038 J L_b^2}{I_y} + \frac{C_w}{I_y}}\right] \qquad (7.10.4.2.5\text{-}2)$$

where:

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

$$U = C_1 g_0 - \frac{C_2 \beta_x}{2} \qquad (7.10.4.2.5\text{-}3)$$

C_1 and C_2:

- If no transverse loads are applied between the ends of the unbraced segment, $C_1 = 0$ and $C_2 = 1$.
- If transverse loads are applied between the ends of the unbraced segment, C_1 and C_2 shall be taken as 0.5 or determined by rational analysis.

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

$$\beta_x = \frac{1}{I_x}\left(\int_A y^3 dA + \int_A yx^2 dA\right) - 2y_0 \qquad (7.10.4.2.5\text{-}4)$$

For singly symmetric I-shapes, as an alternative,

$$\beta_x = 0.9 d_f \left(\frac{2I_{yc}}{I_y} - 1\right)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right] \qquad (7.10.4.2.5\text{-}5)$$

where:

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 (in.)

I_{yc} = moment of inertia of the compression flange about the y-axis (in.^{3})

Alternately, for singly symmetric I-shapes where the smaller flange area is not less than 80 percent of the larger flange area, β_x shall be taken as $-2y_0$.

y_0 = the shear center's y-coordinate (in.)

7.10.4.3—Interaction between Local Buckling and Lateral–Torsional Buckling

For open shapes:

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

- for which the flange's elastic buckling stress, F_e, given in Article 7.5.4.7 is less than the lateral–torsional buckling stress of the beam, F_b, determined in accordance with Article 7.10.4.2, the lateral–torsional buckling resistance shall not exceed:

$$M_{nmb} = \left[\frac{\pi^2 E}{\left(\dfrac{L_b}{r_{ye}\sqrt{C_b}} \right)^2} \right]^{1/3} F_e^{\,2/3} S_{xc} \qquad (7.10.4.3\text{-}1)$$

7.11—MEMBERS IN SHEAR

7.11.1—General

The factored resistance, V_r, of components in shear shall be taken as the least of the factored resistances for the limit states of buckling, yielding, and rupture, where:

$$V_r = \phi_{vu} V_n \qquad (7.11.1\text{-}1)$$

for the limit state of shear rupture, and

$$V_r = \phi_v V_n \qquad (7.11.1\text{-}2)$$

for the limit states of shear buckling and shear yielding.

where:

ϕ_{vu} = resistance factor for shear rupture specified in Article 7.5.4.2
ϕ_v = resistance factor for shear specified in Article 7.5.4.2
V_n = the resistance given in Article 7.5.4.6 (kip)

7.11.2—Stiffeners

7.11.2.1—Crippling of Flat Webs

The factored resistance of flat webs for the limit state of web crippling shall be taken as:

$$R_r = \phi_w R_n \qquad (7.11.2.1\text{-}1)$$

where:

ϕ_w = resistance factor for web crippling specified in Article 7.5.4.2
R_n = the nominal web crippling resistance determined as follows:

C7.11.2.1

This Article matches Section J.9.1 of the *Aluminum Design Manual* (AA, 2015).

- For concentrated forces applied at a distance from a member support that equals or exceeds $d/2$:

$$R_n = \frac{C_{wa}(N + 5.4)}{C_{wb}} \quad (7.11.2.1\text{-}2)$$

- For concentrated forces applied at a distance from a member support that is less than $d/2$:

$$R_n = \frac{1.2C_{wa}(N + 1.3)}{C_{wb}} \quad (7.11.2.1\text{-}3)$$

in which:

$$C_{wa} = t^2 \sin\theta_w \left(0.46F_{cy} + 0.02\sqrt{EF_{cy}}\right) \quad (7.11.2.1\text{-}4)$$

$$C_{wb} = 0.4 + R_i(1 - \cos\theta_w) \quad (7.11.2.1\text{-}5)$$

where:

d = member depth (in.)
N = length of the bearing surface at the concentrated force (in.)
t = web thickness (in.)
θ_w = angle between the plane of web and the plane of the bearing surface $(\theta_w \leq 90°)$
R_i = for extruded shapes, $R_i = 0$; for all other shapes, R_i is the inside bend radius at the juncture of the flange and web (in.)

