CHAPTER J

DESIGN OF CONNECTIONS

This chapter addresses connecting elements, connectors and the affected elements of connected members not subject to *fatigue loads*.

The chapter is organized as follows:

User Note: For cases not included in this chapter, the following sections apply:
- Chapter K Design of HSS and Box Member Connections
- Appendix 3 Design for Fatigue

J1. GENERAL PROVISIONS

1. Design Basis

The *design strength*, ϕR_n, and the *allowable strength* R_n/Ω, of *connections* shall be determined in accordance with the provisions of this chapter and the provisions of Chapter B.

The *required strength* of the connections shall be determined by *structural analysis* for the specified *design loads*, consistent with the type of construction specified, or shall be a proportion of the required strength of the connected members when so specified herein.

Where the gravity axes of intersecting axially loaded members do not intersect at one point, the effects of eccentricity shall be considered.

2. Simple Connections

Simple connections of *beams*, girders and trusses shall be designed as flexible and are permitted to be proportioned for the reaction shears only, except as otherwise indicated in the design documents. Flexible beam connections shall accommodate end rotations of simple beams. Some inelastic but self-limiting deformation in the connection is permitted to accommodate the end rotation of a simple beam.

3. Moment Connections

End connections of restrained *beams*, girders and trusses shall be designed for the combined effect of forces resulting from moment and shear induced by the rigidity of the connections. Response criteria for moment connections are provided in Section B3.6b.

User Note: See Chapter C and Appendix 7 for analysis requirements to establish the *required strength* for the design of connections.

4. Compression Members With Bearing Joints

Compression members relying on *bearing* for *load* transfer shall meet the following requirements:

(1) When *columns* bear on bearing plates or are finished to bear at *splices*, there shall be sufficient connectors to hold all parts securely in place.

(2) When compression members other than columns are finished to bear, the splice material and its connectors shall be arranged to hold all parts in line and their required strength shall be the lesser of:

(i) An axial tensile force of 50% of the required compressive strength of the member; or

(ii) The moment and shear resulting from a transverse load equal to 2% of the required compressive strength of the member. The transverse load shall be applied at the location of the splice exclusive of other loads that act on the member. The member shall be taken as pinned for the determination of the shears and moments at the splice.

User Note: All compression *joints* should also be proportioned to resist any tension developed by the *load combinations* stipulated in Section B2.

5. Splices in Heavy Sections

When tensile forces due to applied tension or flexure are to be transmitted through *splices* in heavy sections, as defined in Sections A3.1c and A3.1d, by complete-joint-penetration groove (CJP) welds, the following provisions apply: (1) material notch-toughness requirements as given in Sections A3.1c and A3.1d; (2) weld access hole details as given in Section J1.6; (3) *filler metal* requirements as given in Section J2.6; and (4) thermal cut surface preparation and inspection requirements as given in Section M2.2. The foregoing provision is not applicable to splices of elements of *built-up shapes* that are welded prior to assembling the shape.

User Note: CJP groove welded splices of heavy sections can exhibit detrimental effects of weld shrinkage. Members that are sized for compression that are also subject to tensile forces may be less susceptible to damage from shrinkage if they are spliced using partial-joint-penetration PJP groove welds on the flanges and fillet-welded web plates, or using bolts for some or all of the splice.

6. Weld Access Holes

All weld access holes required to facilitate welding operations shall be detailed to provide room for weld backing as needed. The access hole shall have a length from the toe of the weld preparation not less than $1^1/_2$ times the thickness of the material in which the hole is made, nor less than $1^1/_2$ in. (38 mm). The access hole shall have a height not less than the thickness of the material with the access hole, nor less than $^3/_4$ in. (19 mm), nor does it need to exceed 2 in. (50 mm).

For sections that are rolled or welded prior to cutting, the edge of the web shall be sloped or curved from the surface of the flange to the *reentrant* surface of the access hole. In hot-rolled shapes, and *built-up shapes* with CJP *groove welds* that join the web-to-flange, weld access holes shall be free of notches and sharp reentrant corners. No arc of the weld access hole shall have a radius less than $^3/_8$ in. (10 mm).

In built-up shapes with fillet or *partial-joint-penetration groove welds* that join the web-to-flange, weld access holes shall be free of notches and sharp reentrant corners. The access hole shall be permitted to terminate perpendicular to the flange, providing the weld is terminated at least a distance equal to the weld size away from the access hole.

For heavy sections as defined in Sections A3.1c and A3.1d, the *thermally cut* surfaces of weld access holes shall be ground to bright metal and inspected by either magnetic particle or dye penetrant methods prior to deposition of *splice* welds. If the curved transition portion of weld access holes is formed by predrilled or sawed holes, that portion of the access hole need not be ground. Weld access holes in other shapes need not be ground nor inspected by dye penetrant or magnetic particle methods.

7. Placement of Welds and Bolts

Groups of welds or bolts at the ends of any member which transmit axial force into that member shall be sized so that the center of gravity of the group coincides with the center of gravity of the member, unless provision is made for the eccentricity. The foregoing provision is not applicable to end connections of single angle, double angle and similar members.

8. Bolts in Combination With Welds

Bolts shall not be considered as sharing the *load* in combination with welds, except that shear connections with any grade of bolts permitted by Section A3.3, installed in standard holes or short slots transverse to the direction of the load, are permitted to be considered to share the load with longitudinally loaded *fillet welds*. In such connections the *available strength* of the bolts shall not be taken as greater than 50% of the available strength of bearing-type bolts in the connection.

In making welded alterations to structures, existing rivets and high-strength bolts tightened to the requirements for *slip-critical connections* are permitted to be utilized for carrying loads present at the time of alteration and the welding need only provide the additional required strength.

9. High-Strength Bolts in Combination With Rivets

In both new work and alterations, in connections designed as *slip-critical connections* in accordance with the provisions of Section J3, high-strength bolts are permitted to be considered as sharing the *load* with existing rivets.

10. Limitations on Bolted and Welded Connections

Joints with *pretensioned bolts* or welds shall be used for the following connections:

(1) *Column splices* in all multi-story structures over 125 ft (38 m) in height
(2) Connections of all *beams* and *girders* to columns and any other beams and girders on which the *bracing* of columns is dependent in structures over 125 ft (38 m) in height
(3) In all structures carrying cranes of over 5 ton (50 kN) capacity: roof truss splices and connections of trusses to columns; column splices; column bracing; knee braces; and crane supports
(4) Connections for the support of machinery and other live *loads* that produce impact or reversal of load

Snug-tightened joints or joints with ASTM A307 bolts shall be permitted except where otherwise specified.

