2. Design of Welded Connections

2.0 Scope

This section covers the requirements for the design of welded connections. It is divided into four Parts, described as follows:

Part A—Common Requirements of Nontubular and Tubular Connections. This part covers the requirements applicable to all connections, regardless of the product form or the type of loading, and shall be used with the applicable requirements of Parts B, C, and D.

Part B—Specific Requirements for Nontubular Connections (Statically or Cyclically Loaded). This part covers the specific requirements for connections between non-tubular cross-sections, regardless of the type of loading, and shall be used with the applicable requirements of Parts A and C.

Part C—Specific Requirements for Cyclically Loaded Nontubular Connections. This part covers the specific requirements for connections between nontubular cross-sections subjected to cyclic loads of sufficient magnitude and frequency to cause the potential for fatigue failure, and shall be used with the applicable requirements of Parts A and B.

Part D—Specific Requirements for Tubular Connections. This part covers the specific requirements for connections between tubular cross-sections, regardless of the type of loading, and shall be used with the applicable requirements of Part A.

Part A
Common Requirements of Nontubular and Tubular Connections

2.1 Stresses

2.1.1 Allowable Base-Metal Stresses. The base-metal stresses shall not exceed those specified in the applicable design specifications.

2.1.2 Allowable Increase. Where the applicable design specifications permit the use of increased stresses in the base metal for any reason, a corresponding increase shall be applied to the allowable stresses given herein, but not to the stress ranges permitted for base metal or weld metal subject to cyclic loading.

2.1.3 Laminations and Lamellar Tearing. Where welded joints introduce through-thickness stresses, the anisotropy of the material and the possibility of base-metal separation should be recognized during both design and fabrication (see Commentary).

2.2 Drawings

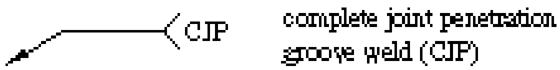
2.2.1 Drawing Information. Full and complete information regarding location, type, size, and extent of all welds shall be clearly shown on the drawings. The drawings shall clearly distinguish between shop and field welds.

2.2.2 Joint Welding Sequence. Drawings of those joints or groups of joints in which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted.

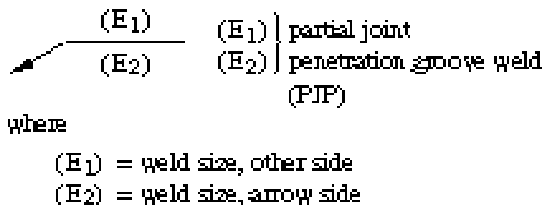
2.2.3 Weld Size and Length. Contract design drawings shall specify the effective weld length and, for partial penetration groove welds, the required weld size, as defined in this code. Shop or working drawings shall specify the groove depths (S) applicable for the weld size (E) required for the welding process and position of welding to be used.

2.2.4 Groove Welds. Detail drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of material required to make them. Both width and thickness of steel backing shall be detailed.

2.2.4.1 Symbols. It is recommended that contract design drawings show complete joint penetration or partial joint penetration groove weld requirements without specifying the groove weld dimensions. The welding symbol without dimensions designates a complete joint penetration weld as follows:



The welding symbol with dimensions above or below the reference line designates a partial joint penetration weld, as follows:



2.2.4.2 Prequalified Detail Dimensions. The joint details specified in 3.12 (PJP) and 3.13 (CJP) have repeatedly demonstrated their adequacy in providing the conditions and clearances necessary for depositing and fusing sound weld metal to base metal. However, the use of these details in prequalified WPSs shall not be interpreted as implying consideration of the effects of welding process on material beyond the fusion boundary nor suitability for a given application.

2.2.4.3 Special Details. When special groove details are required, they shall be completely detailed in the contract plans.

2.2.5 Special Inspection Requirements. Any special inspection requirements shall be noted on the drawings or in the specifications.

2.3 Groove Welds

2.3.1 Effective Weld Length. The maximum effective weld length for any groove weld, square or skewed, shall be the width of the part joined, perpendicular to the direction of tensile or compressive stress. For groove welds transmitting shear, the effective length is the length specified.

2.3.2 Effective Area. The effective area shall be the effective weld length multiplied by the weld size.

2.3.3 Partial Joint Penetration Groove Welds

2.3.3.1 Minimum Weld Size. Partial joint penetration groove weld sizes shall be equal to or greater than the size specified in 3.12.2 unless the WPS is qualified per section 4.

2.3.3.2 Effective Weld Size (Flare Groove). The effective weld size for flare groove welds when filled flush to the surface of a round bar, a 90° bend in a formed section, or a rectangular tube shall be as shown in Table 2.1, except as permitted by 4.10.5.

Table 2.1
Effective Weld Sizes of Flare Groove Welds (see 2.3.3.2)

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
5/16 R	1/2 R*

Note: R = radius of outside surface

*Use 3/8 R for GMAW (except short circuiting transfer) process when R is 1/2 in. (12 mm) or greater.

2.3.4 Complete Joint Penetration Groove Welds

2.3.4.1 Weld Size. The weld size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase in the effective area for design calculations is permitted for weld reinforcement. Groove weld sizes for welds in T-, Y-, and K-connections in tubular members are shown in Table 3.6.

2.4 Fillet Welds

2.4.1 Effective Throat

2.4.1.1 Calculation. The effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld (see Annex I). *Note: See Annex II for formula governing the calculation of effective throats for fillet welds in skewed T-joints. A tabulation of measured legs (W) and acceptable root openings (R) related to effective throats (E) has been provided for dihedral angles between 60° and 135°.*

2.4.1.2 Shear Stress. Stress on the effective throat of fillet welds is considered as shear stress regardless of the direction of the application.

2.4.1.3 Reinforcing Fillet Welds. The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld minus 1/8 in. (3 mm) for any groove detail requiring such deduction (see Figure 3.3 and Annex I).

2.4.2 Length

2.4.2.1 Effective Length (Straight). The effective length of a straight fillet weld shall be the overall length of the full-size fillet, including boxing. No reduction in effective length shall be assumed in design calculations to allow for the start or stop crater of the weld.

2.4.2.2 Effective Length (Curved). The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or slot calculated from this length is greater than the area calculated from 2.5.1, then this latter area shall be used as the effective area of the fillet weld.

2.4.2.3 Minimum Length. The minimum effective length of a fillet weld shall be at least four times the nominal size, or the effective size of the weld shall be considered not to exceed 25% of its effective length.

2.4.3 Effective Area. The effective area shall be the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load.

2.4.4 Minimum Leg Size. See 5.14 for the minimum leg sizes required for fillet welds.

2.4.5 Maximum Fillet Weld Size. The maximum fillet weld size detailed along edges of material shall be the following:

(1) the thickness of the base metal, for metal less than 1/4 in. (6 mm) thick (see Figure 2.1, Detail A)

(2) 1/16 in. (2 mm) less than the thickness of base metal, for metal 1/4 in. (6 mm) or more in thickness (see Figure 2.1, Detail B), unless the weld is designated on the drawing 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 may be less than 1/16 in. (2 mm), provided the weld size is clearly verifiable.

2.4.6 Intermittent Fillet Welds (Minimum Length). The minimum length of an intermittent fillet weld shall be 1-1/2 in. (40 mm).

2.4.7 Fillet Weld Terminations

2.4.7.1 Drawings. The length and disposition of welds, including end returns or boxing, shall be indicated on the design and detail drawings. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may be boxed except as limited by 2.4.7.2 through 2.4.7.5.

2.4.7.2 Lap Joints. In lap joints between parts subject to calculated tensile stress in which one part extends beyond the edge or side of the part to which it is connected, fillet welds shall terminate not less than the size of the weld from the start of the extension (see Commentary).

2.4.7.3 Maximum End Return Length. Flexible connections rely on the flexibility of the outstanding legs. If the outstanding legs are attached with end returned welds, the length of the end return shall not exceed four times the nominal weld size. Examples of flexible connections include framing angles, top angles of seated beam connections and simple end plate connections.

2.4.7.4 Stiffener Welds. Except where the ends of stiffeners are welded to the flange, fillet welds joining transverse stiffeners to girder webs shall start or terminate 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.

2.4.7.5 Opposite Sides of Common Plane. Fillet welds which occur on opposite sides of a common plane shall be interrupted at the corner common to both welds (see Figure 2.12).

2.4.8 Lap Joints. Unless lateral deflection of the parts is prevented, they shall be connected by at least two transverse lines of fillet, plug, or slot welds, or by two or more longitudinal fillet or slot welds.

2.4.8.1 Double-Fillet Welds. Transverse fillet welds in lap joints transferring stress between axially loaded parts shall be double-fillet welded (see Figure 2.5) except where deflection of the joint is sufficiently restrained to prevent it from opening under load.

2.4.8.2 Minimum Overlap. The minimum overlap of parts in stress-carrying lap joints shall be five times the thickness of the thinner part, but not less than 1 inch (25 mm).

2.4.8.3 Fillet Welds in Holes or Slots. Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to the requirements of 2.5. Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the provisions of 2.4.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

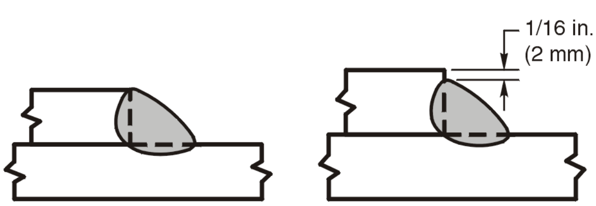


Figure 2.1—Details for Prequalified Fillet Welds (see 2.4.5)

2.5 Plug and Slot Welds

2.5.1 Effective Area. The effective area shall be the nominal area of the hole or slot in the plane of the faying surface.

2.5.2 Minimum Spacing (Plug Welds). The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

2.5.3 Minimum Spacing (Slot Welds). 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.

2.5.4 Slot Ends. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

2.5.5 Prequalified Dimensions. For plug and slot weld dimensions that are prequalified, see 3.10.

2.5.6 Prohibition in Q&T Steel. Plug and slot welds are not permitted in quenched and tempered steels.

2.5.7 Limitation. Plug or slot weld size design shall be based on shear in the plane of the faying surfaces.

2.6 Joint Configuration

2.6.1 General Requirements for Joint Details. In general, details should minimize constraint against ductile behavior, avoid undue concentration of welding, and afford ample access for depositing the weld metal.

2.6.2 Combinations of Welds. If two or more of the general types of welds (groove, fillet, plug, slot) are combined in a single joint, their allowable capacity shall be calculated with reference to the axis of the group in order to determine the allowable capacity of the combination. However, such methods of adding individual capacities of welds does not apply to fillet welds reinforcing groove welds (see Annex I).

2.6.3 Welds with Rivets or Bolts. Rivets or bolts used in bearing type connections shall not be considered as sharing the load in combination with welds. Welds, if used, shall be provided to carry the entire load in the connection. However, connections that are welded to one member and riveted or bolted to the other member are permitted. High-strength bolts properly installed as a slip-critical-type connection prior to welding may be considered as sharing the stress with the welds.

2.7 Beam End Connections

Welded beam end connections shall be designed in accordance with the assumptions about the degree of restraint involved in the designated type of construction.

2.8 Eccentricity

In the design of welded joints, the total stresses, including those due to eccentricity, if any, in alignment of the connected parts and the disposition, size and type of welded joints shall not exceed those provided in this code. For statically loaded structures, the disposition of fillet welds to balance the forces about the neutral axis or axes for end connections of single-angle, double-angle, and similar type members is not required; such weld arrangements at the heel and toe of angle members may be distributed to conform to the length of the various available edges. Similarly, Ts or beams framing into chords of trusses, or similar joints, may be connected with unbalanced fillet welds.

Part B
Specific Requirements for Nontubular Connections (Statically or Cyclically Loaded)

2.9 General

The specific requirements of Part B commonly apply to all connections of nontubular members subject to static or cyclic loading. Part B shall be used with the applicable requirements of Parts A or C.

2.10 Allowable Stresses

The allowable stresses in welds shall not exceed those given in Table 2.3, or as permitted by 2.14.4 and 2.14.5, except as modified by 2.1.2.

2.11 Skewed T-Joints

2.11.1 General. Prequalified skewed T-joint details are shown in Figure 3.11. The details for the obtuse and acute side may be used together or independently depending on service conditions and design with proper consideration for concerns such as eccentricity and rotation. The Engineer shall specify the weld locations and must make clear on the drawings the weld dimensions required. In detailing skewed T-joints, a sketch of the desired joint, weld configuration, and desired weld dimensions shall be clearly shown on the drawing.

2.11.2 Prequalified Minimum Weld Size. See 3.9.3.2 for prequalified minimum weld sizes.

2.11.3 Effective Throat. The effective throat of skewed T-joint welds is dependent on the magnitude of the root opening (see 5.22.1).

2.11.3.1 Z Loss Reduction. The acute side of prequalified skewed T-joints with dihedral angles less than 60° and greater than 30° may be used as shown in Figure 3.11, Detail D. The method of sizing the weld, effective throat "E" or leg "W" shall be specified on the drawing or specification. The "Z" loss dimension specified in Table 2.2 shall apply.

Table 2.2
Z Loss Dimension (Nontubular) (see 2.11.3.1)

	Position of Welding V or OH			Position of Welding H or F		
Dihedral Angles Ψ	Process	Z (in.)	Z (mm)	Process	Z (in.)	Z (mm)
60° > Ψ ≥ 45°	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
45° > Ψ ≥ 30°	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6

2.12 Partial Length Groove Weld Prohibition

Intermittent or partial length groove welds are not permitted except that members built-up of elements connected by fillet welds, at points of localized load application, may have groove welds of limited length to participate in the transfer of the localized load. The groove weld shall extend at uniform size for at least the length required to transfer the load. Beyond this length, the groove shall be transitioned in depth to zero over a distance, not less than four times its depth. The groove shall be filled flush before the application of the fillet weld (see Commentary, Figure C2.24).