7.11.2.2—Bearing Stiffeners

Bearing stiffeners at concentrated forces shall be sufficiently connected to the web to transmit the concentrated force. Such stiffeners shall form a tight and uniform bearing against the flanges unless welds designed to transmit the full concentrated force are provided between flange and stiffener. Only the part of a stiffener cross-section outside the flange-to-web fillet shall be considered effective in bearing. The bearing stiffener shall meet the requirements of Article 7.9 with the length of the stiffener equal to the height of the web.

C7.11.2.2

This Article matches Section J.9.2 of the *Aluminum Design Manual* (AA, 2015).

7.11.2.3—Combined Crippling and Bending of Flat Webs

Combinations of bending and concentrated forces applied at a distance of one-half or more of the member depth from the member support shall satisfy the following equation:

C7.11.2.3

This Article matches Section J.9.3 of the *Aluminum Design Manual* (AA, 2015).

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$$\left(\frac{R_u}{R_r}\right)^{1.5} + \left(\frac{M_u}{M_r}\right)^{1.5} \leq 1.0 \quad (7.11.2.3\text{-}1)$$

where:

R_u = concentrated force resulting from factored loads (kip)
R_r = factored concentrated force resistance determined in accordance with Article 7.11.2.1 (kip)
M_u = moment in the member at the location of the concentrated force resulting from factored loads (kip-in.)
M_r = factored flexural resistance determined in accordance with Article 7.10 (kip-in.)

7.12—CONNECTIONS AND SPLICES

7.12.1—General

Connections shall be designed for the factored member force effects.

Members and connections shall be designed for the effects of any eccentricity in joints.

7.12.2—Bolted Connections

7.12.2.1—General

Bolted connections, except for lacing and handrails, shall not contain less than two bolts.

Contract documents shall specify that all joint surfaces, including surfaces under bolt heads, nuts, and washers, shall be free from foreign material.

Articles 6.13.2.1.1 and 6.13.2.1.2 shall be used to determine whether a connection shall be designed as a slip-critical connection or a bearing connection. Only A325 bolts shall be used in slip-critical connections. The slip resistance of slip-critical connections shall be determined in accordance with Article 7.12.2.8.

C7.12.2.1

Additional requirements related to bolts, nuts, and washers are provided in Article 7.4.3.

7.12.2.2—Factored Resistance

For slip-critical connections, the factored resistance, R_r, of a bolt at the Service II Load Combination shall be taken as:

$$R_r = R_n \quad (7.12.2.2\text{-}1)$$

where:

R_n = nominal slip resistance specified in Article 7.12.2.8

C7.12.2.2

This Article is similar to Article 6.13.2.2.

The resistance of steel parts of the connection (the bolts) is addressed in Section 6, and the resistance of the aluminum parts of the connection (the connected parts) is addressed in Section 7.

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The factored resistance, R_r or T_r, of a bolted connection at the strength limit state shall be taken as either:

$$R_r = \phi R_n \tag{7.12.2.2-2}$$

or:

$$T_r = \phi T_n \tag{7.12.2.2-3}$$

where:

ϕ = resistance factor for bolts taken as"

- ϕ_s for bolts in shear as specified in Article 6.5.4.2
- ϕ_t for bolts in tension as specified in Article 6.5.4.2
- ϕ_{bb} for bolts in bearing as specified in Article 7.5.4.2
- ϕ_y or ϕ_u for connected material in tension as specified in Article 7.5.4.2
- ϕ_v for connected material in shear as specified in Article 7.5.4.2

R_n = nominal shear resistance of the bolt or connected material taken as follows:

- For bolts in shear, R_n shall be taken as specified in Article 7.12.2.7
- For the connected material, R_n shall be taken as specified in Article 7.12.2.9
- For the connected material in tension or shear, R_n shall be taken as specified in Article 7.12.5

T_n = nominal tensile resistance of the bolt taken as follows:

- For bolts in tension, T_n shall be taken as specified in Article 7.12.2.10
- For bolts in combined tension and shear, T_n shall be taken as specified in Article 7.12.2.11

7.12.2.3—Washers

Hardened washers shall be provided for A325 bolted connections where required by Article 6.13.2.3.2.