J2. WELDS

All provisions of AWS D1.1/D1.1M apply under this Specification, with the exception that the provisions of the listed AISC Specification Sections apply under this Specification in lieu of the cited AWS provisions as follows:

(1) Section J1.6 in lieu of AWS D1.1/D1.1M, Section 5.17.1
(2) Section J2.2a in lieu of AWS D1.1/D1.1M, Section 2.3.2
(3) Table J2.2 in lieu of AWS D1.1/D1.1M, Table 2.1
(4) Table J2.5 in lieu of AWS D1.1/D1.1M, Table 2.3
(5) Appendix 3, Table A-3.1 in lieu of AWS D1.1/D1.1M, Table 2.5
(6) Section B3.11 and Appendix 3 in lieu of AWS D1.1/D1.1M, Section 2, Part C
(7) Section M2.2 in lieu of AWS D1.1/D1.1M, Sections 5.15.4.3 and 5.15.4.4

1. Groove Welds

1a. Effective Area

The effective area of *groove welds* shall be considered as the length of the weld times the effective throat.

The effective throat of a *complete-joint-penetration (CJP) groove weld* shall be the thickness of the thinner part joined.

The effective throat of a *partial-joint-penetration (PJP) groove weld* shall be as shown in Table J2.1.

TABLE J2.1
Effective Throat of Partial-Joint-Penetration Groove Welds

Welding Process	Welding Position F (flat), H (horizontal), V (vertical), OH (overhead)	Groove Type (AWS D1.1/D1.1M, Figure 3.3)	Effective Throat
Shielded metal arc (SMAW)	All	J or U groove	depth of groove
Gas metal arc (GMAW) Flux cored arc (FCAW)	All	60° V	depth of groove
Submerged arc (SAW)	F	J or U groove 60° bevel or V	depth of groove
Gas metal arc (GMAW) Flux cored arc (FCAW)	F, H	45° bevel	depth of groove
Shielded metal arc (SMAW)	All	45° bevel	depth of groove minus $^1/_8$ in. (3 mm)
Gas metal arc (GMAW) Flux cored arc (FCAW)	V, OH	45° bevel	depth of groove minus $^1/_8$ in. (3 mm)

User Note: The effective throat of a partial-joint-penetration groove weld is dependent on the process used and the weld position. The *design drawings* should either indicate the effective throat required or the weld strength required, and the fabricator should detail the *joint* based on the weld process and position to be used to weld the joint.

The effective weld throat for flare groove welds when filled flush to the surface of a round bar or a 90° bend in a *formed section* or rectangular *HSS*, shall be as shown in Table J2.2, unless other effective throats are demonstrated by tests. The effective throat of flare groove welds filled less than flush shall be as shown in Table J2.2, less the greatest perpendicular dimension measured from a line flush to the base metal surface to the weld surface.

Larger effective throats than those in Table J2.2 are permitted for a given welding procedure specification (WPS), provided the fabricator can establish by qualification the consistent production of such larger effective throat. Qualification shall consist of sectioning the weld normal to its axis, at mid-length and terminal ends. Such sectioning shall be made on a number of combinations of material sizes representative of the range to be used in the fabrication.

TABLE J2.2
Effective Weld Throats of Flare Groove Welds

Welding Process	Flare Bevel Groove[a]	Flare V-Groove
GMAW and FCAW-G	$^5/_8\ R$	$^3/_4\ R$
SMAW and FCAW-S	$^5/_{16}\ R$	$^5/_8\ R$
SAW	$^5/_{16}\ R$	$^1/_2\ R$

[a] For flare bevel groove with $R < 3/8$ in. (10 mm), use only reinforcing fillet weld on filled flush joint.
General note: R = radius of joint surface (can be assumed to be $2t$ for HSS), in. (mm)

TABLE J2.3
Minimum Effective Throat of Partial-Joint-Penetration Groove Welds

Material Thickness of Thinner Part Joined, in. (mm)	Minimum Effective Throat, [a] in. (mm)
To $^1/_4$ (6) inclusive	$^1/_8$ (3)
Over $^1/_4$ (6) to $^1/_2$ (13)	$^3/_{16}$ (5)
Over $^1/_2$ (13) to $^3/_4$ (19)	$^1/_4$ (6)
Over $^3/_4$ (19) to $1^1/_2$ (38)	$^5/_{16}$ (8)
Over $1^1/_2$ (38) to $2^1/_4$ (57)	$^3/_8$ (10)
Over $2^1/_4$ (57) to 6 (150)	$^1/_2$ (13)
Over 6 (150)	$^5/_8$ (16)

[a] See Table J2.1.

1b. Limitations

The minimum effective throat of a *partial-joint-penetration groove weld* shall not be less than the size required to transmit calculated *forces* nor the size shown in Table J2.3. Minimum weld size is determined by the thinner of the two parts joined.

2. Fillet Welds

2a. Effective Area

The effective area of a *fillet weld* shall be the *effective length* multiplied by the effective throat. The effective throat of a fillet weld shall be the shortest distance from the root to the face of the diagrammatic weld. An increase in effective throat

TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thinner Part Joined, in. (mm)	Minimum Size of Fillet Weld, [a] in. (mm)
To $^1/_4$ (6) inclusive	$^1/_8$ (3)
Over $^1/_4$ (6) to $^1/_2$ (13)	$^3/_{16}$ (5)
Over $^1/_2$ (13) to $^3/_4$ (19)	$^1/_4$ (6)
Over $^3/_4$ (19)	$^5/_{16}$ (8)

[a] Leg dimension of fillet welds. Single pass welds must be used.
Note: See Section J2.2b for maximum size of fillet welds.

is permitted if consistent penetration beyond the root of the diagrammatic weld is demonstrated by tests using the production process and procedure variables.

For fillet welds in holes and slots, the effective length shall be the length of the centerline of the weld along the center of the plane through the throat. In the case of overlapping fillets, the effective area shall not exceed the nominal cross-sectional area of the hole or slot, in the plane of the *faying surface*.

2b. Limitations

The minimum size of fillet welds shall be not less than the size required to transmit calculated forces, nor the size as shown in Table J2.4. These provisions do not apply to *fillet weld reinforcements* of partial- or *complete-joint-penetration groove welds*.

The maximum size of *fillet welds* of connected parts shall be:

(a) Along edges of material less than $^1/_4$-in. (6 mm) thick; not greater than the thickness of the material.
(b) Along edges of material $^1/_4$ in. (6 mm) or more in thickness; not greater than the thickness of the material minus $^1/_{16}$ in. (2 mm), unless the weld is especially designated on the drawings to be built out to obtain full-throat thickness. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld is permitted to be less than $^1/_{16}$ in. (2 mm) provided the weld size is clearly verifiable.