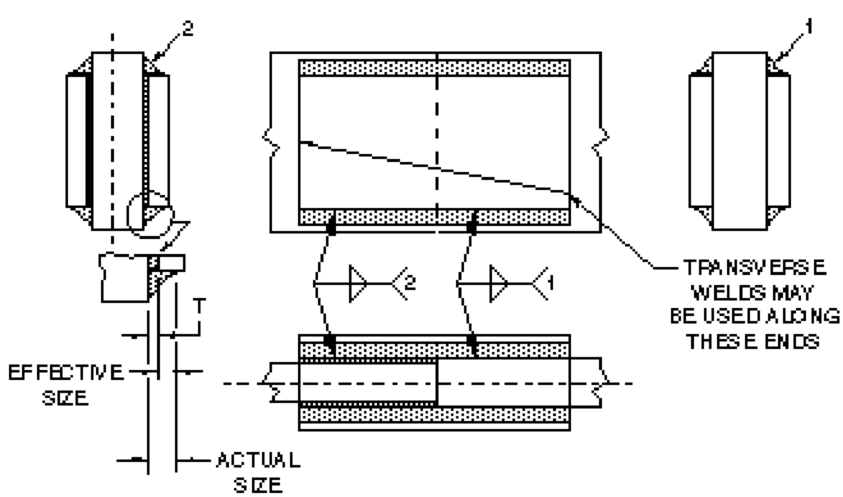
2.13 Filler Plates

Filler plates may be used in the following:

(1) Splicing parts of different thicknesses

(2) Connections that, due to existing geometric alignment, must accommodate offsets to permit simple framing

2.13.1 Filler Plates Less Than 1/4 in. (6 mm). Filler plates less than 1/4 in. (6 mm) thick shall not be used to transfer stress, but shall be kept flush with the welded edges of the stress-carrying part. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler plate (see Figure 2.2).



NOTE: THE EFFECTIVE AREA OF WELD 2 SHALL EQUAL THAT OF WELD 1, BUT ITS SIZE SHALL BE ITS EFFECTIVE SIZE PLUS THE THICKNESS OF THE FILLER PLATE T.

Figure 2.2—Filler Plates Less Than 1/4 in. (6 mm) Thick (see 2.13.1)

2.13.2 Filler Plates 1/4 in. (6 mm) or Larger. Any filler plate 1/4 in. (6 mm) or more in thickness shall extend beyond the edges of the splice plate or connection material. It shall be welded to the part on which it is fitted, and the joint shall be of sufficient strength to transmit the splice plate or connection material stress applied at the surface of the filler plate as an eccentric load. The welds joining the splice plate or connection material to the filler plate shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid over stressing the filler plate along the toe of the weld (see Figure 2.3).

2.14 Fillet Welds

2.14.1 Longitudinal Fillet Welds. If longitudinal fillet welds are used alone in end connections of flat bar tension members, the length of each fillet weld shall be no less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 8 in. (200 mm) unless end transverse welds or intermediate plug or slot welds are used.

2.14.2 Intermittent Fillet Welds. Intermittent fillet welds may be used to carry calculated stress.

2.14.3 Corner and T-Joint Reinforcement. If fillet welds are used to reinforce groove welds in corner and T-joints, the fillet weld size shall not be less than 25% of the thickness of the thinner part joined, but need not be greater than 3/8 in. (10 mm).

2.14.4 In-Plane Center of Gravity Loading. The allowable stress in a linear weld group loaded in-plane through the center of gravity is the following:

$$F_v = 0.30F_{EXX} (1.0 + 0.50 \sin^{1.5} \Theta)$$

where:

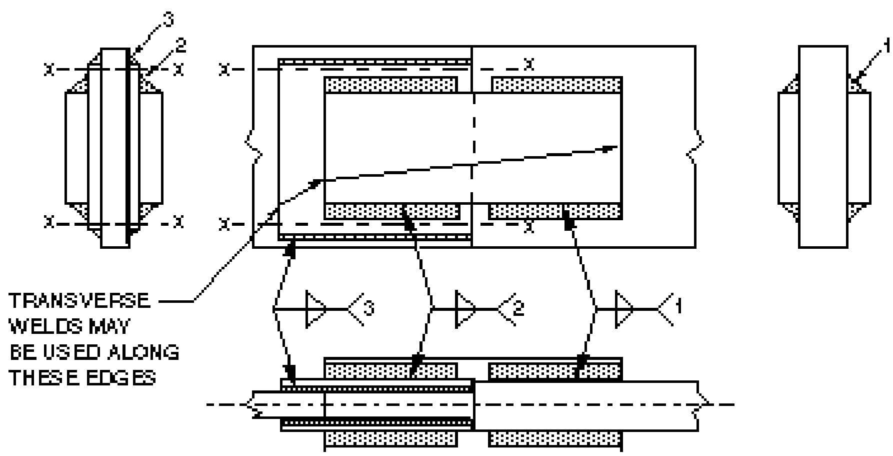
F_v = allowable unit stress, ksi (MPa)
F_{EXX} = electrode classification number, i.e., minimum specified strength, ksi (MPa)
Θ = angle of loading measured from the weld longitudinal axis, degrees

2.14.5 Instantaneous Center of Rotation. The allowable stresses in weld elements within a weld group that are loaded in-plane and analyzed using an instantaneous center of rotation method to maintain deformation compatibility and the nonlinear load-deformation behavior of variable angle loaded welds is the following:

$$F_{vx} = \Sigma F_{vix}$$
$$F_{vy} = \Sigma F_{viy}$$
$$F_{vi} = 0.30 F_{EXX} (1.0 + 0.50 \sin^{1.5}\Theta) f(p)$$
$$f(p) = [p(1.9 - 0.9p)]^{0.3}$$
$$M = \Sigma [F_{viy} (x) - F_{vix} (y)]$$

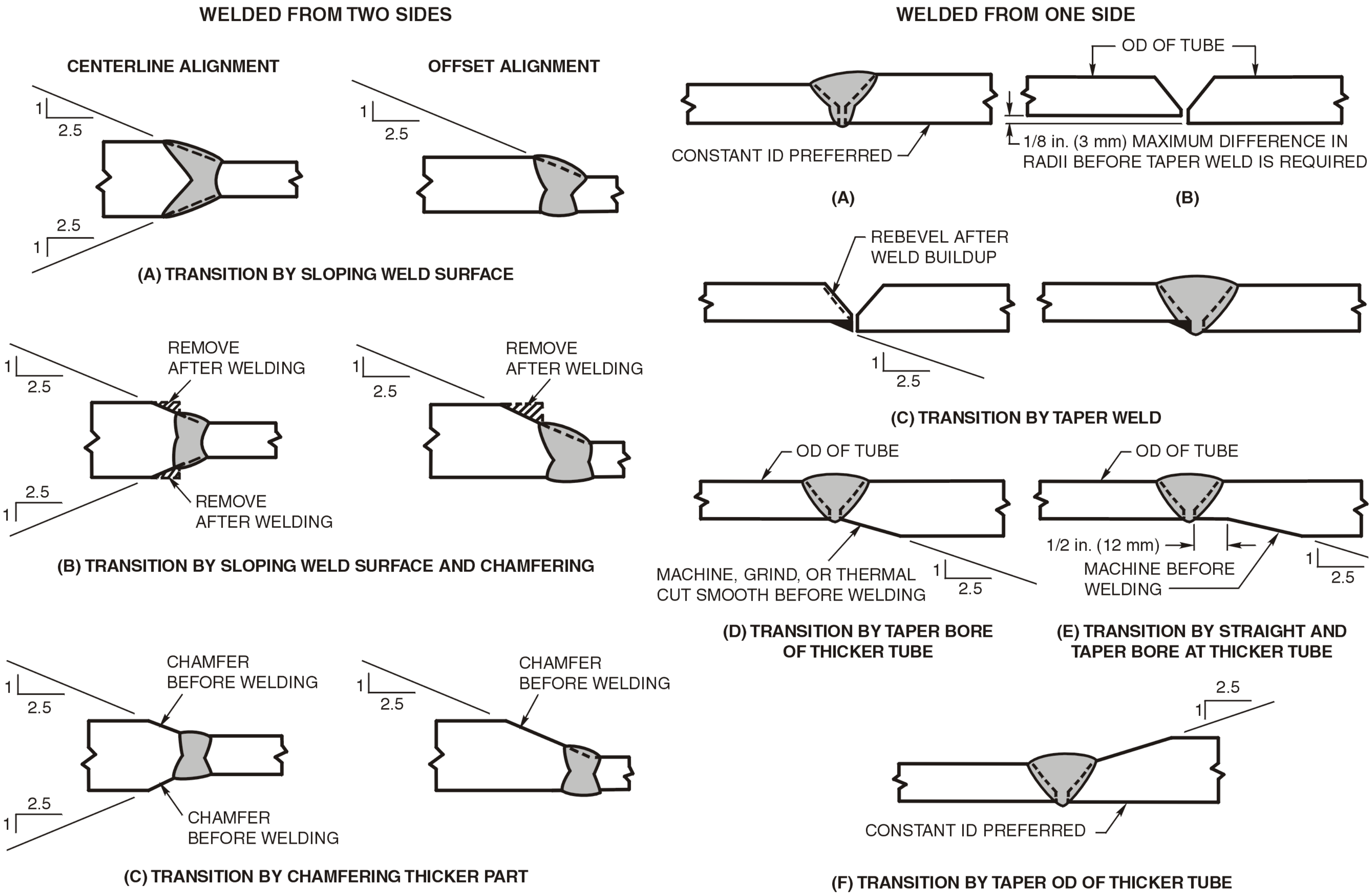
where:

F_{vix} = x component of stress F_{vi}
F_{viy} = y component of stress F_{vi}
M = moment of external forces about the instantaneous center of rotation
p = Δ_i/Δ_m ratio of element "i" deformation to deformation in element at maximum stress



Notes:
1. The effective area of weld 2 shall equal that of weld 1. The length of weld 2 shall be sufficient to avoid overstressing the filler plates in shear along planes x-x.
2. The effective area of weld 3 shall equal that of weld 1, and there shall be no overstress of the ends of weld 3 resulting from the eccentricity of the forces acting on the filler plates.

Figure 2.3—Filler Plates 1/4 in. (6 mm) or Thicker (see 2.13.2)



Notes:
1. Groove may be of any permitted or qualified type and detail.
2. Transition slopes shown are the maximum permitted.

Note 3: In (B), (D), and (E) groove may be any permitted or qualified type and detail. Transition slopes shown are maximum permitted.

Figure 2.4—Transition of Thickness of Butt Joints in Parts of Unequal Thickness (Tubular) (see 2.41)

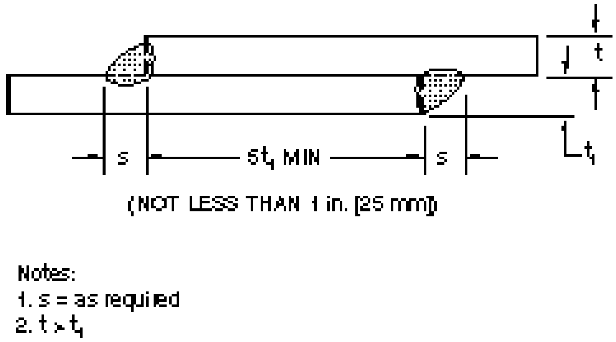


Figure 2.5—Double-Fillet Welded Lap Joint (see 2.4.8.1)

$\Delta_m = 0.209\ (\Theta + 2)^{-0.32}$ W, deformation of weld element at maximum stress, in. (mm)
$\Delta_u = 1.087\ (\Theta + 6)^{-0.65}$ W, < 0.17W, deformation of weld element at ultimate stress (fracture), usually in element furthest from instantaneous center of rotation, in. (mm)
W = leg size of the fillet weld, in. (mm)
Δ_i = deformation of weld elements at intermediate stress levels, linearly proportioned to the critical deformation based on distance from the instantaneous center of rotation, in. = $r_i\Delta_u/r_{crit}$
r_{crit} = distance from instantaneous center of rotation to weld element with minimum Δ_u/r_i ratio, in. (mm)

2.15 Built-Up Members

If two or more plates or rolled shapes are used to build up a member, sufficient welding (of the fillet, plug, or slot type) shall be provided to make the parts act in unison but not less than that which may be required to transfer calculated stress between the parts joined.

2.16 Maximum Spacing of Intermittent Welds

The maximum longitudinal spacing of intermittent welds connecting two or more rolled shapes or plates in contact with one another shall not exceed 24 in. (600 mm).

2.17 Compression Members

In built-up compression members, the longitudinal spacing of intermittent welds connecting a plate component to other components shall not exceed 12 in. (300 mm) nor the plate thickness times $4000/\sqrt{F_y}$ for F_y in psi; [$332/\sqrt{F_y}$ for F_y in MPa] (F_y = specified minimum yield strength of the type steel being used.) The unsupported width of web, cover plate, or diaphragm plates, between adjacent lines of welds, shall not exceed the plate thickness times $8000/\sqrt{F_y}$ (for F_y in psi), [$664/\sqrt{F_y}$ for F_y in MPa.]

When the unsupported width exceeds this limit, but a portion of its width no greater than 800 times the thickness would satisfy the stress requirements, the member will be considered acceptable.

2.18 Tension Members

In built-up tension members, the longitudinal spacing of intermittent welds connecting a plate component to other components, or connecting two plate components to each other, shall not exceed 12 in. (300 mm) or 24 times the thickness of the thinner plate.

2.19 End Returns

Side or end fillet welds terminating at ends or sides of header angles, brackets, beam seats and similar connections shall be returned continuously around the corners for a distance at least twice the nominal size of the weld except as provided in 2.4.7.