7.12.2.4—Holes

Holes shall comply with Article 6.13.2.4.

7.12.2.5—Size of Bolts

The size of bolts shall comply with Article 6.13.2.5, except that the minimum nominal diameter shall be 0.5 in.

7.12.2.6—Spacing of Bolts

7.12.2.6.1—Minimum Spacing and Clear Distance

The distance between bolt centers shall not be less than 2.5 times the nominal diameter of the bolt. For oversized or slotted holes, the minimum clear distance between the edges of adjacent bolt holes shall not be less than twice the nominal diameter of the bolt.

C7.12.2.6.1

The requirement for the distance between hole centers matches Section J.3.2 of the *Aluminum Design Manual* (AA, 2015). The requirement for the clear distance between the edges of adjacent holes matches Article 6.13.2.6.1.

7.12.2.6.2—Minimum Edge Distance

The distance from the center of a bolt to an edge of a part shall not be less than 1.5 times the nominal diameter of the bolt. See Article 7.12.2.9 for the effect of edge distance on bearing strength.

C7.12.2.6.2

This Article matches Section J.3.3 of the *Aluminum Design Manual* (AA, 2015). Bearing strength is reduced when the hole is less than two bolt diameters from an edge.

7.12.2.7—Shear Resistance

The nominal shear resistance of bolts shall be determined in accordance with Article 6.13.2.7.

7.12.2.8—Slip Resistance

The nominal slip resistance of a bolt in a slip-critical connection shall be determined in accordance with Article 6.13.2.8. Aluminum members in slip-critical connections shall have tensile yield strength of at least 15 ksi. Aluminum surfaces abrasion-blasted with coal slag to SSPC SP-5 (SSPC, 2007) to an average substrate profile of 2.0 mils in contact with similar aluminum surfaces or zinc painted steel surfaces with a maximum dry film thickness of 4 mils shall be considered to be Class B surface conditions. Slip coefficients for other surfaces shall be determined in accordance with the Research Council on Structural Connection's *Specification for Structural Joints Using High Strength Bolts* (RCSC, 2009).

C7.12.2.8

This Article matches Section J.3.7 of the *Aluminum Design Manual* (AA, 2015).

7.12.2.9—Bearing Resistance at Holes and Slots

The nominal bearing resistance of a connected part shall be determined as follows:

- For a bolt in a hole:

$$R_n = d_e tF_{tu} \leq 2\, DtF_{tu} \qquad (7.12.2.9\text{-}1)$$

- For a bolt in a slot with the slot perpendicular to the direction of force:

$$R_n = 1.33DtF_{tu} \qquad (7.12.2.9\text{-}2)$$

The edge distance perpendicular to the slot length and slot length shall be sized to avoid overstressing the material between the slot and the edge of the part.

C7.12.2.9

This Article matches Section J.3.6 of the *Aluminum Design Manual* (AA, 2015).

where:

d_e = distance from the center of the bolt to the edge of the part in the direction of force (in.)
t = for plain holes, thickness of the connected part; for countersunk holes, thickness of the connected part less $^1/_2$ the countersink depth (in.)
F_{tu} = tensile ultimate strength of the connected part (ksi)
D = nominal diameter of the bolt (in.)

7.12.2.10—Tensile Resistance

The nominal tensile resistance of bolts shall be determined as specified in Article 6.13.2.10.

7.12.2.11—Combined Tension and Shear

The nominal tensile resistance of bolts subjected to combined shear and axial tension shall be determined in accordance with Article 6.13.2.11.

7.12.2.12—Shear Resistance of Anchor Bolts

The nominal shear resistance of anchor bolts shall be determined in accordance with Article 6.13.2.12.