The minimum length of fillet welds designed on the basis of strength shall be not less than four times the nominal weld size, or else the effective size of the weld shall be considered not to exceed one quarter of its length. If longitudinal fillet welds are used alone in end connections of flat-bar tension members, the length of each fillet weld shall be not less than the perpendicular distance between them. For the effect of longitudinal fillet weld length in end connections upon the effective area of the connected member, see Section D3.

For end-loaded fillet welds with a length up to 100 times the weld size, it is permitted to take the *effective length* equal to the actual length. When the length of the end-loaded fillet weld exceeds 100 times the weld size, the effective length shall be determined by multiplying the actual length by the reduction factor, β, determined as follows:

$$\beta = 1.2 - 0.002(l/w) \le 1.0 \quad \text{(J2-1)}$$

where
l = actual length of end-loaded weld, in. (mm)
w = size of weld leg, in. (mm)

When the length of the weld exceeds 300 times the leg size, w, the effective length shall be taken as $180w$.

Intermittent fillet welds are permitted to be used to transfer calculated *stress* across a *joint* or *faying surfaces* and to join components of *built-up members*. The length of any segment of intermittent fillet welding shall be not less than four times the weld size, with a minimum of $1^1/_2$ in. (38 mm).

In *lap joints,* the minimum amount of lap shall be five times the thickness of the thinner part joined, but not less than 1 in. (25 mm). Lap joints joining plates or bars subjected to axial stress that utilize transverse fillet welds only shall be fillet welded along the end of both lapped parts, except where the deflection of the lapped parts is sufficiently restrained to prevent opening of the joint under maximum loading.

Fillet weld terminations are permitted to be stopped short or extend to the ends or sides of parts or be boxed except as limited by the following:

(1) For overlapping elements of members in which one connected part extends beyond an edge of another connected part that is subject to calculated tensile stress, fillet welds shall terminate not less than the size of the weld from that edge.
(2) For *connections* where flexibility of the outstanding elements is required, when *end returns* are used the length of the return shall not exceed four times the nominal size of the weld nor half the width of the part.
(3) Fillet welds joining *transverse stiffeners* to *plate girder* webs $^3/_4$-in. (19 mm) thick or less shall end not less than four times nor more than six times the thickness of the web from the web toe of the web-to-flange welds, except where the ends of *stiffeners* are welded to the flange.
(4) Fillet welds that occur on opposite sides of a common plane shall be interrupted at the corner common to both welds.

User Note: Fillet weld terminations should be located approximately one weld size from the edge of the connection to minimize notches in the base metal. Fillet welds terminated at the end of the joint, other than those connecting stiffeners to girder webs, are not a cause for correction.

Fillet welds in holes or slots are permitted to be used to transmit shear and resist *loads* perpendicular to the faying surface in lap joints or to prevent the *buckling* or separation of lapped parts and to join components of built-up members. Such fillet welds may overlap, subject to the provisions of Section J2. Fillet welds in holes or slots are not to be considered plug or *slot welds*.

3. Plug and Slot Welds

3a. Effective Area

The effective shearing area of *plug* and *slot welds* shall be considered as the nominal cross-sectional area of the hole or slot in the plane of the *faying surface*.

3b. Limitations

Plug or slot welds are permitted to be used to transmit shear in *lap joints* or to prevent *buckling* or separation of lapped parts and to join component parts of *built-up members*.

The diameter of the holes for a *plug weld* shall not be less than the thickness of the part containing it plus $^5/_{16}$ in. (8 mm), rounded to the next larger odd $^1/_{16}$ in. (even mm), nor greater than the minimum diameter plus $^1/_8$ in. (3 mm) or $2^1/_4$ times the thickness of the weld.

The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

The length of slot for a slot weld shall not exceed 10 times the thickness of the weld. The width of the slot shall be not less than the thickness of the part containing it plus $^5/_{16}$ in. (8 mm) rounded to the next larger odd $^1/_{16}$ in. (even mm), nor shall it be larger than $2^1/_4$ times the thickness of the weld. The ends of the slot shall be semicircular or shall have the corners rounded to a radius of not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction on any line shall be two times the length of the slot.

The thickness of plug or slot welds in material $^5/_8$ in. (16 mm) or less in thickness shall be equal to the thickness of the material. In material over $^5/_8$-in. (16 mm) thick, the thickness of the weld shall be at least one-half the thickness of the material but not less than $^5/_8$ in. (16 mm).

4. Strength

The *design strength*, ϕR_n and the *allowable strength*, R_n/Ω, of welded joints shall be the lower value of the base material strength determined according to the *limit states* of *tensile rupture* and *shear rupture* and the *weld metal* strength determined according to the limit state of *rupture* as follows:

For the base metal

$$R_n = F_{nBM} A_{BM} \quad \text{(J2-2)}$$

TABLE J2.5
Available Strength of Welded Joints, ksi (MPa)

Load Type and Direction Relative to Weld Axis	Pertinent Metal	ϕ and Ω	Nominal Stress (F_{nBM} or F_{nw}) ksi (MPa)	Effective Area (A_{BM} or A_{we}) in.^{2} (mm^2)	Required Filler Metal Strength Level [a][b]
COMPLETE-JOINT-PENETRATION GROOVE WELDS					
Tension Normal to weld axis	Strength of the joint is controlled by the base metal				Matching filler metal shall be used. For T- and corner joints with backing left in place, notch tough filler metal is required. See Section J2.6.
Compression Normal to weld axis	Strength of the joint is controlled by the base metal				Filler metal with a strength level equal to or one strength level less than matching filler metal is permitted.
Tension or compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.				Filler metal with a strength level equal to or less than matching filler metal is permitted.
Shear	Strength of the joint is controlled by the base metal				Matching filler metal shall be used.[c]
PARTIAL-JOINT-PENETRATION GROOVE WELDS INCLUDING FLARE V-GROOVE AND FLARE BEVEL GROOVE WELDS					
Tension Normal to weld axis	Base	ϕ = 0.75 Ω = 2.00	F_u	See J4	Filler metal with a strength level equal to or less than matching filler metal is permitted.
	Weld	ϕ = 0.80 Ω = 1.88	$0.60F_{EXX}$	See J2.1a	
Compression Column to base plate and column splices designed per Section J1.4(1)	Compressive stress need not be considered in design of welds joining the parts.				
Compression Connections of members designed to bear other than columns as described in Section J1.4(2)	Base	ϕ = 0.90 Ω = 1.67	F_y	See J4	
	Weld	ϕ = 0.80 Ω = 1.88	$0.60F_{EXX}$	See J2.1a	
Compression Connections not finished-to-bear	Base	ϕ = 0.90 Ω = 1.67	F_y	See J4	
	Weld	ϕ = 0.80 Ω = 1.88	$0.90F_{EXX}$	See J2.1a	
Tension or compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.				
Shear	Base	Governed by J4			
	Weld	ϕ = 0.75 Ω = 2.00	$0.60F_{EXX}$	See J2.1a	