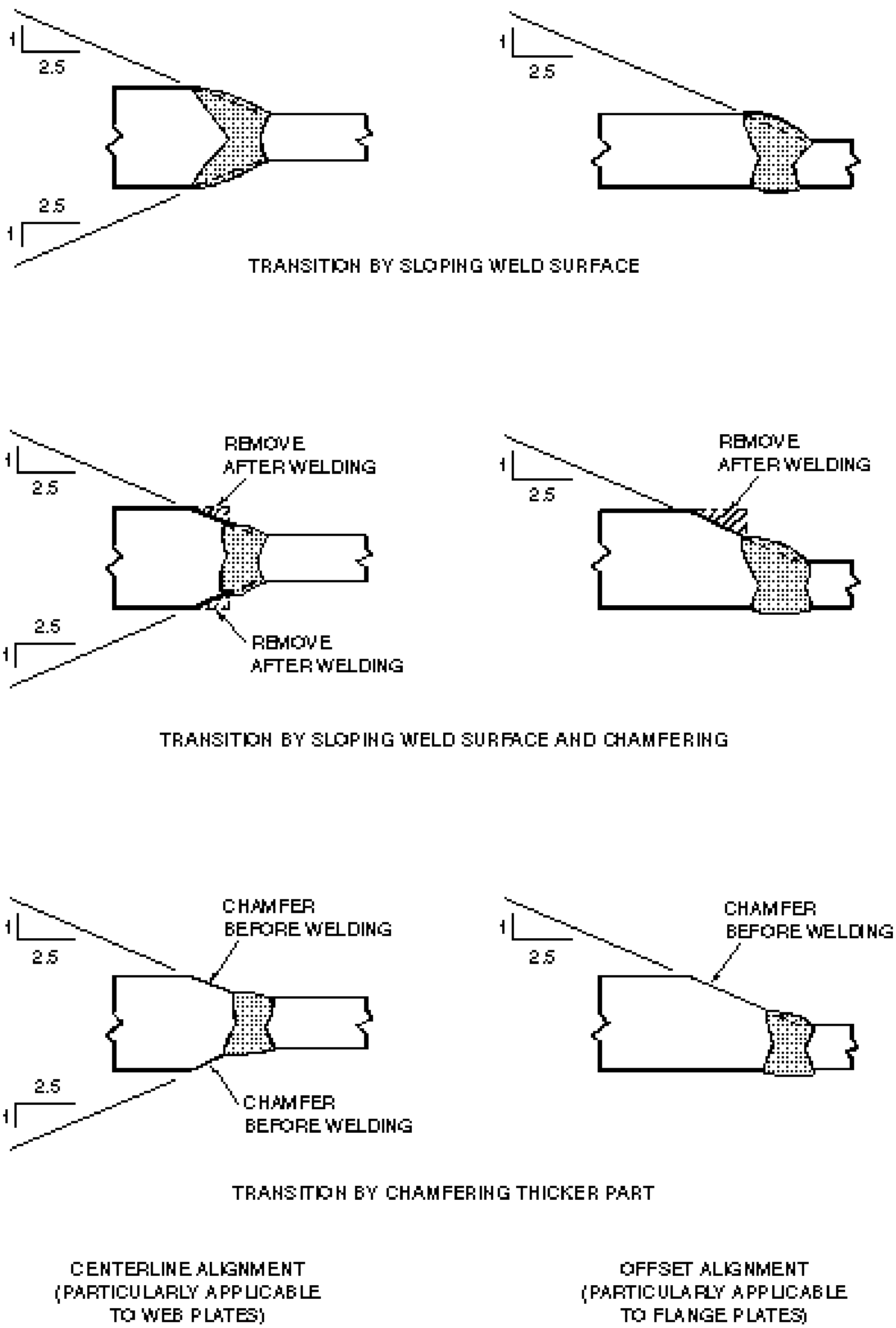
2.20 Transitions of Thicknesses and Widths

Tension butt joints between axially aligned members of different thicknesses or widths, or both, and subject to tensile stress greater than one-third the allowable design tensile stress shall be made in such a manner that the slope in the transition does not exceed 1 in 2-1/2 (see Figure 2.6 for thickness and Figure 2.7 for width). The transition shall be accomplished by chamfering the thicker part, tapering the wider part, sloping the weld metal, or by any combination of these.

Part C
Specific Requirements for Cyclically Loaded Nontubular Connections

2.21 General

Part C applies only to nontubular members and connections subject to cyclic load of frequency and magnitude sufficient to initiate cracking and progressive failure (fatigue). The provisions of Part C shall be applied to minimize the possibility of such a failure mechanism. The Engineer shall provide either complete details, including weld sizes, or shall specify the planned cycle life and the maximum range of moments, shears and reactions for the connections.



Notes:
1. Groove may be of any permitted or qualified type and detail.
2. Transition slopes shown are the maximum permitted.

Figure 2.6—Transition of Butt Joints in Parts of Unequal Thickness (Nontubular) (see 2.20 and 2.29.1)

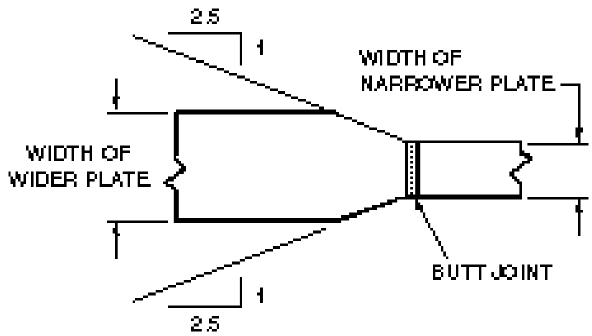


Figure 2.7—Transition of Widths (Statically Loaded Nontubular) (see 2.20)

2.21.1 Symmetrical Sections. For members having symmetrical cross sections, the connection welds shall be arranged symmetrically about the axis of the member, or proper allowance shall be made for unsymmetrical distribution of stresses.

2.21.2 Angle Member. For axially stressed angle members, the center of gravity of the connecting welds shall lie between the line of the center of gravity of the angle's cross section and the centerline of the connected leg. If the center of gravity of the connecting weld lies outside of this zone, the total stresses, including those due to the eccentricity from the center of gravity of the angle, shall not exceed those permitted by this code.

2.21.3 Continuous Welds. When a member is built up of two or more pieces, the pieces shall be connected along their longitudinal joints by sufficient continuous welds to make the pieces act in unison.

2.22 Allowable Stresses

Except as modified by 2.23 and 2.24, allowable unit stresses in welds shall not exceed those listed in Table 2.3, or as determined by 2.14.4 or 2.14.5, as applicable.

2.23 Combined Stresses

In the case of axial stress combined with bending, the allowable stress, or stress range, as applicable, of each kind shall be governed by the requirements of 2.22 and 2.24 and the maximum combined stresses calculated therefrom shall be limited in accordance with the requirements of the applicable general specifications.

2.24 Cyclic Load Stress Range

The allowable stress range (fatigue) for structures subject to cyclic loading shall be provided in Table 2.4 and Figures 2.8, 2.9, and 2.10 for the applicable condition and cycle life.

2.25 Corner and T-Joints

2.25.1 Fillet Weld Reinforcement. Groove welds in corner and T-joints shall be reinforced by fillet welds with leg sizes not less than 25% of the thickness of the thinner part joined, but need not exceed 3/8 in. (10 mm).

2.25.2 Weld Arrangement. Corner and T-joints that are to be subjected to bending about an axis parallel to the joint shall have their welds arranged to avoid concentration of tensile stress at the root of any weld.

2.26 Connections or Splices—Tension and Compression Members

Connections or splices of tension or compression members made by groove welds shall have complete joint penetration (CJP) welds. Connections or splices made with fillet or plug welds, except as noted in 2.31, shall be designed for an average of the calculated stress and the strength of the member, but not less than 75% of the strength of the member; or if there is repeated application of load, the maximum stress or stress range in such connection or splice shall not exceed the fatigue stress permitted by the applicable general specification.

2.26.1 RT or UT Requirements. When required by Table 2.4, weld soundness, for CJP groove welds subject to tension and reversal of stress, shall be established by radiographic or ultrasonic testing in conformance with section 6.

2.27 Prohibited Joints and Welds

2.27.1 Partial Joint Penetration Groove Welds. Partial joint penetration groove welds subject to tension normal to their longitudinal axis shall not be used where design criteria indicate cyclic loading could produce fatigue failure.

2.27.2 One-Sided Groove Welds. Groove welds, made from one side only, are prohibited, if the welds are made:

(1) without any backing, or

(2) with backing, other than steel, that has not been qualified in accordance with section 4.

These prohibitions for groove welds made from one side only shall not apply to the following:

Table 2.3
Allowable Stresses in Nontubular Connection Welds
(see 2.10 and 2.22)

<table>
<tr><th>Type of Weld</th><th colspan="2">Stress in Weld[1]</th><th>Allowable Connection Stress[5]</th><th>Required Filler Metal Strength Level[2]</th></tr>
<tr><td rowspan="4">Complete joint penetration groove welds</td><td colspan="2">Tension normal to the effective area</td><td>Same as base metal</td><td>Matching filler metal shall be used.</td></tr>
<tr><td colspan="2">Compression normal to the effective area</td><td>Same as base metal</td><td>Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used.</td></tr>
<tr><td colspan="2">Tension or compression parallel to the axis of the weld</td><td>Same as base metal</td><td rowspan="2">Filler metal with a strength level equal to or less than matching filler metal may be used.</td></tr>
<tr><td colspan="2">Shear on the effective areas</td><td>0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal</td></tr>
<tr><td rowspan="5">Partial joint penetration groove welds</td><td rowspan="2">Compression normal to effective area</td><td>Joint not designed to bear</td><td>0.50 × nominal tensile strength of filler metal, except stress on base metal shall not exceed 0.60 × yield strength of base metal</td><td rowspan="5">Filler metal with a strength level equal to or less than matching filler metal may be used.</td></tr>
<tr><td>Joint designed to bear</td><td>Same as base metal</td></tr>
<tr><td colspan="2">Tension or compression parallel to the axis of the weld[3]</td><td>Same as base metal</td></tr>
<tr><td colspan="2">Shear parallel to axis of weld</td><td>0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal</td></tr>
<tr><td colspan="2">Tension normal to effective area</td><td>0.30 × nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed 0.60 × yield strength of base metal</td></tr>
<tr><td rowspan="2">Fillet weld</td><td colspan="2">Shear on effective area</td><td>0.30 × nominal tensile strength of filler metal[4]</td><td rowspan="2">Filler metal with a strength level equal to or less than matching filler metal may be used.</td></tr>
<tr><td colspan="2">Tension or compression parallel to axis of weld[3]</td><td>Same as base metal</td></tr>
<tr><td>Plug and slot welds</td><td colspan="2">Shear parallel to faying surfaces (on effective area)</td><td>0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal</td><td>Filler metal with a strength level equal to or less than matching filler metal may be used.</td></tr>
</table>

Notes:
1. For definition of effective area, see 2.3.2 for groove welds, 2.4.3 for fillet welds, and 2.5.1 for plug and slot welds.
2. For matching filler metal to base metal strength for code approved steels, see Table 3.1 and Annex M.
3. Fillet weld and partial joint penetration groove welds joining the component elements of built-up members, such as flange-to-web connections, may be designed without regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
4. Alternatively, see 2.14.4 and 2.14.5.
5. For cyclically loaded connections, see 2.10, 2.22, 2.23, and 2.24. For statically loaded connections, see 2.10.

Table 2.4
Fatigue Stress Provisions—Tension or Reversal Stresses* (Nontubulars) (see 2.24)

<table>
<tr><th>General Condition</th><th>Situation</th><th colspan="4">Stress Category (see Figure 2.8)</th><th>Example (see Figure 2.8)</th></tr>
<tr><td>Plain material</td><td>Base metal with rolled or cleaned surfaces. Oxygen-cut edges with ANSI smoothness of 1000 or less.</td><td colspan="4">A</td><td>1, 2</td></tr>
<tr><td>Built-up members</td><td>Base metal and weld metal in members without attachments, built up of plates or shapes connected by continuous complete or partial joint penetration groove welds or by continuous fillet welds parallel to the direction of applied stress.</td><td colspan="4">B</td><td>3, 4, 5, 7</td></tr>
<tr><td></td><td>Calculated flextural stress at toe of transverse stiffener welds on girder webs or flanges.</td><td colspan="4">C</td><td>6</td></tr>
<tr><td></td><td>Base metal at end of partial length welded cover plates having square or tapered ends, with or without welds across the ends.</td><td colspan="4">E</td><td>7</td></tr>
<tr><td>Groove welds</td><td>Base metal and weld metal at complete joint penetration groove welded splices of rolled and welded sections having similar profiles when welds are ground[1] and weld soundness established by nondestructive testing.[2]</td><td colspan="4">B</td><td>8, 9</td></tr>
<tr><td></td><td>Base metal and weld metal in or adjacent to complete joint penetration groove welded splices at transitions in width or thickness, with welds ground[1] to provide slopes no steeper than 1 to 2-1/2[3] for yield strength less than 90 ksi (620 MPa) and a radius[8] of $R \geq 2$ ft (0.6 m) for yield strength ≥ 90 ksi (620 MPa), and weld soundness established by nondestructive testing.[2]</td><td colspan="4">B</td><td>10, 11a, 11b</td></tr>
<tr><td rowspan="2">Groove welded connections</td><td rowspan="2">Base metal at details of any length attached by groove welds subjected to transverse or longitudinal loading, or both, when weld soundness transverse to the direction of stress is established by nondestructive testing[2] and the detail embodies a transition radius, R, with the weld termination ground[1] when</td><td rowspan="2">Longitudinal loading</td><td colspan="3">Transverse loading[4]</td><td rowspan="2">Example (see Figure 2.8)</td></tr>
<tr><td>Materials having equal or unequal thickness sloped,[6] welds ground,[1] web connections excluded.</td><td>Materials having equal thickness, not ground; web connections excluded.</td><td>Materials having unequal thickness, not sloped or ground, including web connections.</td></tr>
<tr><td></td><td>(a) $R \geq 24$ in. (600 mm)</td><td>B</td><td>B</td><td>C</td><td>E</td><td>13</td></tr>
<tr><td></td><td>(b) 24 in. (600 mm) $> R \geq 6$ in. (150 mm)</td><td>C</td><td>C</td><td>C</td><td>E</td><td>13</td></tr>
<tr><td></td><td>(c) 6 in. (150 mm) $> R \geq 2$ in. (50 mm)</td><td>D</td><td>D</td><td>D</td><td>E</td><td>13</td></tr>
<tr><td></td><td>(d) 2 in. (50 mm) $> R \geq 0$[7]</td><td>E</td><td>E</td><td>E</td><td>E</td><td>12, 13</td></tr>
</table>

*Except as noted for fillet and stud welds.