7.12.3—Welded Connections

7.12.3.1—General

Welding shall comply with AWS D1.2/D1.2M.

7.12.3.2—Factored Resistance

7.12.3.2.1—General

The factored resistance of welded connections, R_r, at the strength limit state shall be taken as given in Articles 7.12.3.2.2 through 7.12.3.2.4. Filler strengths shall be taken from Table 7.12.3.2.1-1.

Table 7.12.3.2.1-1—Filler Strengths

Filler	Tensile Ultimate Strength, F_{tuw} (ksi)
4043	24
5183	40
5356	35
5556	42

C7.12.3.2.1

Filler strengths given in Table 7.12.3.2.1-1 match those in Table A.3.6 in the *Aluminum Design Manual* (AA, 2015).

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7.12.3.2.2—Complete Penetration Groove-Welded Connections

7.12.3.2.2a—Tension and Compression

The factored resistance of complete penetration groove-welded connections subjected to tension or compression normal to the effective area of the weld shall be taken as:

$$R_r = \phi_e F_{tuw} \qquad (7.12.3.2.2a\text{-}1)$$

where:

ϕ_e = resistance factor for weld metal specified in Article 7.5.4.2

F_{tuw} = least of the welded tensile ultimate strengths of the base metals and the filler (ksi). Welded tensile ultimate strengths of base metals shall be determined from Article 7.4.1 and tensile ultimate strengths of fillers from Table 7.12.3.2.1-1.

The factored resistance of complete penetration groove-welded connections subjected to tension or compression parallel to the axis of the weld shall be taken as the factored resistance of the base metal.

C7.12.3.2.2a

The strength of complete penetration groove welds may be governed by the welded strength of either of the base metals joined or by the strength of the filler metal. Usually, the filler metal is selected so that its strength equals or exceeds the strength of the welded base metals, but this is not required.

7.12.3.2.2b—Shear

The factored resistance of complete penetration groove-welded connections subjected to shear on the effective area of the weld shall be taken as:

$$R_r = \phi_e F_{suw} \qquad (7.12.3.2.2b\text{-}1)$$

where:

ϕ_e = resistance factor for weld metal specified in Article 7.5.4.2

F_{suw} = least of the welded shear ultimate strengths of the base metals and the filler (ksi)

Welded shear ultimate strengths of base metals shall be determined from Article 7.4.1 and shear ultimate strengths of fillers shall be taken as $0.5F_{tuw}$, where F_{tuw} is determined from Table 7.12.3.2.1-1.

7.12.3.2.3—Partial Penetration Groove-Welded Connections

Where practical, partial penetration groove welds should be avoided.

C7.12.3.2.3

Partial penetration groove welds may be used if necessary, but where practical should be avoided.

7.12.3.2.3a—Tension and Compression

The factored resistance of partial penetration groove-welded connections subjected to tension normal to the effective area of the weld shall be taken as the lesser of:

$$R_r = 0.6\phi_e F_{tuw} \quad (7.12.3.2.3a\text{-}1)$$

where:

ϕ_e = resistance factor for weld metal specified in Article 7.5.4.2
F_{tuw} = tensile ultimate strength of the filler (ksi) from Table 7.12.3.2.1-1

or:

$$R_r = \phi_e F_{tuw} \quad (7.12.3.2.3a\text{-}2)$$

where:

ϕ_e = resistance factor for base metal at welds specified in Article 7.5.4.2
F_{tuw} = welded tensile ultimate strength of the base metal from Article 7.4.1 (ksi)

The factored resistance of partial penetration groove-welded connections subjected to tension or compression parallel to the axis of the weld or compression normal to the effective area shall be taken as the factored resistance of the base metal.

C7.12.3.2.3a

The strength of partial penetration groove weld metal is factored by 0.6 to account for the notch effect that may occur due to incomplete penetration at the root of the weld.