TABLE J2.5 (continued) Available Strength of Welded Joints, ksi (MPa)

Load Type and Direction Relative to Weld Axis	Pertinent Metal	ϕ and Ω	Nominal Stress (F_{nBM} or F_{nw}) ksi (MPa)	Effective Area (A_{BM} or A_{we}) in.^{2} (mm^2)	Required Filler Metal Strength Level [a][b]
FILLET WELDS INCLUDING FILLETS IN HOLES AND SLOTS AND SKEWED T–JOINTS					
Shear	Base	Governed by J4			Filler metal with a strength level equal to or less than matching filler metal is permitted.
	Weld	$\phi = 0.75$ $\Omega = 2.00$	$0.60F_{EXX}$[d]	See J2.2a	
Tension or compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.				
PLUG AND SLOT WELDS					
Shear Parallel to faying surface on the surface on the effective area	Base	Governed by J4			Filler metal with a strength level equal to or less than matching filler metal is permitted.
	Weld	$\phi = 0.75$ $\Omega = 2.00$	$0.60F_{EXX}$	See J2.3a	

[a] For matching weld metal see AWS D1.1/D1.1M, Section 3.3.
[b] Filler metal with a strength level one strength level greater than matching is permitted.
[c] Filler metals with a strength level less than matching may be used for groove welds between the webs and flanges of built-up sections transferring shear loads, or in applications where high restraint is a concern. In these applications, the weld joint shall be detailed and the weld shall be designed using the thickness of the material as the effective throat, where $\phi = 0.80$, $\Omega = 1.88$ and $0.60F_{EXX}$ is the nominal strength.
[d] Alternatively, the provisions of Section J2.4(a) are permitted provided the deformation compatibility of the various weld elements is considered. Sections J2.4(b) and (c) are special applications of Section J2.4(a) that provide for deformation compatibility.

For the weld metal

$$R_n = F_{nw}A_{we} \quad \text{(J2-3)}$$

where

F_{nBM} = nominal *stress* of the base metal, ksi (MPa)
F_{nw} = nominal stress of the weld metal, ksi (MPa)
A_{BM} = cross-sectional area of the base metal, in.^{2} (mm^2)
A_{we} = effective area of the weld, in.^{2} (mm^2)

The values of ϕ, Ω, F_{nBM} and F_{nw} and limitations thereon are given in Table J2.5.

Alternatively, for *fillet welds* the *available strength* is permitted to be determined as follows:

$$\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$$

(a) For a linear weld group with a uniform leg size, loaded through the center of gravity

$$R_n = F_{nw}A_{we} \quad \text{(J2-4)}$$

where

$$F_{nw} = 0.60F_{EXX}\left(1.0 + 0.50\sin^{1.5}\theta\right) \quad \text{(J2-5)}$$

and

F_{EXX} = *filler metal* classification strength, ksi (MPa)
θ = angle of loading measured from the weld longitudinal axis, degrees

User Note: A linear weld group is one in which all elements are in a line or are parallel.

(b) For weld elements within a weld group that are analyzed using an instantaneous center of rotation method, the components of the *nominal strength*, R_{nx} and R_{ny}, and the *nominal moment capacity*, M_n, are permitted to be determined as follows:

$$R_{nx} = \sum F_{nwix}A_{wei} \quad \text{(J2-6a)}$$

$$R_{ny} = \sum F_{nwiy}A_{wei} \quad \text{(J2-6b)}$$

$$M_n = \sum\left[F_{nwiy}A_{wei}(x_i) - F_{nwix}A_{wei}(y_i)\right] \quad \text{(J2-7)}$$

where

A_{wei} = effective area of weld throat of the ith weld element, in.^{2} (mm^2)
$F_{nwi} = 0.60F_{EXX}(1.0 + 0.50\sin^{1.5}\theta_i)f(p_i)$ (J2-8)
$f(p_i) = [p_i(1.9 - 0.9p_i)]^{0.3}$ (J2-9)
F_{nwi} = nominal stress in the ith weld element, ksi (MPa)
F_{nwix} = x-component of nominal stress, F_{nwi}, ksi (MPa)
F_{nwiy} = y-component of nominal stress, F_{nwi}, ksi (MPa)
p_i = Δ_i/Δ_{mi}, ratio of element i deformation to its deformation at maximum stress
r_{cr} = distance from instantaneous center of rotation to weld element with minimum Δ_{ui}/r_i ratio, in. (mm)
r_i = distance from instantaneous center of rotation to ith weld element, in. (mm)
x_i = x component of r_i
y_i = y component of r_i
Δ_i = $r_i\Delta_{ucr}/r_{cr}$ = deformation of the ith weld element at an intermediate stress level, linearly proportioned to the critical deformation based on distance from the instantaneous center of rotation, r_i, in. (mm)
Δ_{mi} = $0.209(\theta_i + 2)^{-0.32}w$, deformation of the ith weld element at maximum stress, in. (mm)
Δ_{ucr} = deformation of the weld element with minimum Δ_{ui}/r_i ratio at ultimate stress (rupture), usually in the element furthest from instantaneous center of rotation, in. (mm)
Δ_{ui} = $1.087(\theta_i + 6)^{-0.65}w \le 0.17w$, deformation of the ith weld element at ultimate stress (rupture), in. (mm)
θ_i = angle between the longitudinal axis of ith weld element and the direction of the resultant force acting on the element, degrees

(c) For fillet weld groups concentrically loaded and consisting of elements with a uniform leg size that are oriented both longitudinally and transversely to the direction of applied *load*, the combined strength, R_n, of the fillet weld group shall be determined as the greater of

(i) $R_n = R_{nwl} + R_{nwt}$ (J2-10a)

or

(ii) $R_n = 0.85\, R_{nwl} + 1.5\, R_{nwt}$ (J2-10b)

where

R_{nwl} = total nominal strength of longitudinally loaded fillet welds, as determined in accordance with Table J2.5, kips (N)

R_{nwt} = total nominal strength of transversely loaded fillet welds, as determined in accordance with Table J2.5 without the alternate in Section J2.4(a), kips (N)

5. Combination of Welds

If two or more of the general types of welds (groove, fillet, plug, slot) are combined in a single *joint*, the strength of each shall be separately computed with reference to the axis of the group in order to determine the strength of the combination.