(continued)

Table 2.4 (Continued)

General Condition	Situation	Stress Category (see Figure 2.8)	Example (see Figure 2.8)
Groove welds	Base metal and weld metal in, or adjacent to, complete joint penetration groove welded splices either not requiring transition or when required with transitions having slopes no greater than 1 to 2-1/2[3] for yield strength less than 90 ksi (620 MPa) and a radius[8] of R ≥ 2 ft (0.6 m) for yield strength ≥ 90 ksi (620 MPa), and when in either case reinforcement is not removed and weld soundness is established by nondestructive testing.[2]	C	8, 9, 10, 11a, 11b
Groove or fillet welded connections	Base metal at details attached by groove or fillet welds subject to longitudinal loading where the details embody a transition radius, R, less than 2 in.[7] (50 mm), and when the detail length, L, parallel to the line of stress is		
	(a) < 2 in. (50 mm)	C	12, 14, 15, 16
	(b) 2 in. (50 mm) ≤ L < 4 in. (100 mm)	D	12
	(c) L ≥ 4 in. (100 mm)	E	12
Fillet welded connections	Base metal at details attached by fillet welds parallel to the direction of stress regardless of length when the detail embodies a transition radius, R, 2 in. (50 mm) or greater and with the weld termination ground.[1]		
	(a) When R ≥ 24 in. (600 mm)	B[5]	13
	(b) When 24 in. (600 mm) > R ≥ 6 in. (150 mm)	C[5]	13
	(c) When 6 in. (150 mm) > R ≥ 2 in. (50 mm)	D[5]	13
Fillet welds	Shear stress on throat of fillet welds.	F	8a
	Base metal at intermittent welds attaching transverse stiffeners and stud-type shear connectors.	C	7, 14
	Base metal at intermittent welds attaching longitudinal stiffeners.	E	—
Stud welds	Shear stress on nominal shear area of Type B shear connectors.	F	14
Plug and slot welds	Base metal adjacent to or connected by plug or slot welds.	E	—

Notes:
1. Finished according to 5.24.4.1 and 5.24.4.2.
2. Either RT or UT to meet quality requirements of 6.12.2 or 6.13.2 for welds subject to tensile stress.
3. Sloped as required by 2.29.1.
4. Applicable only to complete joint penetration groove welds.
5. Shear stress on throat of weld (loading through the weld in any direction) is governed by Category F.
6. Slopes similar to those required by Note 3 are mandatory for categories listed. If slopes are not obtainable, Category E must be used.
7. Radii less than 2 in. (50 mm) need not be ground.
8. Radii used as required by 2.29.3.

*Except as noted for fillet and stud welds.

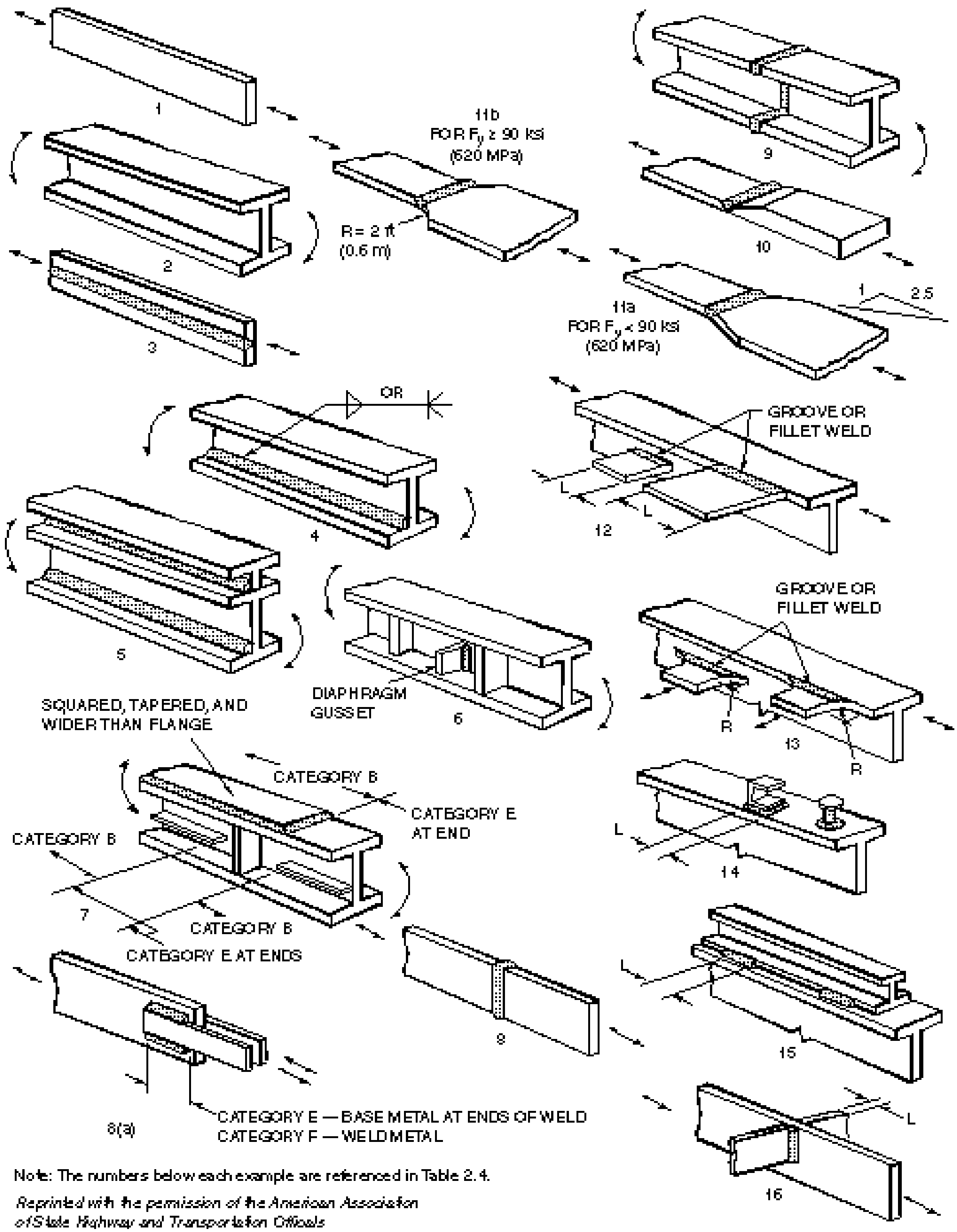


Figure 2.8—Examples of Various Fatigue Categories (see 2.24)

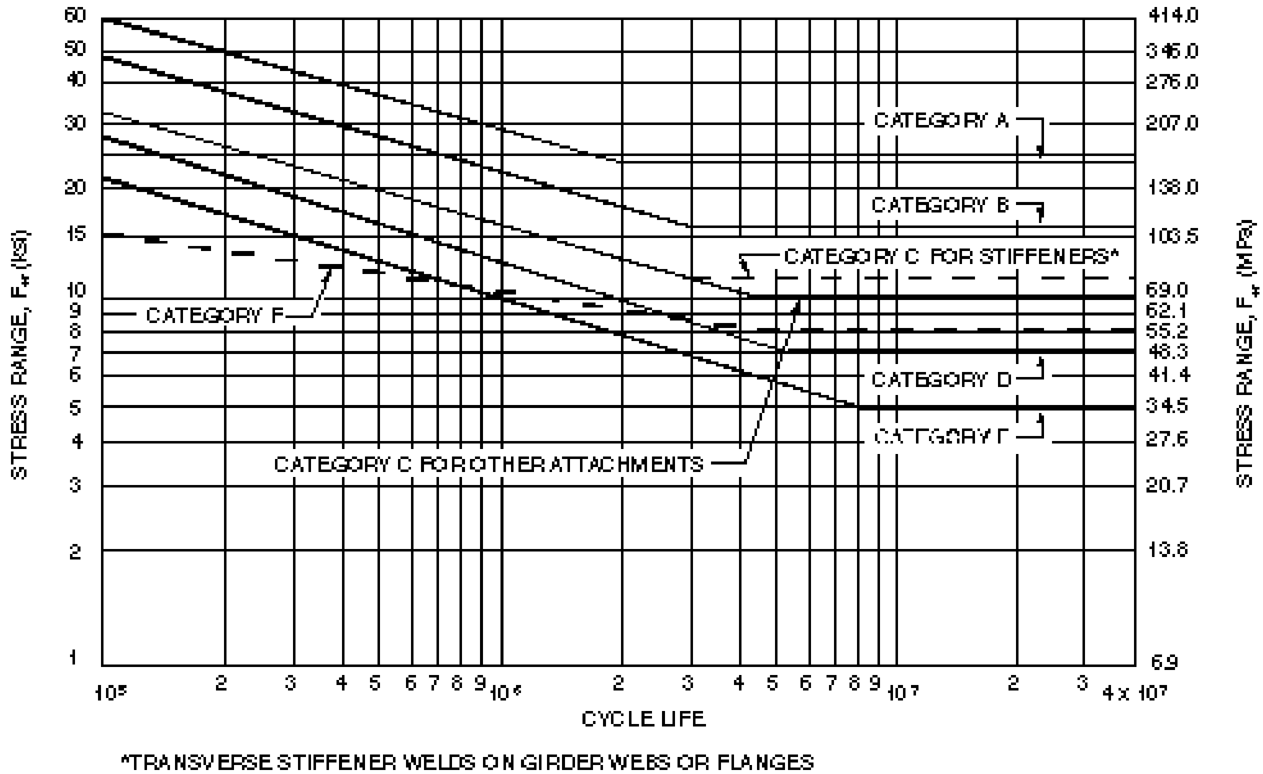


Figure 2.9—Design Stress Range Curves for Categories A to F— Redundant Structures (Nontubular) (see 2.24)

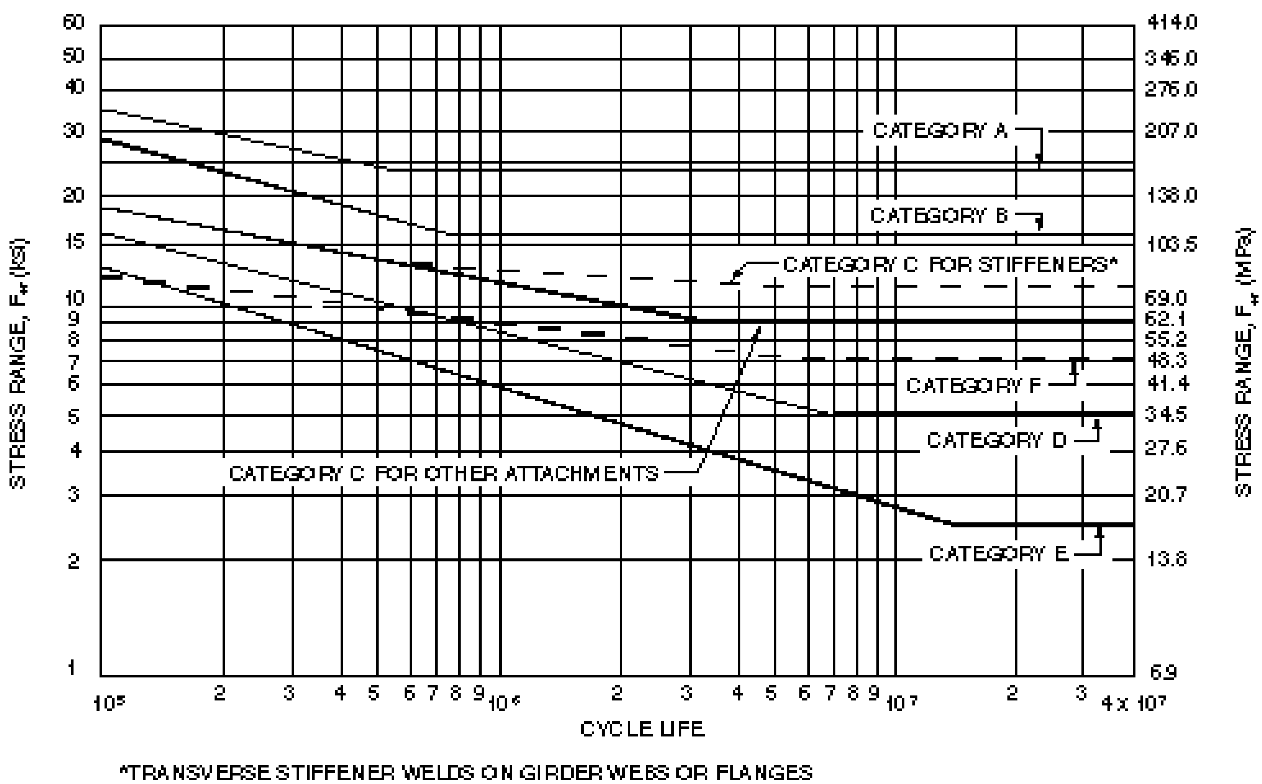


Figure 2.10—Design Stress Range Curves for Categories A to F— Nonredundant Structures (Nontubular) (see 2.24)

(a) Secondary or nonstress-carrying members and shoes or other nonstressed appurtenances, and

(b) Corner joints parallel to the direction of calculated stress, between components for built-up members designed primarily for axial stress

2.27.3 Intermittent Groove Welds. Intermittent groove welds are prohibited.

2.27.4 Intermittent Fillet Welds. Intermittent fillet welds, except as provided in 2.30.1, are prohibited.

2.27.5 Horizontal Position Limitation. Bevel-groove and J-grooves in butt joints for other than the horizontal position are prohibited.