7.12.3.2.3b—Shear

The factored resistance of partial penetration groove-welded connections subjected to shear on the effective area of the weld shall be taken as the lesser of:

$$R_r = 0.6\phi_e F_{suw} \quad (7.12.3.2.3b\text{-}1)$$

where:

ϕ_e = resistance factor for weld metal specified in Article 7.5.4.2
F_{suw} = shear ultimate strength of the filler taken as $0.5F_{tuw}$, where F_{tuw} is determined from Table 7.12.3.2.1-1 (ksi)

or:

$$R_r = \phi_e F_{suw} \quad (7.12.3.2.3b\text{-}2)$$

where:

ϕ_e = resistance factor for base metal at welds specified in Article 7.5.4.2

F_{suw} = welded shear ultimate strength of the base metal from Article 7.4.1 (ksi)

7.12.3.2.4—Fillet-Welded Connections

The factored resistance of fillet-welded connections subjected to tension or compression parallel to the axis of the weld or compression normal to the axis of the weld shall be taken as the factored resistance of the base metal.

The factored resistance of fillet-welded connections subjected to tension perpendicular to the axis of the weld or shear shall be taken as:

$$R_r = \phi_e F_{sw} \tag{7.12.3.2.4-1}$$

where:

ϕ_e = resistance factor for weld metal specified in Article 7.5.4.2

F_{sw} = least of (kips/in.):

- the product of the weld filler's shear ultimate strength, $0.5F_{tuw}$ (ksi), and the weld's effective throat (in.)
- for base metal in shear at the weld–base metal joint, the product of the base metal's welded shear ultimate strength, $0.6F_{tuw}$ (ksi), and the fillet size, S_w (in.)
- for base metal in tension at the weld–base metal joint, the product of the base metal's welded tensile ultimate strength, F_{tuw} (ksi), and the fillet size, S_w (in.)

Welded tensile ultimate strengths of base metals shall be determined from Article 7.4.1 and tensile ultimate strengths of weld fillers from Table 7.12.3.2.1-1.

C7.12.3.2.4

The strength of fillet welds may be governed by either the base metal's welded strength or by the filler metal strength. Usually (but not always), the strength of the filler metal governs the strength of the joint because the area of the weld is based on the weld throat, which is less than the area of the base metal which is based on the weld size.

7.12.3.3—Effective Area

The effective area shall be determined as defined in AWS D1.2/D1.2M.

C7.12.3.3

Weld effective areas given in the *Aluminum Design Manual* (AA, 2015) match those given in AWS D1.2/D1.2M.

7.12.3.4—Size of Fillet Welds

The size used in design of a fillet weld along edges of connected parts shall not exceed:

- For material less than 0.25 in. thick, the thickness of the material;
- For material 0.25 in. or more in thickness, 0.625 in. less than the material thickness, unless the weld is designated on the contract documents to be built out to obtain full throat thickness.

C7.12.3.4

Maximum fillet weld size requirements match those given in Article 6.13.3.4 for steel welds. Minimum fillet weld size requirements match those given in AWS D1.2/D1.2M, Table 2.2. If fillet welds are too small they may crack upon cooling or when stressed by unanticipated loads.

The minimum size of a fillet weld shall be as given in Table 7.12.3.4-1, except that the weld size shall not exceed the thickness of the thinner part joined.

Table 7.12.3.4-1—Minimum Size of Fillet Welds

Base Metal Thickness, *t*, of Thicker Part Joined (in.)	Minimum Size of Fillet Weld (in.)
$t \leq 0.25$	0.125
$0.25 < t \leq 0.5$	0.1875
$t > 0.5$	0.25

7.12.3.5—Fillet Weld End Returns

Fillet weld end returns shall comply with Article 6.13.3.6.