6. Filler Metal Requirements

The choice of *filler metal* for use with *complete-joint-penetration groove welds* subject to tension normal to the effective area shall comply with the requirements for matching filler metals given in AWS D1.1/D1.1M.

User Note: The following User Note Table summarizes the AWS D1.1/D1.1M provisions for matching filler metals. Other restrictions exist. For a complete list of base metals and prequalified matching filler metals see AWS D1.1/D1.1M, Table 3.1.

Base Metal		Matching Filler Metal
A36 ≤ 3/4 in. thick		60 & 70 ksi filler metal
A36 > ¾ in. A588* A1011	A572 (Gr. 50 & 55) A913 (Gr. 50) A992 A1018	SMAW: E7015, E7016, E7018, E7028 Other processes: 70 ksi filler metal
A913	(Gr. 60 & 65)	80 ksi filler metal

*For corrosion resistance and color similar to the base metal, see AWS D1.1/D1.1M, subclause 3.7.3.

Notes:
Filler metals shall meet the requirements of AWS A5.1, A5.5, A5.17, A5.18, A5.20, A5.23, A5.28 or A5.29.
In joints with base metals of different strengths, use either a filler metal that matches the higher strength base metal or a filler metal that matches the lower strength and produces a low hydrogen deposit.

Filler metal with a specified minimum Charpy V-*notch toughness* of 20 ft-lb (27 J) at 40 °F (4 °C) or lower shall be used in the following *joints*:

(1) Complete-joint-penetration groove welded T- and corner joints with steel backing left in place, subject to tension normal to the effective area, unless the joints

are designed using the *nominal strength* and *resistance factor* or *safety factor* as applicable for a *partial-joint-penetration groove weld*

(2) Complete-joint-penetration groove welded *splices* subject to tension normal to the effective area in heavy sections as defined in Sections A3.1c and A3.1d

The manufacturer's Certificate of Conformance shall be sufficient evidence of compliance.

7. Mixed Weld Metal

When Charpy V-*notch toughness* is specified, the process consumables for all *weld metal*, tack welds, root pass and subsequent passes deposited in a *joint* shall be compatible to ensure notch-tough composite weld metal.

J3. BOLTS AND THREADED PARTS

1. High-Strength Bolts

Use of *high-strength bolts* shall conform to the provisions of the *Specification for Structural Joints Using High-Strength Bolts*, hereafter referred to as the RCSC *Specification*, as approved by the Research Council on Structural Connections, except as otherwise provided in this Specification. High-strength bolts in this Specification are grouped according to material strength as follows:

Group A—ASTM A325, A325M, F1852, A354 Grade BC, and A449

Group B—ASTM A490, A490M, F2280, and A354 Grade BD

When assembled, all *joint* surfaces, including those adjacent to the washers, shall be free of scale, except tight *mill scale*.

Bolts are permitted to be installed to the snug-tight condition when used in:

(a) *bearing-type connections* except as noted in Section E6 or Section J1.10
(b) tension or combined shear and tension applications, for Group A bolts only, where loosening or *fatigue* due to vibration or *load* fluctuations are not design considerations

The snug-tight condition is defined as the tightness required to bring the connected plies into firm contact. Bolts to be tightened to a condition other than snug tight shall be clearly identified on the *design drawings*.

All high-strength bolts specified on the design drawings to be used in pretensioned or slip-critical joints shall be tightened to a bolt tension not less than that given in Table J3.1 or J3.1M. Installation shall be by any of the following methods: *turn-of-nut method*, a direct-tension-indicator, twist-off-type tension-control bolt, calibrated wrench, or alternative design bolt.

User Note: There are no specific minimum or maximum tension requirements for snug-tight bolts. Fully *pretensioned bolts* such as ASTM F1852 or F2280 are permitted unless specifically prohibited on design drawings.

TABLE J3.1
Minimum Bolt Pretension, kips*

Bolt Size, in.	Group A (e.g., A325 Bolts)	Group B (e.g., A490 Bolts)
1/2	12	15
5/8	19	24
3/4	28	35
7/8	39	49
1	51	64
1 1/8	56	80
1 1/4	71	102
1 3/8	85	121
1 1/2	103	148

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kip, as specified in ASTM specifications for A325 and A490 bolts with UNC threads.

TABLE J3.1M
Minimum Bolt Pretension, kN*

Bolt Size, mm	Group A (e.g., A325M Bolts)	Group B (e.g., A490M Bolts)
M16	91	114
M20	142	179
M22	176	221
M24	205	257
M27	267	334
M30	326	408
M36	475	595

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kN, as specified in ASTM specifications for A325M and A490M bolts with UNC threads.

When bolt requirements cannot be provided within the RCSC *Specification* limitations because of requirements for lengths exceeding 12 diameters or diameters exceeding 1 1/2 in. (38 mm), bolts or threaded rods conforming to Group A or Group B materials are permitted to be used in accordance with the provisions for threaded parts in Table J3.2.

When ASTM A354 Grade BC, A354 Grade BD, or A449 bolts and threaded rods are used in slip-critical connections, the bolt geometry including the thread *pitch*, thread length, head and nut(s) shall be equal to or (if larger in diameter) proportional to that required by the RCSC *Specification*. Installation shall comply with all applicable requirements of the RCSC *Specification* with modifications as required for the increased diameter and/or length to provide the design pretension.

TABLE J3.2
Nominal Strength of Fasteners and Threaded Parts, ksi (MPa)

Description of Fasteners	Nominal Tensile Strength, F_{nt}, ksi (MPa)[a]	Nominal Shear Strength in Bearing-Type Connections, F_{nv}, ksi (MPa)[b]
A307 bolts	45 (310)	27 (188)[c] [d]
Group A (e.g., A325) bolts, when threads are not excluded from shear planes	90 (620)	54 (372)
Group A (e.g., A325) bolts, when threads are excluded from shear planes	90 (620)	68 (457)
Group B (e.g., A490) bolts, when threads are not excluded from shear planes	113 (780)	68 (457)
Group B (e.g., A490) bolts, when threads are excluded from shear planes	113 (780)	84 (579)
Threaded parts meeting the requirements of Section A3.4, when threads are not excluded from shear planes	$0.75F_u$	$0.450F_u$
Threaded parts meeting the requirements of Section A3.4, when threads are excluded from shear planes	$0.75F_u$	$0.563F_u$

[a] For high-strength bolts subject to tensile fatigue loading, see Appendix 3.
[b] For end loaded connections with a fastener pattern length greater than 38 in. (965 mm), F_{nv} shall be reduced to 83.3% of the tabulated values. Fastener pattern length is the maximum distance parallel to the line of force between the centerline of the bolts connecting two parts with one faying surface.
[c] For A307 bolts the tabulated values shall be reduced by 1% for each 1/16 in. (2 mm) over 5 diameters of length in the grip.
[d] Threads permitted in shear planes.