2.27.6 Plug and Slot Welds. Plug and slot welds on primary tension members are prohibited.

2.27.7 Fillet Welds < 3/16 in. (5 mm). Fillet weld sizes less than 3/16 in. (5 mm) shall be prohibited.

2.28 Fillet Weld Terminations

For details and structural elements such as brackets, beam seats, framing angles, and simple end plates, the outstanding legs of which are subject to cyclic (fatigue) stresses that would tend to cause progressive failure initiating from a point of maximum stress at the weld termination, fillet welds shall be returned around the side or end for a distance not less than two times the weld size or the width of the part, whichever is less.

2.29 Transition of Thicknesses and Widths

2.29.1 Tension Butt-Joint Thickness. Butt joints between parts having unequal thicknesses and subject to tensile stress shall have a smooth transition between the offset surfaces at a slope of no more than 1 in 2-1/2 with the surface of either part. The transition may be accomplished by sloping weld surfaces, by chamfering the thicker part, or by a combination of the two methods (see Figure 2.6).

2.29.2 Shear or Compression Butt-Joint Thickness. In butt joints between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished as specified in 2.29.1 when offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected. When the offset is equal to or less than the thickness of the thinner part connected, the face of the weld shall be sloped no more than 1 in 2-1/2 from the surface of the thinner part or shall be sloped to the surface of the thicker part if this requires a lesser slope with the following exception: Truss member joints and beam and girder flange joints shall be made with smooth transitions of the type specified in 2.29.1.

2.29.3 Tension Butt-Joint Width. Butt joints between parts having unequal width and subject to tensile stress shall have a smooth transition between offset edges at a slope of no more than 1 in 2-1/2 with the edge of either part or shall be transitioned with a 2.0 ft (600 mm) minimum radius tangent to the narrower part of the center of the butt joints (see Figure 2.11). A radius transition is required for steels having a yield strength greater than or equal to 90 ksi (620 MPa).

2.30 Stiffeners

2.30.1 Intermittent Fillet Welds. Intermittent fillet welds used to connect stiffeners to beams and girders shall comply with the following requirements:

(1) Minimum length of each weld shall be 1-1/2 in. (40 mm).

(2) A weld shall be made on each side of the joint. The length of each weld shall be at least 25% of the joint length.

(3) Maximum end-to-end clear spacing of welds shall be twelve times the thickness of the thinner part but not more than 6 in. (150 mm).

(4) Each end of stiffeners, connected to a web, shall be welded on both sides of the joint.

2.30.2 Arrangement. Stiffeners, if used, shall preferably be arranged in pairs on opposite sides of the web. Stiffeners may be welded to tension or compression flanges. The fatigue stress or stress ranges at the points of attachment to the tension flange or tension portions of the web shall comply with the fatigue requirements of the general specification. Transverse fillet welds may be used for welding stiffeners to flanges.

2.30.3 Single-Sided Welds. If stiffeners are used on only one side of the web, they shall be welded to the compression flange.

2.31 Connections or Splices in Compression Members with Milled Joints

If members subject to compression only are spliced and full-milled bearing is provided, the splice material and its welding shall be arranged, unless otherwise stipulated by the applicable general specifications, to hold all parts in alignment and shall be proportioned to carry 50% of the calculated stress in the member. Where such members are in full-milled bearing on base plates, there shall be sufficient welding to hold all parts securely in place.

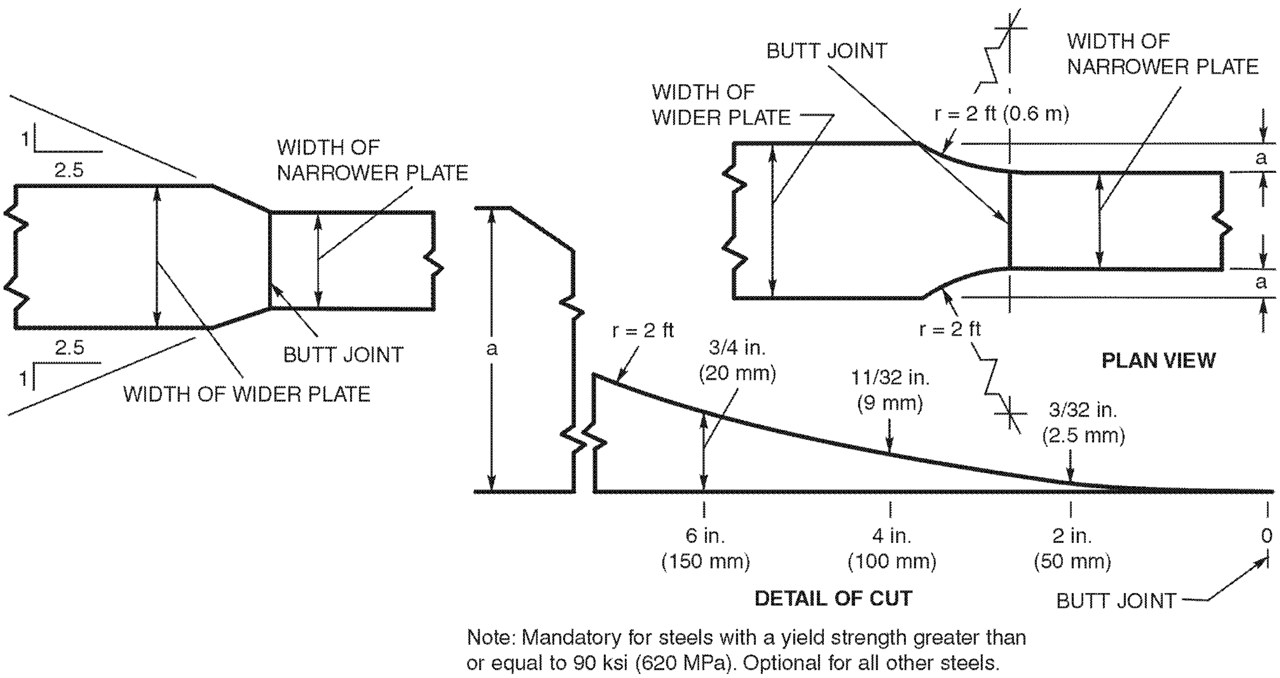


Figure 2.11—Transition of Width (Cyclically Loaded Nontubular) (see 2.29.3)

2.32 Lap Joints

2.32.1 Longitudinal Fillet Welds. If longitudinal fillet welds are used alone in lap joints of end connections, the length of each fillet weld shall be no less than the perpendicular distance between the welds. The transverse spacing of the welds shall not exceed 16 times the thickness of the connected thinner part unless suitable provision is made (as by intermediate plug or slot welds) to prevent buckling or separation of the parts. The longitudinal fillet weld may be either at the edges of the member or in slots.

2.32.2 Hole or Slot Spacing. When fillet welds in holes or slots are used, the clear distance from the edge of the hole or slot to the adjacent edge of the part containing it, measured perpendicular to the direction of stress, shall be no less than five times the thickness of the part nor less than two times the width of the hole or slot. The strength of the part shall be determined from the critical net section of the base metal.

2.33 Built-Up Sections

Girders (built-up I sections) shall preferably be made with one plate in each flange, i.e., without cover plates. The unsupported projection of a flange shall be no more than permitted by the applicable general specification. The thickness and width of a flange may be varied by butt joint welding parts of different thickness or width with transitions conforming to the requirements of 2.29.

2.34 Cover Plates

2.34.1 Thickness and Width. Cover plates shall preferably be limited to one on any flange. The maximum thickness of cover plates on a flange (total thickness of all cover plates if more than one is used) shall not be greater than 1-1/2 times the thickness of the flange to which the cover plate is attached. The thickness and width of a cover plate may be varied by butt joint welding parts of different thickness or width with transitions conforming to the requirements of 2.29. Such plates shall be assembled and welds ground smooth before being attached to the flange. The width of a cover plate, with recognition of dimensional tolerances allowed by ASTM A 6, shall allow suitable space for a fillet weld along each edge of the joint between the flange and the plate cover.

2.34.2 Partial Length. Any partial length cover plate shall extend beyond the theoretical end by the terminal distance, or it shall extend to a section where the stress or stress range in the beam flange is equal to the allowable fatigue stress permitted by 2.24, whichever is greater. The theoretical end of the cover plate is the section at which the stress in the flange without that cover plate equals the allowable stress exclusive of fatigue considerations. The terminal distance beyond the theoretical end shall be at least sufficient to allow terminal development in one of the following manners:

(1) Preferably, terminal development shall be made with the end of the cover plate cut square, with no reduction of width in the terminal development length, and with a continuous fillet weld across the end and along both edges of the cover plate or flange to connect the cover plate to the flange. For this condition, the terminal development length, measured from the actual end of the cover plate, shall be 1-1/2 times the width of the cover plate at its theoretical end. See also 2.28 and Figure 2.12.

(2) Alternatively, terminal development may be made with no weld across the end of the cover plate provided that all of the following conditions are met:

(a) The terminal development length, measured from the actual end of the cover plate, is twice the width.

(b) The width of the cover plate is symmetrically tapered to a width no greater than 1/3 the width at the theoretical end, but no less than 3 in. (75 mm).

(c) There is a continuous fillet weld along both edges of the plate in the tapered terminal development length to connect it to the flange.

2.34.3 Terminal Fillet Welds. Fillet welds connecting a cover plate to the flange in the region between terminal developments shall be continuous welds of sufficient size to transmit the incremental longitudinal shear between the cover plate and the flange. Fillet welds in each terminal development shall be of sufficient size to develop the cover plate's portion of the stress in the beam or girder at the inner end of the terminal development length and in no case shall the welds be smaller than the minimum size permitted by 5.14.

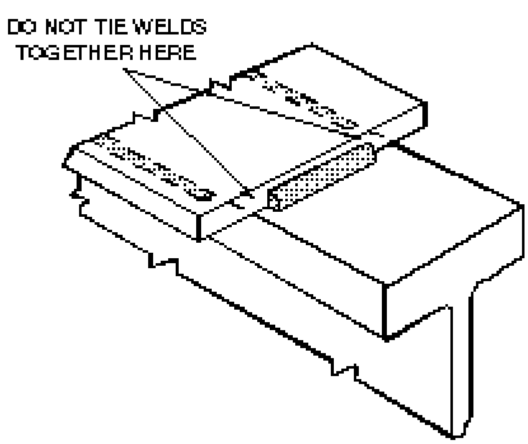


Figure 2.12—Fillet Welds on Opposite Sides of a Common Plane of Contact (see 2.4.7.5)

Part D
Specific Requirements for Tubular Connections

2.35 General

The specific requirements of Part D apply only to tubular connections, and shall be used with the applicable requirements of Part A. All provisions of Part D apply to static applications and cyclic applications, with the exception of the fatigue provisions of 2.36.6, which are unique to cyclic applications.

2.35.1 Eccentricity. Moments caused by significant deviation from concentric connections shall be provided for in analysis and design. See Figure 2.14(H) for an illustration of an eccentric connection.

2.36 Allowable Stresses

2.36.1 Base-Metal Stresses. These provisions may be used in conjunction with any applicable design specifications in either allowable stress design (ASD) or load and resistance factor design (LRFD) formats. Unless the applicable design specification provides otherwise, tubular connection design shall be as described in 2.36.5, 2.36.6 and 2.40. The base-metal stresses shall be those specified in the applicable design specifications, with the following limitations:

2.36.2 Circular Section Limitations. Limitations on diameter/thickness for circular sections, and largest flat width/thickness ratio for box sections, beyond which local buckling or other local failure modes must be considered, shall be in accordance with the governing design code. Limits of applicability for the criteria given in 2.40 shall be observed as follows:

(1) circular tubes: $D/t < 3300/F_y$ [for F_y in ksi], $478/F_y$ [for F_y in MPa]

(2) box section gap connections: $D/t \le 210/\sqrt{F_y}$ [for F_y in ksi], $80/\sqrt{F_y}$ [for F_y in MPa] but not more than 35

(3) box section overlap connections: $D/t \le 190/\sqrt{F_y}$ [for F_y in ksi], $72/\sqrt{F_y}$ [for F_y in MPa]

2.36.3 Welds Stresses. The allowable stresses in welds shall not exceed those given in Table 2.5, or as permitted by 2.14.4 and 2.14.5, except as modified by 2.36.5, 2.36.6, and 2.40.

2.36.4 Fiber Stresses. Fiber stresses due to bending shall not exceed the values prescribed for tension and compression, unless the members are compact sections (able to develop full plastic moment) and any transverse weld is proportioned to develop fully the strength of sections joined.