7.12.4—Block Shear Rupture Resistance

The block shear factored resistance shall be taken as:

$$R_r = \phi_{bs} R_n \tag{7.12.4-1}$$

where:

ϕ_{bs} = resistance factor for block shear specified in Article 7.5.4.2

For connections on a failure path with shear on some segments and tension on the other segments:

If $F_{tu} A_{nt} \geq F_{su} A_{nv}$, then

$$R_n = F_{sy} A_{gv} + F_{tu} A_{nt} \tag{7.12.4-2}$$

otherwise:

$$R_n = F_{su} A_{nv} + F_{ty} A_{gt} \tag{7.12.4-3}$$

where for bolted connections:

F_{tu} = specified minimum tensile ultimate strength (ksi)
A_{nt} = net area in tension (in.^{2})
F_{su} = shear ultimate strength (ksi)
A_{nv} = net area in shear (in.^{2})
F_{sy} = shear yield strength (ksi)
A_{gv} = gross area in shear (in.^{2})
F_{ty} = specified minimum tensile yield strength (ksi)
A_{gt} = gross area in tension (in.^{2})

For weld-affected zones, use F_{tuw} for F_{tu} and F_{suw} for F_{su}.

C7.12.4

This Article matches Section J.7.3 of the *Aluminum Design Manual* (AA, 2015).

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7.12.5—Connection Elements

7.12.5.1—General

This Article applies to the design of connection elements such as plates, gussets, angles, and brackets.

7.12.5.2—Tension

The factored tensile resistance, R_r, of connection elements is the lesser of the resistances for tensile yielding and tensile rupture given in Article 7.8.2.1.

7.12.5.3—Shear

The factored shear resistance, R_r, of connection elements is the lesser of the resistances for shear yielding and shear rupture. The factored shear yielding resistance of connection elements shall be taken as:

$$R_r = \phi_v F_{sy} A_{gv} \qquad (7.12.5.3\text{-}1)$$

where:

ϕ_v = resistance factor for shear specified in Article 7.5.4.2
F_{sy} = shear yield strength of the connection element (ksi)
A_{gv} = gross area of the connection element subject to shear (in.^{2})

The factored shear rupture resistance of connection elements shall be taken as:

$$R_r = \phi_{vu} F_{su} A_{nv} \qquad (7.12.5.3\text{-}2)$$

where:

ϕ_{vu} = resistance factor for shear rupture of connection elements specified in Article 7.5.4.2
F_{su} = shear ultimate strength of the connection element (ksi)
A_{nv} = net area of the connection element subject to shear (in.^{2})

For welded connection elements, $F_{sy} = F_{syw}$ and $F_{su} = F_{suw}$.

where:

F_{syw} = shear yield strength in the weld-affected zone (ksi)

C7.12.5.3

This Article is similar to Article 6.13.5.3.

7.12.6—Splices

Splices shall be designed at the strength limit state to satisfy the connection requirements of Article 7.12.1.

7.12.7—Pins

7.12.7.1—Factored Resistance

The factored resistance of a pinned connection shall be taken as:

$$R_r = \phi R_n \quad (7.12.7.1\text{-}1)$$

or

$$M_r = \phi M_n \quad (7.12.7.1\text{-}2)$$

where:

ϕ = resistance factor for pins taken as:

- ϕ_v for yielding of pins in shear as specified in Article 7.5.4.2
- ϕ_{vu} for rupture of pins in shear as specified in Article 7.5.4.2
- ϕ_f for yielding of pins in flexure as specified in Article 7.5.4.2
- ϕ_{ft} for rupture of pins in flexure as specified in Article 7.5.4.2
- ϕ_b for pins in bearing as specified in Article 7.5.4.2
- ϕ_{vu} for connected material in shear as specified in Article 7.5.4.2

R_n = nominal shear resistance of the pin or connected material taken as follows:

- For yielding of pins in shear, R_n shall be taken as specified in Article 7.12.7.4
- For rupture of pins in shear, R_n shall be taken as specified in Article 7.12.7.4
- For pins in bearing, R_n shall be taken as specified in Article 7.12.7.6
- For the connected material in shear, R_n shall be taken as specified in Article 7.12.5.3

M_n = nominal flexural resistance of the pin taken as follows:

- For yielding of pins in flexure, R_n shall be taken as specified in Article 7.12.7.5
- For rupture of pins in flexure, R_n shall be taken as specified in Article 7.12.7.5

C7.12.7.1

This Article matches Section J.6 of the *Aluminum Design Manual* (AA, 2015).