2. Size and Use of Holes

The maximum sizes of holes for bolts are given in Table J3.3 or Table J3.3M, except that larger holes, required for tolerance on location of anchor rods in concrete foundations, are permitted in *column* base details.

Standard holes or *short-slotted holes* transverse to the direction of the *load* shall be provided in accordance with the provisions of this specification, unless oversized holes, short-slotted holes parallel to the load, or *long-slotted holes* are approved

TABLE J3.3
Nominal Hole Dimensions, in.

Bolt Diameter, in.	Hole Dimensions: Standard (Dia.)	Oversize (Dia.)	Short-Slot (Width × Length)	Long-Slot (Width × Length)
1/2	9/16	5/8	9/16 × 11/16	9/16 × 1 1/4
5/8	11/16	13/16	11/16 × 7/8	11/16 × 1 9/16
3/4	13/16	15/16	13/16 × 1	13/16 × 1 7/8
7/8	15/16	1 1/16	15/16 × 1 1/8	15/16 × 2 3/16
1	1 1/16	1 1/4	1 1/16 × 1 5/16	1 1/16 × 2½
≥ 1 1/8	d + 1/16	d + 5/16	(d + 1/16) × (d + 3/8)	(d + 1/16) × (2.5 × d)

TABLE J3.3M
Nominal Hole Dimensions, mm

Bolt Diameter, mm	Hole Dimensions: Standard (Dia.)	Oversize (Dia.)	Short-Slot (Width × Length)	Long-Slot (Width × Length)
M16	18	20	18 × 22	18 × 40
M20	22	24	22 × 26	22 × 50
M22	24	28	24 × 30	24 × 55
M24	27[a]	30	27 × 32	27 × 60
M27	30	35	30 × 37	30 × 67
M30	33	38	33 × 40	33 × 75
≥ M36	d + 3	d + 8	(d + 3) × (d + 10)	(d + 3) × 2.5d

[a] Clearance provided allows the use of a 1-in. bolt if desirable.

by the *engineer of record*. Finger *shims* up to 1/4 in. (6 mm) are permitted in *slip-critical connections* designed on the basis of standard holes without reducing the nominal shear strength of the *fastener* to that specified for slotted holes.

Oversized holes are permitted in any or all plies of slip-critical connections, but they shall not be used in *bearing-type connections*. Hardened washers shall be installed over oversized holes in an outer ply.

Short-slotted holes are permitted in any or all plies of slip-critical or bearing-type connections. The slots are permitted without regard to direction of loading in slip-critical connections, but the length shall be normal to the direction of the load in bearing-type connections. Washers shall be installed over short-slotted holes in an outer ply; when high-strength bolts are used, such washers shall be hardened washers conforming to ASTM F436.

When Group B bolts over 1 in. (25 mm) in diameter are used in slotted or oversized holes in external plies, a single hardened washer conforming to ASTM F436, except with 5/16-in. (8 mm) minimum thickness, shall be used in lieu of the standard washer.

User Note: Washer requirements are provided in the RCSC *Specification*, Section 6.

Long-slotted holes are permitted in only one of the connected parts of either a slip-critical or bearing-type connection at an individual *faying surface*. Long-slotted holes are permitted without regard to direction of loading in slip-critical connections, but shall be normal to the direction of load in bearing-type connections. Where long-slotted holes are used in an outer ply, plate washers, or a continuous bar with standard holes, having a size sufficient to completely cover the slot after installation, shall be provided. In high-strength bolted connections, such plate washers or continuous bars shall be not less than 5/16-in. (8 mm) thick and shall be of structural grade material, but need not be hardened. If hardened washers are required for use of high-strength bolts, the hardened washers shall be placed over the outer surface of the plate washer or bar.

3. Minimum Spacing

The distance between centers of standard, oversized or slotted holes shall not be less than 2 2/3 times the nominal diameter, d, of the *fastener*; a distance of 3d is preferred.

User Note: ASTM F1554 anchor rods may be furnished in accordance to product specifications with a body diameter less than the nominal diameter. Load effects such as bending and elongation should be calculated based on minimum diameters permitted by the product specification. See ASTM F1554 and the table, "Applicable ASTM Specifications for Various Types of Structural Fasteners," in Part 2 of the AISC *Steel Construction Manual*.

4. Minimum Edge Distance

The distance from the center of a standard hole to an edge of a connected part in any direction shall not be less than either the applicable value from Table J3.4 or Table J3.4M, or as required in Section J3.10. The distance from the center of an oversized or slotted hole to an edge of a connected part shall be not less than that required for a standard hole to an edge of a connected part plus the applicable increment, C_2, from Table J3.5 or Table J3.5M.

User Note: The edge distances in Tables J3.4 and J3.4M are minimum edge distances based on standard fabrication practices and workmanship tolerances. The appropriate provisions of Sections J3.10 and J4 must be satisfied.

5. Maximum Spacing and Edge Distance

The maximum distance from the center of any bolt to the nearest edge of parts in contact shall be 12 times the thickness of the connected part under consideration,

TABLE J3.4
Minimum Edge Distance[a] from Center of Standard Hole[b] to Edge of Connected Part, in.

Bolt Diameter, in.	Minimum Edge Distance
1/2	3/4
5/8	7/8
3/4	1
7/8	1 1/8
1	1 1/4
1 1/8	1 1/2
1 1/4	1 5/8
Over 1 1/4	1 1/4 × d

[a] If necessary, lesser edge distances are permitted provided the appropriate provisions from Sections J3.10 and J4 are satisfied, but edge distances less than one bolt diameter are not permitted without approval from the engineer of record.
[b] For oversized or slotted holes, see Table J3.5.

TABLE J3.4M
Minimum Edge Distance[a] from Center of Standard Hole[b] to Edge of Connected Part, mm

Bolt Diameter, mm	Minimum Edge Distance
16	22
20	26
22	28
24	30
27	34
30	38
36	46
Over 36	1.25d

[a] If necessary, lesser edge distances are permitted provided the appropriate provisions from Sections J3.10 and J4 are satisfied, but edge distances less than one bolt diameter are not permitted without approval from the engineer of record.
[b] For oversized or slotted holes, see Table J3.5M.

TABLE J3.5
Values of Edge Distance Increment C_2, in.