Table 2.5
Allowable Stresses in Tubular Connection Welds (see 2.36.3)

Type of Weld	Tubular Application	Kind of Stress	Allowable Stress Design (ASD)	Load and Resistance Factor Design (LRFD)		Required Filler Metal Strength Level[1]
			Allowable Stress	Resistance Factor Φ	Nominal Strength	
Complete Joint Penetration Groove Weld	Longitudinal butt joints (longitudinal seams)	Tension or compression parallel to axis of the weld[2]	Same as for base metal[3]	0.9	0.6 F_y	Filler metal with strength equal to or less than matching filler metal may be used.
		Beam or torsional shear	Base metal 0.40 F_y Filler metal 0.3 F_{EXX}	0.9 0.8	0.6 F_y 0.6 F_{EXX}	
	Circumferential butt joints (girth seams)	Compression normal to the effective area[2]	Same as for base metal	0.9	F_y	Matching filler metal shall be used.
		Shear on effective area		Base metal 0.9 Weld metal 0.8	0.6 F_y 0.6 F_{EXX}	
		Tension normal to the effective area		0.9	F_y	
	Weld joints in structural T-, Y-, or K-connections in structures designed for critical loading such as fatigue, which would normally call for complete joint penetration welds.	Tension, compression or shear on base metal adjoining weld conforming to detail of Figures 3.6 and 3.8–3.10 (tubular weld made from outside only without backing).	Same as for base metal or as limited by connection geometry (see 2.40 provisions for ASD)	Same as for base metal or as limited by connection geometry (see 2.40 provisions for LRFD)		Matching filler metal shall be used.
		Tension, compression, or shear on effective area of groove welds, made from both sides or with backing.				
Fillet Weld	Longitudinal joints of built-up tubular members	Tension or compression parallel to axis of the weld.	Same as for base metal	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Shear on effective area.	0.30 F_{EXX}[5]	0.75	0.6 F_{EXX}	
	Joints in structural T-, Y-, or K-connections in circular lap joints and joints of attachments to tubes.	Shear on effective throat regardless of direction of loading (see 2.39 and 2.40.1.3).	0.30 F_{EXX} or as limited by connection geometry (see 2.40)	0.75 or as limited by connection geometry (see 2.40 for provision for LRFD)	0.6 F_{EXX}	Filler metal with a strength level equal to or less than matching filler metal may be used.[4]

(continued)

Table 2.5 (Continued)

Type of Weld	Tubular Application	Kind of Stress		Allowable Stress Design (ASD)	Load and Resistance Factor Design (LRFD)		Required Filler Metal Strength Level[1]
				Allowable Stress	Resistance Factor Φ	Nominal Strength	
Plug and Slot Welds	Shear parallel to faying surfaces (on effective area)			Base metal $0.40\ F_y$ Filler metal $0.3\ F_{EXX}$	Not Applicable		Filler metal with a strength level equal to or less than matching filler metal may be used.
Partial Joint Penetration Groove Weld	Longitudinal seam of tubular members	Tension or compression parallel to axis of the weld[2]		Same as for base metal[3]	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Circumferential and longitudinal joints that transfer loads	Compression normal to the effective area	Joint not designed to bear	$0.50\ F_{EXX}$, except that stress on adjoining base metal shall not exceed $0.60\ F_y$.	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
			Joint designed to bear	Same as for base metal			
		Shear on effective area		$0.30\ F_{EXX}$, except that stress on adjoining base metal shall not exceed $0.50\ F_y$ for tension, or $0.40\ F_y$ for shear.	0.75	$0.6\ F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Tension on effective area			Base metal 0.9 Filler metal 0.8	F_y $0.6\ F_{EXX}$	
	Structural T-, Y-, or K-connection in ordinary structures	Load transfer across the weld as stress on the effective throat (see 2.39 and 2.40.1.3)		$0.30\ F_{EXX}$ or as limited by connection geometry (see 2.40), except that stress on an adjoining base metal shall not exceed $0.50\ F_y$ for tension and compression, nor $0.40\ F_y$ for shear.	Base metal 0.9 Filler metal 0.8	F_y $0.6\ F_{EXX}$	Matching filler metal shall be used.
					or as limited by connection geometry (see 2.40 provisions for LRFD)		

Notes:
1. For matching filler metal see Table 3.1.
2. Beam or torsional shear up to 0.30 minimum specified tensile strength of filler metal is permitted, except that shear on adjoining base metal shall not exceed $0.40\ F_y$ (LRFD; see shear).
3. Groove and fillet welds parallel to the longitudinal axis of tension or compression members, except in connection areas, are not considered as transferring stress and hence may take the same stress as that in the base metal, regardless of electrode (filler metal) classification. Where the provisions of 2.40.1 are applied, seams in the main member within the connection area shall be complete joint penetration groove welds with matching filler metal, as defined in Table 3.1.
4. See 2.40.1.3.
5. Alternatively, see 2.14.4 and 2.14.5.

2.36.5 Load and Resistance Factor Design. Resistance factors, Φ, given elsewhere in this section, may be used in context of load and resistance factor design (LRFD) calculations in the following format:

$$\Phi \times (P_u \text{ or } M_u) = \Sigma(LF \times \text{Load})$$

where P_u or M_u is the ultimate load or moment as given herein; and *LF* is the load factor as defined in the governing LRFD design code, e.g., *AISC Load and Resistance Factor Design Specification for Structural Steel in Buildings*.

2.36.6 Fatigue

2.36.6.1 Stress Range and Member Type. In the design of members and connections subject to repeated variations in live load stress, consideration shall be given to the number of stress cycles, the expected range of stress, and type and location of member or detail.

2.36.6.2 Fatigue Stress Categories. The type and location of material shall be categorized as shown in Table 2.6.

2.36.6.3 Basic Allowable Stress Limitation. Where the applicable design specification has a fatigue requirement, the maximum stress shall not exceed the basic allowable stress provided elsewhere, and the range of stress at a given number of cycles shall not exceed the values given in Figure 2.13.

2.36.6.4 Cumulative Damage. Where the fatigue environment involves stress ranges of varying magnitude and varying numbers of applications, the cumulative fatigue damage ratio, *D*, summed over all the various loads, shall not exceed unity, where

$$D = \sum \frac{n}{N}$$

where

n = number of cycles applied at a given stress range
N = number of cycles for which the given stress range would be allowed in Figure 2.13

2.36.6.5 Critical Members. For critical members whose sole failure mode would be catastrophic, D (see 2.36.6.4) shall be limited to a fractional value of 1/3.

2.36.6.6 Fatigue Behavior Improvement. For the purpose of enhanced fatigue behavior, and where specified in contract documents, the following profile improvements may be undertaken for welds in tubular T-, Y-, or K-connections:

(1) A capping layer may be applied so that the as-welded surface merges smoothly with the adjoining base metal, and approximates the profile shown in Figure 3.10. Notches in the profile shall not be deeper than 0.04 in. or 1 mm, relative to a disc having a diameter equal to or greater than the branch member thickness.

(2) The weld surface may be ground to the profile shown in Figure 3.10. Final grinding marks shall be transverse to the weld axis.

(3) The toe of the weld may be peened with a blunt instrument, so as to produce local plastic deformation which smooths the transition between weld and base metal, while inducing a compressive residual stress. Such peening shall always be done after visual inspection, and be followed by magnetic–particle inspection as described below. Consideration should be given to the possibility of locally degraded notch toughness due to peening.

In order to qualify fatigue categories X1 and K1, representative welds (all welds for nonredundant structures or where peening has been applied) shall receive magnetic-particle inspection for surface and near-surface discontinuities. Any indications which cannot be resolved by light grinding shall be repaired in accordance with 5.26.1.4.

2.36.6.7 Size and Profile Effects. Applicability of welds to the fatigue categories listed below is limited to the following weld size or base-metal thicknesses:

C1	2 in. (50 mm) thinner member at transition
C2	1 in. (25 mm) attachment
D	1 in. (25 mm) attachment
E	1 in. (25 mm) attachment
ET	1.5 in. (38 mm) branch
F	0.7 in. (18 mm) weld size
FT	1 in. (25 mm) weld size

For applications exceeding these limits, consideration should be given to reducing the allowable stresses or improving the weld profile (see Commentary). For T-, Y-, and K-connections, two levels of fatigue performance are provided for in Table 2.7. The designer shall designate when Level I is to apply; in the absence of such designation, and for applications where fatigue is not a consideration, Level II shall be the minimum acceptable standard.

2.37 Identification

Members in tubular structures shall be identified as shown in Figure 2.14.

2.38 Symbols

Symbols used in section 2, Part D, are as shown in Annex XII.

Table 2.6
Stress Categories for Type and Location of Material for Circular Sections (see 2.36.6.2)

Stress Category	Situation	Kinds of Stress[1]
A	Plain unwelded pipe.	TCBR
B	Pipe with longitudinal seam.	TCBR
B	Butt splices, complete joint penetration groove welds, ground flush and inspected by RT or UT (Class R).	TCBR
B	Members with continuously welded longitudinal stiffeners.	TCBR
C_1	Butt splices, complete joint penetration groove welds, as welded.	TCBR
C_2	Members with transverse (ring) stiffeners.	TCBR
D	Members with miscellaneous attachments such as clips, brackets, etc.	TCBR
D	Cruciform and T-joints with complete joint penetration welds (except at tubular connections).	TCBR
DT	Connections designed as a simple T-, Y-, or K-connections with complete joint penetration groove welds conforming to Figures 3.8–3.10 (including overlapping connections in which the main member at each intersection meets punching shear requirements) (see Note 2).	TCBR in branch member. (Note: Main member must be checked separately per category K_1 or K_2.)
E	Balanced cruciform and T-joints with partial joint penetration groove welds or fillet welds (except at tubular connections).	TCBR in member; weld must also be checked per category F.
E	Members where doubler wrap, cover plates, longitudinal stiffeners, gusset plates, etc., terminate (except at tubular connections).	TCBR in member; weld must also be checked per category F.
ET	Simple T-, Y-, and K-connections with partial joint penetration groove welds or fillet welds; also, complex tubular connections in which the punching shear capacity of the main member cannot carry the entire load and load transfer is accomplished by overlap (negative eccentricity), gusset plates, ring stiffeners, etc. (see Note 2).	TCBR in branch member. (Note: Main member in simple T-, Y-, or K-connections must be checked separately per category K_1 or K_2; weld must also be checked per category FT and 2.40.1.)
F	End weld of cover plate or doubler wrap; welds on gusset plates, stiffeners, etc.	Shear in weld.
F	Cruciform and T-joints, loaded in tension or bending, having fillet or partial joint penetration groove welds (except at tubular connections).	Shear in weld (regardless of direction of loading). See 2.39.
FT	Simple T-, Y-, or K-connections loaded in tension or bending, having fillet or partial joint penetration groove welds.	Shear in weld (regardless of direction of loading).

(continued)

Table 2.6 (Continued)

Stress Category	Situation	Kinds of Stress[1]
X_2	Intersecting members at simple T-, Y-, and K-connections; any connection whose adequacy is determined by testing an accurately scaled model or by theoretical analysis (e.g., finite element).	Greatest total range of hot spot stress or strain on the outside surface of intersecting members at the toe of the weld joining them—measured after shakedown in model or prototype connection or calculated with best available theory.
X_1	As for X_2, profile improved per 2.36.6.6 and 2.36.6.7.	As for X_2
X_1	Unreinforced cone-cylinder intersection.	Hot-spot stress at angle change; calculate per Note 4.
K_2	Simple T-, Y-, and K-connections in which the gamma ratio R/t_c of main member does not exceed 24 (see Note 3).	Punching shear for main members; calculate per Note 5.
K_1	As for K_2, profile improved per 2.36.6.6 and 2.36.6.7.	

Notes:
1. T = tension, C = compression, B = bending, R = reversal—i.e., total range of nominal axial and bending stress.
2. Empirical curves (Figure 2.13) based on "typical" connection geometries; if actual stress concentration factors or hot spot strains are known, use of curve X_1 or X_2 is preferred.
3. Empirical curves (Figure 2.13) based on tests with gamma (R/t_c) of 18 to 24; curves on safe side for very heavy chord members (low R/t_c); for chord members (R/t_c greater than 24) reduce allowable stress in proportion to

$$\frac{\text{Allowable fatigue stress}}{\text{Stress from curve K}} = \left(\frac{24}{R/t_c}\right)^{0.7}$$

Where actual stress concentration factors or hot-spot strains are known, use of curve X_1 or X_2 is preferred.

4. Stress concentration factor – $SCF = \frac{1}{\cos \overline{\Psi}} + 1.17 \tan \overline{\Psi} \sqrt{\gamma_b}$

where
$\overline{\Psi}$ = angle change at transition
γ_b = radius to thickness ratio of tube at transition

5. Cyclic range of punching shear is given by

$$V_p = \tau \sin \theta [\alpha f_a + \sqrt{(0.67 f_{by})^2 + (1.5 f_{bz})^2}]$$

where
τ and θ are defined in Figure 2.14, and
f_a = cyclic range of nominal branch member stress for axial load.
f_{by} = cyclic range of in-plane bending stress.
f_{bz} = cyclic range of out-of-plane bending stress.
α is as defined in Table 2.9.

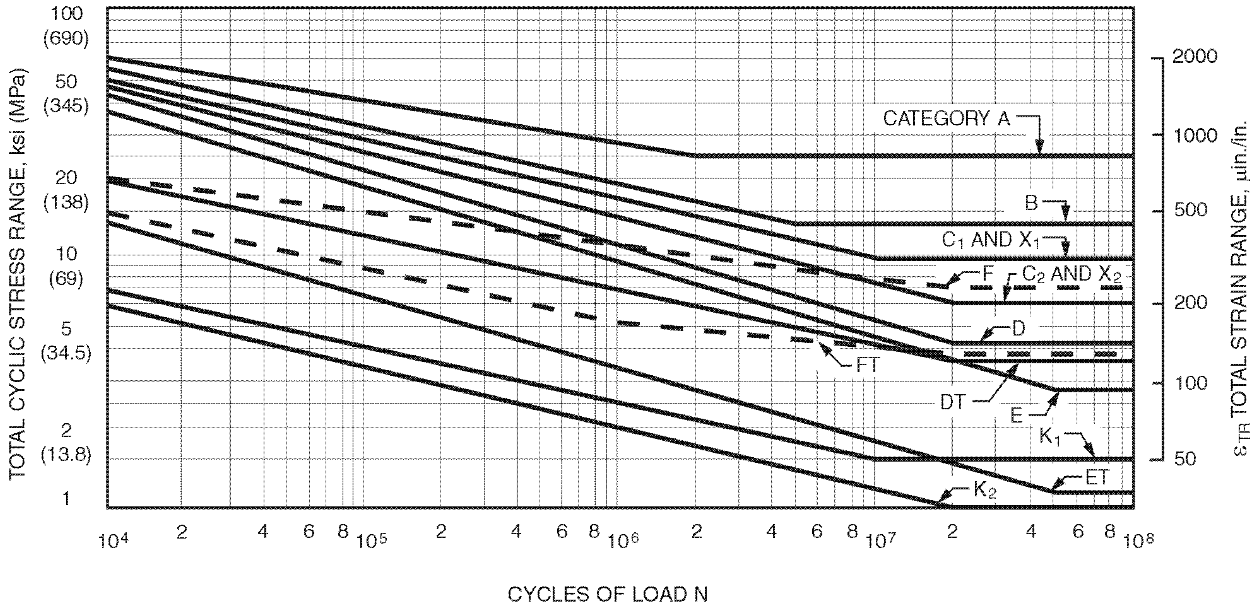


Figure 2.13—Allowable Fatigue Stress and Strain Ranges for Stress Categories (see Table 2.6), Redundant Tubular Structures for Atmospheric Service (see 2.36.6.3)