7.12.7.2—Minimum Edge Distance

The distance from the center of a pin to the edge of a part shall not be less than 1.5 times the nominal diameter of the pin. See Article 7.12.7.6 for the effect of edge distance on bearing strength.

7.12.7.3—Holes

The nominal diameter of holes for pins shall not be more than 0.0313 in. greater than the nominal diameter of the pin.

7.12.7.4—Shear Resistance

The nominal resistance for shear yielding is:

$$R_n = \frac{\pi D^2 F_{sy}}{4} \quad (7.12.7.4\text{-}1)$$

where:

D = nominal diameter of the pin (in.)
F_{sy} = shear yield strength of the pin determined in accordance with Table 7.4.1-3

The nominal resistance for shear rupture is:

$$R_n = \frac{\pi D^2 F_{su}}{4} \quad (7.12.7.4\text{-}2)$$

where:

D = nominal diameter of the pin (in.)
F_{su} = shear ultimate strength of the pin determined in accordance with Table 7.4.1-3

7.12.7.5—Flexural Resistance

The nominal resistance for flexural yielding is:

$$M_n = \frac{\pi D^3 F_{ty}}{21.3} \quad (7.12.7.5\text{-}1)$$

where:

D = nominal diameter of the pin (in.)
F_{ty} = tensile yield strength of the pin determined in accordance with Table 7.4.1-1

The nominal resistance for flexural rupture is:

$$M_n = \frac{\pi D^3 F_{tu}}{21.3} \quad (7.12.7.5\text{-}2)$$

where:

D = nominal diameter of the pin (in.)
F_{tu} = tensile ultimate strength of the pin determined in accordance with Table 7.4.1-1

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7.12.7.6—Bearing Resistance

The nominal bearing resistance of a connected part shall be determined as follows:

$$R_n = \frac{d_e t F_{tu}}{1.5} \leq 1.33 D t F_{tu} \tag{7.12.7.6-1}$$

where:

d_e = distance from the center of the pin to the edge of the part in the direction of force (in.)
t = thickness of the connected part (in.)
F_{tu} = tensile ultimate strength of the connected part (ksi)
D = nominal diameter of the pin (in.)

7.12.7.7—Combined Shear and Flexure

For pins subjected to shear and flexure:

$$\left(\frac{P_u}{\phi R_n}\right)^3 + \left(\frac{M_u}{\phi M_n}\right) \leq 1.0 \tag{7.12.7.7-1}$$

where:

P_u = shear force on the pin due to the factored loads (kip)
R_n = nominal shear resistance of the pin (kip)
M_u = moment on the pin due to the factored loads (k-in.)
M_n = nominal flexural resistance of the pin (k-in.)

7.13—PROVISIONS FOR STRUCTURE TYPES

7.13.1—Deck Superstructures

7.13.1.1—General

The provisions of this Article shall apply to the design of bridges that use an aluminum deck that is connected to the superstructure with slip-critical connections. The aluminum deck shall be considered an integral part of the bridge superstructure and shall participate in resisting global force effects on the bridge. Connections between the deck and the main structural members shall be designed for interaction effects specified in Article 9.4.1.

C7.13.1.1

Aluminum decks transfer the load from vehicles' tires to the bridge superstructure.

For decks that act compositely with the bridge girders, this load transfer can be thought of as three systems:

- System 3 transfers the load from the tire patch on the top flange of the deck to the ribs that support the top flange. This load causes bending in the top flange.
- System 2 transfers the load transverse to traffic to the bridge girders. This load creates transverse forces in the top and bottom flanges and ribs of the deck.

- System 1 transfers the load in the direction of traffic in participation with the bridge girders to the bridge supports. This load causes longitudinal axial force in the deck.

7.13.1.2—Equivalent Strips

For decks with continuous top and bottom flanges, the equivalent strip used for analysis in accordance with Article 4.6.2.1 shall be as determined for cast-in-place concrete decks.

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