Nominal Diameter of Fastener, in.	Oversized Holes	Slotted Holes		
		Long Axis Perpendicular to Edge		Long Axis Parallel to Edge
		Short Slots	Long Slots[a]	
≤ 7/8	1/16	1/8	3/4d	0
1	1/8	1/8		
≥ 1 1/8	1/8	3/16		

[a] When length of slot is less than maximum allowable (see Table J3.3), C_2 is permitted to be reduced by one-half the difference between the maximum and actual slot lengths.

TABLE J3.5M
Values of Edge Distance Increment C_2, mm

Nominal Diameter of Fastener, mm	Oversized Holes	Slotted Holes		
		Long Axis Perpendicular to Edge		Long Axis Parallel to Edge
		Short Slots	Long Slots[a]	
≤ 22	2	3	0.75d	0
24	3	3		
≥ 27	3	5		

[a] When length of slot is less than maximum allowable (see Table J3.3M), C_2 is permitted to be reduced by one-half the difference between the maximum and actual slot lengths.

but shall not exceed 6 in. (150 mm). The longitudinal spacing of *fasteners* between elements consisting of a plate and a shape or two plates in continuous contact shall be as follows:

(a) For painted members or unpainted members not subject to corrosion, the spacing shall not exceed 24 times the thickness of the thinner part or 12 in. (305 mm).
(b) For unpainted members of *weathering steel* subject to atmospheric corrosion, the spacing shall not exceed 14 times the thickness of the thinner part or 7 in. (180 mm).

User Note: Dimensions in (a) and (b) do not apply to elements consisting of two shapes in continuous contact.

6. Tensile and Shear Strength of Bolts and Threaded Parts

The *design tensile* or *shear strength*, ϕR_n, and the *allowable tensile* or *shear strength*, R_n/Ω, of a snug-tightened or pretensioned high-strength bolt or threaded part shall be determined according to the *limit states* of *tension rupture* and *shear rupture* as follows:

$$R_n = F_n A_b \tag{J3-1}$$

$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)

where

A_b = nominal unthreaded body area of bolt or threaded part, in.^{2} (mm^2)

F_n = nominal tensile stress, F_{nt}, or shear stress, F_{nv}, from Table J3.2, ksi (MPa)

The *required tensile strength* shall include any tension resulting from *prying action* produced by deformation of the connected parts.

User Note: The *force* that can be resisted by a snug-tightened or pretensioned high-strength bolt or threaded part may be limited by the *bearing* strength at the bolt hole per Section J3.10. The effective strength of an individual *fastener* may be taken as the lesser of the fastener shear strength per Section J3.6 or the bearing strength at the bolt hole per Section J3.10. The strength of the bolt group is taken as the sum of the effective strengths of the individual fasteners.

7. Combined Tension and Shear in Bearing-Type Connections

The *available tensile strength* of a bolt subjected to combined tension and shear shall be determined according to the *limit states* of *tension and shear rupture* as follows:

$$R_n = F'_{nt} A_b \tag{J3-2}$$

$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)

where

F'_{nt} = nominal tensile *stress* modified to include the effects of shear stress, ksi (MPa)

$$F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \le F_{nt} \quad \text{(LRFD)} \tag{J3-3a}$$

$$F'_{nt} = 1.3F_{nt} - \frac{\Omega F_{nt}}{F_{nv}} f_{rv} \le F_{nt} \quad \text{(ASD)} \tag{J3-3b}$$

F_{nt} = nominal tensile stress from Table J3.2, ksi (MPa)

F_{nv} = nominal shear stress from Table J3.2, ksi (MPa)

f_{rv} = required shear stress using *LRFD* or *ASD load combinations*, ksi (MPa)

The available shear stress of the *fastener* shall equal or exceed the required shear stress, f_{rv}.

User Note: Note that when the required stress, f, in either shear or tension, is less than or equal to 30% of the corresponding *available stress*, the effects of combined *stress* need not be investigated. Also note that Equations J3-3a and J3-3b can be rewritten so as to find a nominal shear stress, F'_{nv}, as a function of the required tensile stress, f_t.

8. High-Strength Bolts in Slip-Critical Connections

Slip-critical connections shall be designed to prevent *slip* and for the *limit states* of *bearing-type connections*. When slip-critical bolts pass through *fillers*, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The available slip resistance for the limit state of slip shall be determined as follows:

$$R_n = \mu D_u h_f T_b n_s \tag{J3-4}$$

(a) For standard size and short-slotted holes perpendicular to the direction of the *load*

$\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)

(b) For oversized and short-slotted holes parallel to the direction of the load

$\phi = 0.85$ (LRFD) $\Omega = 1.76$ (ASD)

(c) For long-slotted holes

$\phi = 0.70$ (LRFD) $\Omega = 2.14$ (ASD)

where

μ = mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(i) For Class A surfaces (unpainted clean *mill scale* steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

$$\mu = 0.30$$

(ii) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

$$\mu = 0.50$$

D_u = 1.13, a multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension. The use of other values may be approved by the *engineer of record*.

T_b = minimum *fastener* tension given in Table J3.1, kips, or Table J3.1M, kN

h_f = factor for fillers, determined as follows:

(i) Where there are no fillers or where bolts have been added to distribute loads in the filler

$$h_f = 1.0$$

(ii) Where bolts have not been added to distribute the *load* in the filler:

(a) For one filler between connected parts

$$h_f = 1.0$$

(b) For two or more fillers between connected parts

$$h_f = 0.85$$

n_s = number of slip planes required to permit the connection to slip

9. Combined Tension and Shear in Slip-Critical Connections

When a *slip-critical connection* is subjected to an applied tension that reduces the net clamping force, the available *slip* resistance per bolt, from Section J3.8, shall be multiplied by the factor, k_{sc}, as follows:

$$k_{sc} = 1 - \frac{T_u}{D_u T_b n_b} \quad \text{(LRFD)} \qquad \text{(J3-5a)}$$

$$k_{sc} = 1 - \frac{1.5T_a}{D_u T_b n_b} \quad \text{(ASD)} \qquad \text{(J3-5b)}$$

where

T_a = required tension force using *ASD load combinations*, kips (kN)

T_u = required tension force using *LRFD load combinations*, kips (kN)

n_b = number of bolts carrying the applied tension

10. Bearing Strength at Bolt Holes

The *available bearing strength*, ϕR_n and R_n/Ω, at bolt holes shall be determined for the *limit state* of *bearing* as follows:

$$\phi = 0.75 \text{ (LRFD)} \qquad \Omega = 2.00 \text{ (ASD)}$$

The nominal bearing strength of the connected material, R_n, is determined as follows:

(a) For a bolt in a *connection* with standard, oversized and short-slotted holes, independent of the direction of loading, or a long-slotted hole with the slot parallel to the direction of the bearing *force*