Table 2.7
Fatigue Category Limitations on Weld Size or Thickness and Weld Profile (Tubular Connections) (see 2.36.6.7)

	Level I	Level II
Weld Profile	Limiting Branch Member Thickness for Categories X_1, K_1, DT in. (mm)	Limiting Branch Member Thickness for Categories X_2, K_2 in. (mm)
Standard flat weld profile Figure 3.8	0.375 (10)	0.625 (16)
Profile with toe fillet Figure 3.9	0.625 (16)	1.50 (38) qualified for unlimited thickness for static compression loading
Concave profile, as welded, Figure 3.10 with disk test per 2.36.6.6(1)	1.00 (25)	unlimited
Concave smooth profile Figure 3.10 fully ground per 2.36.6.6(2)	unlimited	—

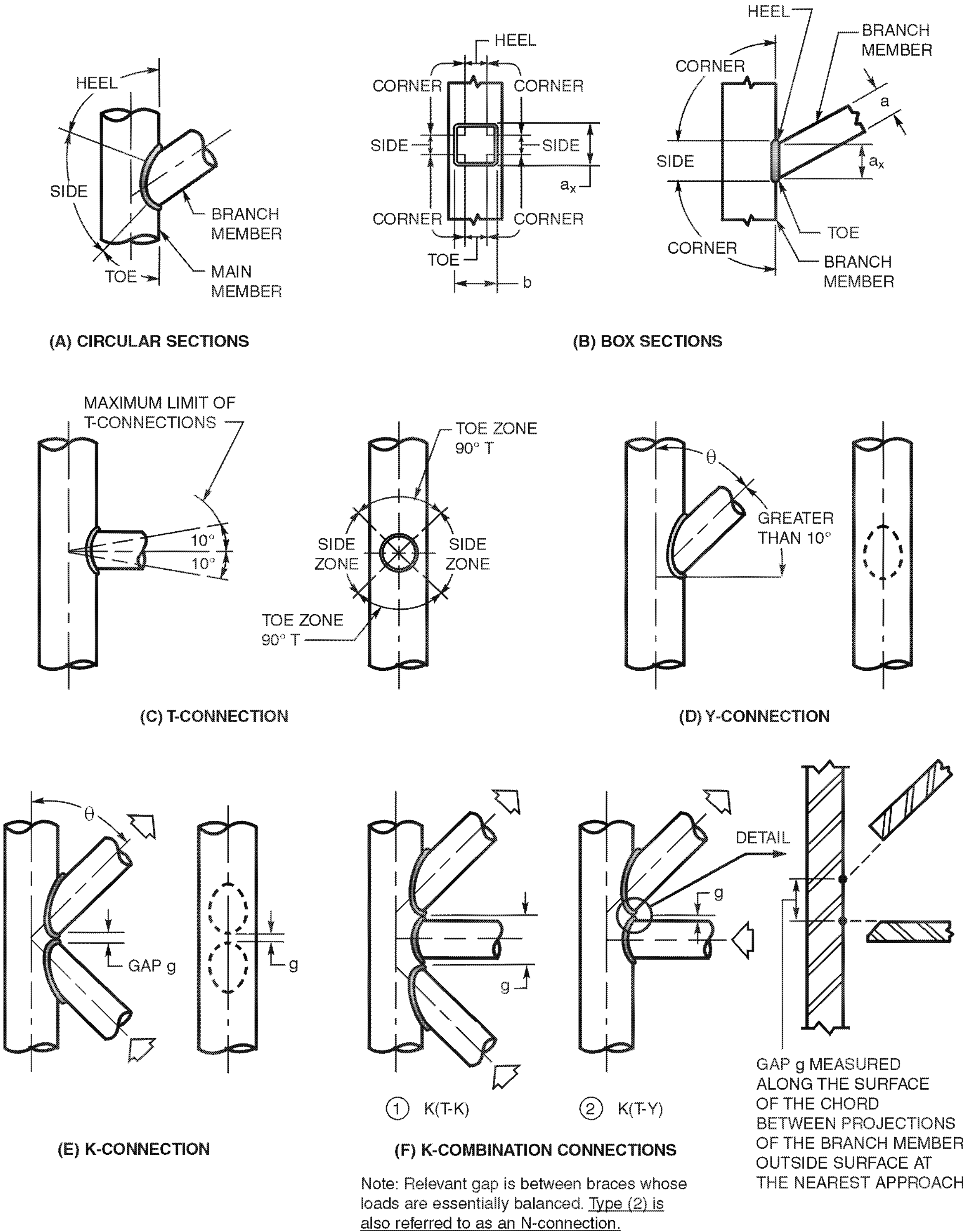


Figure 2.14—Parts of a Tubular Connection (see 2.37)

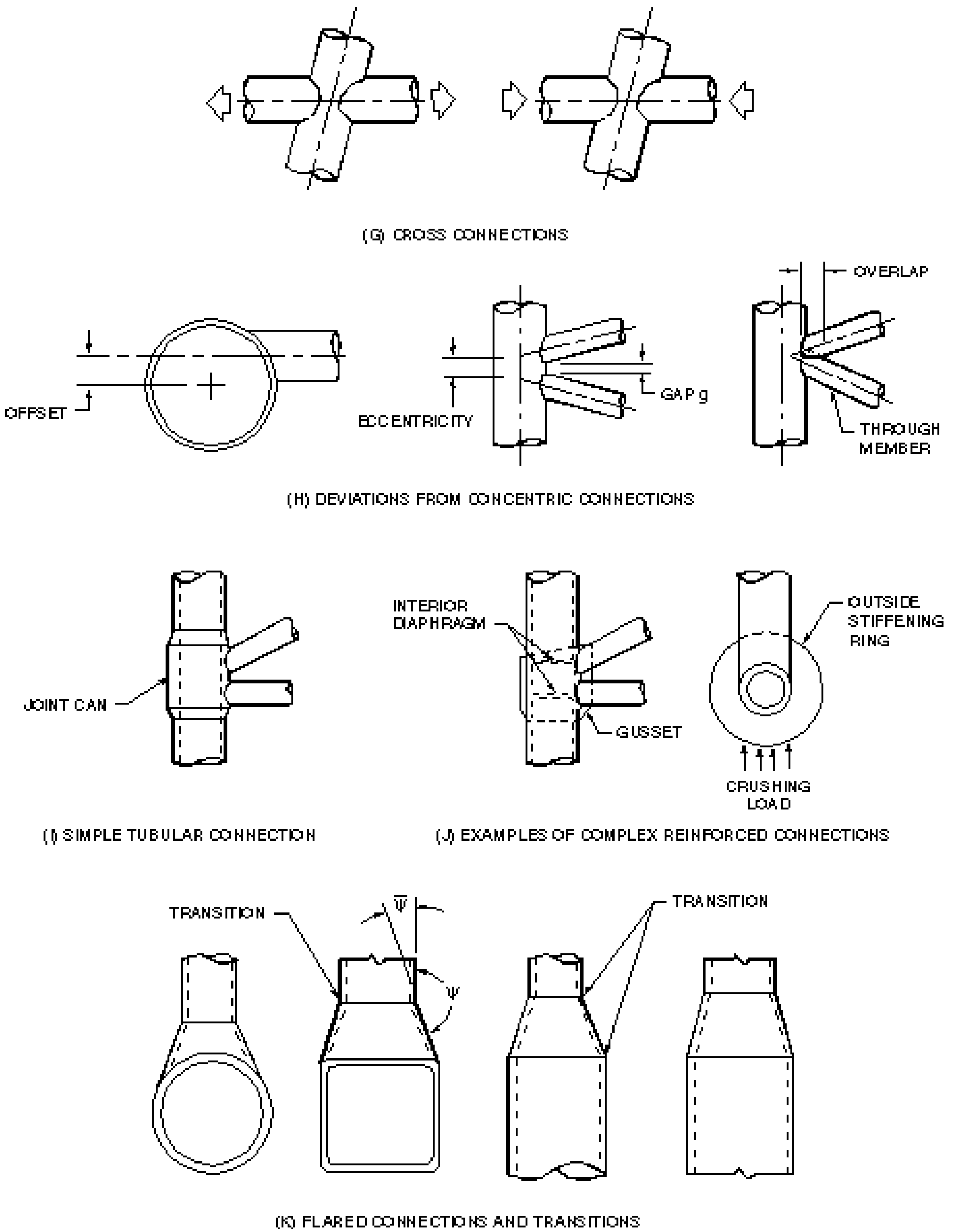
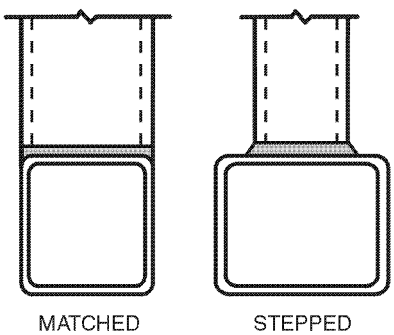
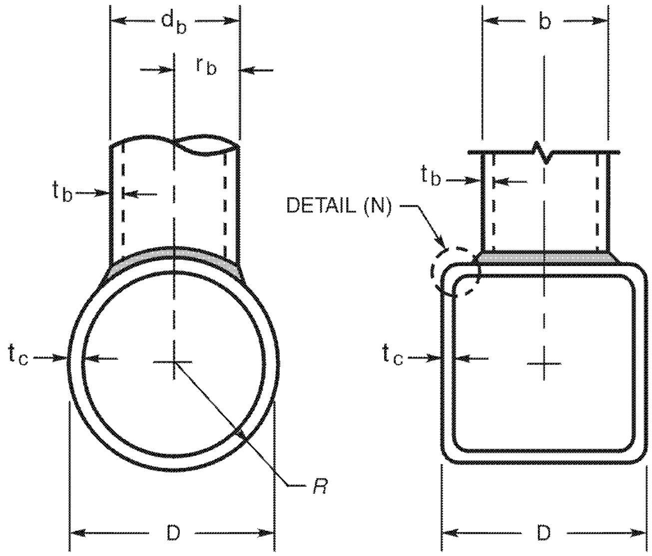


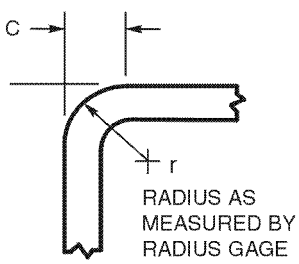
Figure 2.14 (Continued)—Parts of a Tubular Connection (see 2.37)



(L) CONNECTION TYPES FOR BOX SECTIONS



(M) GEOMETRIC PARAMETERS



(N) CORNER DIMENSION OR RADIUS MEASUREMENT

PARAMETER	CIRCULAR SECTIONS	BOX SECTIONS
β	r_b/R OR d_b/D	b/D
η	—	a_x/D
γ	R/t_c	$D/2t_c$
τ	t_b/t_c	t_b/t_c
θ	ANGLE BETWEEN MEMBER CENTERLINES	
ψ	LOCAL DIHEDRAL ANGLE AT A GIVEN POINT ON WELDED JOINT	
C	CORNER DIMENSION AS MEASURED TO THE POINT OF TANGENCY OR CONTACT WITH A 90 DEGREE SQUARE PLACED ON THE CORNER	

Figure 2.14 (Continued)—Parts of a Tubular Connection (see 2.37)

2.39 Weld Design

2.39.1 Fillet Welds

2.39.1.1 Effective Area. The effective area shall be in accordance with 2.4.3 and the following: the effective length of fillet welds in structural T-, Y-, and K-connections shall be calculated in accordance with 2.39.4 or 2.39.5, using the radius or face dimensions of the branch member as measured to the centerline of the weld.

2.39.1.2 Beta Limitation for Prequalified Details. Details for prequalified fillet welds in tubular T-, Y-, and K-connections are described in Figure 3.2. These details are limited to $\beta \le 1/3$ for circular connections, and $\beta \le 0.8$ for box sections. They are also subject to the limitations of 3.9.2. For a box section with large corner radii, a smaller limit on β may be required to keep the branch member and the weld on the flat face.

2.39.1.3 Lap Joints. Lap joints of telescoping tubes (as opposed to an interference slip-on joint as used in tapered poles) in which the load is transferred via the weld may be single fillet welded in accordance with Figure 2.15.

2.39.2 Groove Welds.

The effective area shall be in accordance with 2.3.2 and the following: the effective length of groove welds in structural T-, Y-, and K-connections shall be calculated in accordance with 2.39.4 or 2.39.5, using the mean radius r_m or face dimensions of the branch member.

2.39.2.1 Prequalified Partial Joint Penetration Groove Weld Details. Prequalified partial joint penetration groove welds in tubular T-, Y-, or K-connections shall conform to Figure 3.5. The Engineer shall use the figure in conjunction with Table 2.8 to calculate the minimum weld size in order to determine the maximum weld stress except where such calculations are waived by 2.40.1.3(2).

The Z loss dimension shall be deducted from the distance from the work point to the theoretical weld face to find the minimum weld size.

2.39.2.2 Prequalified Complete Joint Penetration Groove Weld Details Welded from One Side without Backing in T-, Y-, and K-Connections. See 3.13.4 for the detail options. If fatigue behavior improvement is required, the details selected shall be based on the profile requirements of 2.36.6.6 and Table 2.7.

2.39.3 Stresses in Welds. When weld allowable stress calculations are required for circular sections, the nominal stress in the weld joining branch to chord in a simple T-, Y-, or K-connection shall be computed as:

$$f_{weld} = \frac{t_b}{t_w}\left[\frac{f_a}{K_a}\left(\frac{r_m}{r_w}\right) + \left(\frac{f_b}{K_b}\right)\frac{r_m^2}{r_w^2}\right]$$

where:

t_b = thickness of branch member
t_w = effective throat of the weld
f_a and f_b = nominal axial and bending stresses in the branch

For r_m and r_w, see Figure 2.16.

K_a and K_b are effective length and section factors given in 2.39.4 and 2.39.5.