(i) When deformation at the bolt hole at *service load* is a design consideration

$$R_n = 1.2 l_c t F_u \le 2.4 d t F_u \qquad \text{(J3-6a)}$$

(ii) When deformation at the bolt hole at service load is not a design consideration

$$R_n = 1.5 l_c t F_u \le 3.0 d t F_u \qquad \text{(J3-6b)}$$

(b) For a bolt in a connection with long-slotted holes with the slot perpendicular to the direction of force

$$R_n = 1.0 l_c t F_u \le 2.0 d t F_u \qquad \text{(J3-6c)}$$

(c) For connections made using bolts that pass completely through an unstiffened box member or *HSS*, see Section J7 and Equation J7-1;

where

F_u = *specified minimum tensile strength* of the connected material, ksi (MPa)

d = nominal bolt diameter, in. (mm)

l_c = clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material, in. (mm)

t = thickness of connected material, in. (mm)

For connections, the bearing resistance shall be taken as the sum of the bearing resistances of the individual bolts.

Bearing strength shall be checked for both bearing-type and *slip-critical connections*. The use of oversized holes and short- and long-slotted holes parallel to the line of force is restricted to slip-critical connections per Section J3.2.

User Note: The effective strength of an individual *fastener* is the lesser of the fastener shear strength per Section J3.6 or the bearing strength at the bolt hole per Section J3.10. The strength of the bolt group is the sum of the effective strengths of the individual fasteners.

11. Special Fasteners

The *nominal strength* of special *fasteners* other than the bolts presented in Table J3.2 shall be verified by tests.

12. Tension Fasteners

When bolts or other *fasteners* in tension are attached to an unstiffened box or *HSS* wall, the strength of the wall shall be determined by rational analysis.

J4. AFFECTED ELEMENTS OF MEMBERS AND CONNECTING ELEMENTS

This section applies to elements of members at *connections* and connecting elements, such as plates, gussets, angles and brackets.

1. Strength of Elements in Tension

The *design strength*, ϕR_n, and the *allowable strength*, R_n/Ω, of affected and connecting elements loaded in tension shall be the lower value obtained according to the *limit states* of *tensile yielding* and *tensile rupture*.

(a) For tensile yielding of connecting elements

$$R_n = F_y A_g \qquad \text{(J4-1)}$$

$$\phi = 0.90 \text{ (LRFD)} \qquad \Omega = 1.67 \text{ (ASD)}$$

(b) For tensile rupture of connecting elements

$$R_n = F_u A_e \qquad \text{(J4-2)}$$

$\phi = 0.75$ (LRFD) $\quad \Omega = 2.00$ (ASD)

where

A_e = *effective net area* as defined in Section D3, in.^{2} (mm^2); for bolted *splice* plates, $A_e = A_n \leq 0.85A_g$.

User Note: The effective net area of the connection plate may be limited due to *stress* distribution as calculated by methods such as the Whitmore section.

2. Strength of Elements in Shear

The available shear strength of affected and connecting elements in shear shall be the lower value obtained according to the *limit states* of *shear yielding* and *shear rupture*:

(a) For shear yielding of the element:

$$R_n = 0.60F_yA_{gv} \tag{J4-3}$$

$\phi = 1.00$ (LRFD) $\quad \Omega = 1.50$ (ASD)

where

A_{gv} = gross area subject to shear, in.^{2} (mm^2)

(b) For shear rupture of the element:

$$R_n = 0.60F_uA_{nv} \tag{J4-4}$$

$\phi = 0.75$ (LRFD) $\quad \Omega = 2.00$ (ASD)

where

A_{nv} = *net area* subject to shear, in.^{2} (mm^2)

3. Block Shear Strength

The *available strength* for the *limit state* of *block shear rupture* along a shear failure path or paths and a perpendicular tension failure path shall be taken as

$$R_n = 0.60F_uA_{nv} + U_{bs}F_uA_{nt} \leq 0.60F_yA_{gv} + U_{bs}F_uA_{nt} \tag{J4-5}$$

$\phi = 0.75$ (LRFD) $\quad \Omega = 2.00$ (ASD)

where

A_{nt} = *net area* subject to tension, in.^{2} (mm^2)

Where the tension *stress* is uniform, $U_{bs} = 1$; where the tension stress is nonuniform, $U_{bs} = 0.5$.

User Note: Typical cases where U_{bs} should be taken equal to 0.5 are illustrated in the Commentary.

4. Strength of Elements in Compression

The *available strength* of connecting elements in compression for the *limit states* of *yielding* and *buckling* shall be determined as follows:

(a) When $KL/r \leq 25$

$$P_n = F_yA_g \tag{J4-6}$$

$\phi = 0.90$ (LRFD) $\quad \Omega = 1.67$ (ASD)

(b) When $KL/r > 25$, the provisions of Chapter E apply.

5. Strength of Elements in Flexure

The available flexural strength of affected elements shall be the lower value obtained according to the *limit states* of flexural *yielding, local buckling,* flexural *lateral-torsional buckling* and flexural rupture.

J5. FILLERS

1. Fillers in Welded Connections

Whenever it is necessary to use *fillers* in joints required to transfer applied force, the fillers and the connecting welds shall conform to the requirements of Section J5.1a or Section J5.1b, as applicable.

1a. Thin Fillers

Fillers less than 1/4 in. (6 mm) thick shall not be used to transfer *stress*. When the thickness of the fillers is less than 1/4 in. (6 mm), or when the thickness of the filler is 1/4 in. (6 mm) or greater but not adequate to transfer the applied force between the connected parts, the filler shall be kept flush with the edge of the outside connected part, and the size of the weld shall be increased over the required size by an amount equal to the thickness of the filler.

1b. Thick Fillers

When the thickness of the *fillers* is adequate to transfer the applied force between the connected parts, the filler shall extend beyond the edges of the outside connected base metal. The welds joining the outside connected base metal to the filler shall be sufficient to transmit the force to the filler and the area subjected to the applied force in the filler shall be adequate to avoid overstressing the filler. The welds joining the filler to the inside connected base metal shall be adequate to transmit the applied force.

2. Fillers in Bolted Connections

When a bolt that carries *load* passes through *fillers* that are equal to or less than 1/4 in. (6 mm) thick, the shear strength shall be used without reduction. When a bolt that carries load passes through fillers that are greater than 1/4 in. (6 mm) thick, one of the following requirements shall apply:

(a) The shear strength of the bolts shall be multiplied by the factor

$$1 - 0.4(t - 0.25)$$

$$[\text{S.I.: } 1 - 0.0154(t - 6)]$$

but not less than 0.85, where t is the total thickness of the fillers;