In ultimate strength or LRFD format, the following expression for branch axial load capacity P shall apply for both circular and box sections:

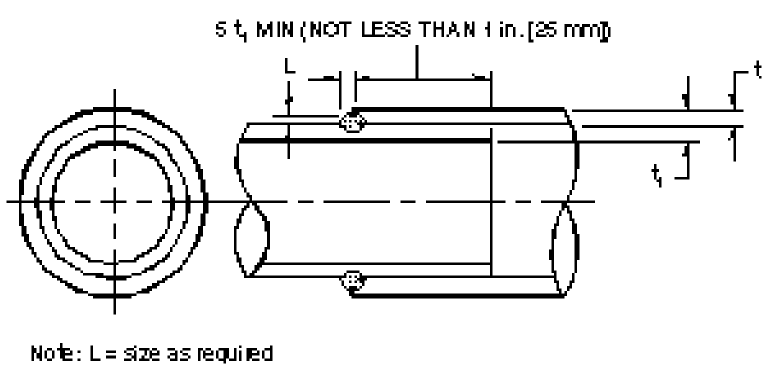


Figure 2.15—Fillet Welded Lap Joint (Tubular) (see 2.39.1.3)

Table 2.8
Z Loss Dimensions for Calculating Prequalified PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes (see 2.39.2.1)

	Position of Welding: V or OH			Position of Welding: H or F		
Groove Angle ϕ	Process	Z (in.)	Z (mm)	Process	Z (in.)	Z (mm)
$\phi \geq 60°$	SMAW	0	0	SMAW	0	0
	FCAW-S	0	0	FCAW-S	0	0
	FCAW-G	0	0	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	0	0	GMAW-S	0	0
$60° > \phi \geq 45°$	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	1/8	3	GMAW-S	1/8	3
$45° > \phi \geq 30°$	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6
	GMAW-S	3/8	10	GMAW-S	1/4	6

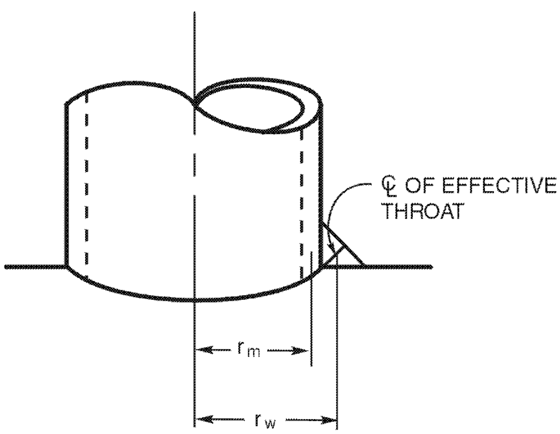


Figure 2.16—Tubular T-, Y-, and K-Connection Fillet Weld Footprint Radius (see 2.39.3)

$$P_u = Q_w \cdot L_{eff}$$

where Q_w = weld line load capacity (kips/inch) and L_{eff} = weld effective length.

For fillet welds,

$$Q_w = 0.6\, t_w F_{EXX}$$

with $\Phi = 0.8$

where F_{EXX} = classified minimum tensile strength of weld deposit.

2.39.4 Circular Connection Lengths. Length of welds and the intersection length in T-, Y-, and K-connections shall be determined as $2\pi rK_a$ where r is the effective radius of the intersection (see 2.39.2, 2.39.1.1 and 2.40.1.3(4)).

$$K_a = x + y + 3\sqrt{(x^2 + y^2)}$$

$$x = 1/(2\,\pi\,\sin\theta)$$

$$y = \frac{1}{3\pi}\left(\frac{3-\beta^2}{2-\beta^2}\right)$$

where:

θ = the acute angle between the two member axes
β = diameter ratio, branch/main, as previously defined

Note: The following may be used as conservative approximations:

$$K_a = \frac{1 + 1/\sin\theta}{2} \text{ for axial load}$$

$$K_b = \frac{3 + 1/\sin\theta}{4\sin\theta} \text{ for in-plane bending}$$

$$K_b = \frac{1 + 3/\sin\theta}{4} \text{ for out-of-plane bending}$$

2.39.5 Box Connection Lengths

2.39.5.1 K- and N-Connections. The effective length of branch welds in structural, planar, gap K- and N-connections between box sections, subjected to predominantly static axial load, shall be taken as:

$2a_x + 2b$, for $\theta \le 50°$

$2a_x + b$, for $\theta \ge 60°$

Thus for $\theta \le 50°$ the heel, toe and sides of the branch can be considered fully effective. For $\theta \ge 60°$, the heel is considered ineffective due to uneven distribution of load. For $50° < \theta < 60°$, interpolate.

2.39.5.2 T-, Y-, and X-Connections. The effective length of branch welds in structural, planar, T-, Y-, and X-connections between box sections, subjected to predominantly static axial load, shall be taken as:

$2a_x + b$, for $\theta \le 50°$

$2a_x$, for $\theta \ge 60°$

For $50° < \theta < 60°$, interpolate.

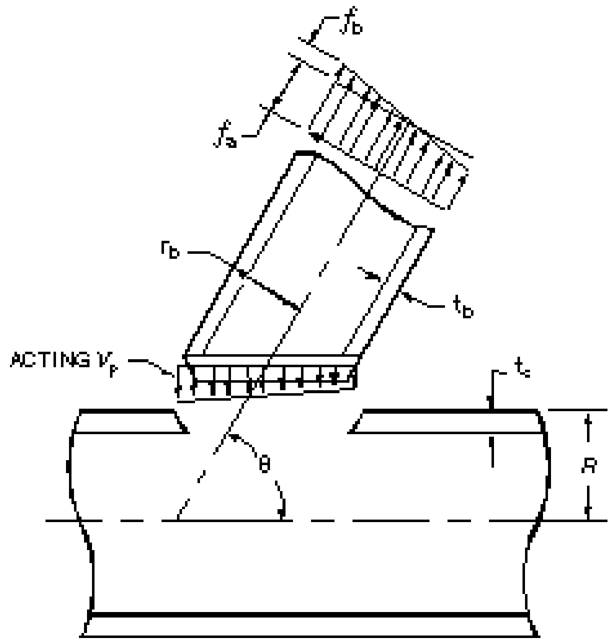


Figure 2.17—Punching Shear Stress (see 2.40.1.1)

2.40 Limitations of the Strength of Welded Connections

2.40.1 Circular T-, Y-, and K-Connections (See 2.42.1.1)

2.40.1.1 Local Failure. Where a T-, Y-, or K-connection is made by simply welding the branch member(s) individually to the main member, local stresses at potential failure surface through the main member wall may limit the usable strength of the welded joint. The shear stress at which such failure occurs depends not only upon the strength of the main member steel, but also on the geometry of the connection. Such connections shall be proportioned on the basis of either (1) punching shear, or (2) ultimate load calculations as given below. The punching shear is an allowable stress design (ASD) criterion and includes the safety factor. The ultimate load format may be used in load and resistance factor design (LRFD), with the resistance factor Φ to be included by the designer, see 2.36.5.

(1) Punching Shear Format. The acting punching shear stress on the potential failure surface (see Figure 2.17) shall not exceed the allowable punching shear stress.

The acting punching shear stress is given by

$$\text{acting } V_p = \tau f_n \sin\theta$$

The allowable punching shear stress is given by

$$\text{allow } V_p = Q_q \cdot Q_f \cdot F_{yo}/(0.6\,\gamma)$$

The allowable V_p shall also be limited by the allowable shear stress specified in the applicable design specification (e.g., 0.4 F_{yo}).

Terms used in the foregoing equations are defined as follows:

τ, θ, γ, β and other parameters of connection geometry are defined in Figure 2.14(M).
f_n is the nominal axial (f_a) or bending (f_b) stress in the branch member (punching shear for each kept separate)
F_{yo} = The specified minimum yield strength of the main member chord, but not more than 2/3 the tensile strength.
Q_q, Q_f are geometry modifier and stress interaction terms, respectively, given in Table 2.9.

For bending about two axes (e.g., y and z), the effective resultant bending stress in circular and square box sections may be taken as

$$f_b = \sqrt{f_{by}^2 + f_{bz}^2}$$

For combined axial and bending stresses, the following inequality shall be satisfied:

$$\left[\frac{\text{Acting } V_p}{\text{allow } V_p}\right]_{\text{axial}}^{1.75} + \left[\frac{\text{acting } V_p}{\text{allow } V_p}\right]_{\text{bending}} \le 1.0$$

Table 2.9
Terms for Strength of Connections (Circular Sections) (see 2.40.1.1)

Branch member Geometry and load modifier Q_q	$Q_q = \left(\frac{1.7}{\alpha} + \frac{0.18}{\beta}\right) Q_\beta^{0.7(\alpha-1)}$	For axial loads (see Note 6)
	$Q_q = \left(\frac{2.1}{\alpha} + \frac{0.6}{\beta}\right) Q_\beta^{1.2(\alpha-0.67)}$	For bending
Q_β	$Q_\beta = 1.0$	For $\beta \le 0.6$
(needed for Q_q)	$Q_\beta = \frac{0.3}{\beta(1-0.833\beta)}$	For $\beta > 0.6$
chord ovalizing	$\alpha = 1.0 + 0.7\ g/d_b$ $1.0 \le \alpha < 1.7$	For axial load in gap K-connections having all members in same plane and loads transverse to main member essentially balanced (see Note 3)
parameter	$\alpha = 1.7$ $\alpha = 2.4$	For axial load in T- and Y-connections For axial load in cross connections
α (needed for Q_q)	$\alpha = 0.67$ $\alpha = 1.5$	For in-plane bending (see Note 5) For out-of-plane bending (see Note 5)
Main member stress interaction term Q_f (See Notes 4 and 5)	$Q_f = 1.0 - \lambda\gamma\overline{U}^2$	
	$\lambda = 0.030$	For axial load in branch member
	$\lambda = 0.044$	For in-plane bending in branch member
	$\lambda = 0.018$	For out-of-plane bending in branch member

Notes:
1. γ, β are geometry parameters defined by Figure 2.14 (M).
2. F_{yo} = the specified minimum yield strength of the main member, but not more than 2/3 the tensile strength.
3. Gap g is defined in Figures 2.14 (E), (F) and (H); d_b is branch diameter.
4. $\overline{U}$ is the utilization ratio (ratio of actual to allowable) for longitudinal compression (axial, bending) *in the main member* at the connection under consideration.

$$\overline{U}^2 = \left(\frac{f_a}{0.6F_{yo}}\right)^2 + \left(\frac{f_b}{0.6F_{yo}}\right)^2$$

5. For combinations of the in-plane bending and out-of-plane bending, use interpolated values of α and λ.
6. For general collapse (transverse compression) also see 2.40.1.2.

(2) LRFD Format (loads factored up to ultimate condition—see 2.36.5)

Branch member loadings at which plastic chord wall failure in the main member occurs are given by:

axial load: $P_u \sin\theta = t_c^2\ F_{yo}[6\pi\beta Q_q]\ Q_f$

bending moment:

$$M_u \sin\theta = t_c^2\ F_{yo}[d_b/4][6\pi\beta Q_q]\ Q_f$$

with the resistance factor $\Phi = 0.8$.

Q_f should be computed with $\overline{U}^2$ redefined as $(P_c/AF_{yo})^2 + (M_c/SF_{yo})^2$ where P_c and M_c are factored chord load and moment, A is area, S is section modulus.

These loadings are also subject to the chord material shear strength limits of:

$$P_u \sin\theta \le \pi\ d_b t_c\ F_{yo}/\sqrt{3}$$

$$M_u \sin\theta \le d_b^2\ t_c\ F_{yo}/\sqrt{3}$$

with $\Phi = 0.95$

where

t_c = chord wall thickness
d_b = branch member diameter and other terms are defined as 2.40.1.1 (1).

The limit state for combinations of axial load P and bending moment M is given by:

$$(P/P_u)^{1.75} + M/M_u \le 1.0$$

2.40.1.2 General Collapse. Strength and stability of a main member in a tubular connection, with any reinforcement, shall be investigated using available technology in accordance with the applicable design code. General collapse is particularly severe in cross connections and connections subjected to crushing loads, see Figure 2.14(G) and (J). Such connections may be reinforced by increasing the main member thickness, or by use of diaphragms, rings, or collars.

(1) For unreinforced circular cross connections, the allowable transverse chord load, due to compressive branch member axial load P, shall not exceed

$$P \sin \theta = t_c^2 \ F_y \ (1.9 + 7.2 \ \beta) Q_\beta Q_f$$

(2) For circular cross connections reinforced by a "joint can" having increased thickness t_c, and length, L, the allowable branch axial load, P, may be employed as

$$P = P_{(1)} + [P_{(2)} - P_{(1)}]L/2.5D \qquad \text{for } L < 2.5/D$$

$$P = P_{(2)} \qquad \text{for } L \geq 2.5/D$$

where $P_{(1)}$ is obtained by using the nominal main member thickness in the equation in (1); and $P_{(2)}$ is obtained by using the joint can thickness in the same equation.

The ultimate limit state may be taken as 1.8 times the foregoing ASD allowable, with $\Phi = 0.8$.

(3) For circular K-connections in which the main member thickness required to meet the local shear provisions of 2.40.1.1 extends at least D/4 beyond the connecting branch member welds, general collapse need not be checked.

2.40.1.3 Uneven Distribution of Load (Weld Sizing)

(1) Due to differences in the relative flexibilities of the main member loaded normal to its surface, and the branch member carrying membrane stresses parallel to its surface, transfer of load across the weld is highly nonuniform, and local yielding can be expected before the connection reaches its design load. To prevent "unzipping" or progressive failure of the weld and ensure ductile behavior of the joint, the minimum welds provided in simple T-, Y-, or K-connections shall be capable of developing, at their ultimate breaking strength, the lesser of the brace member yield strength or local strength (punching shear) of the main member. The ultimate breaking strength of fillet welds and partial joint penetration groove welds shall be computed at 2.67 times the basic allowable stress for 60 ksi (415 MPa) or 70 ksi (485 MPa) tensile strength and at 2.2 times the basic allowable stress for higher strength levels. The ultimate punching shear shall be taken as 1.8 times the allowable V_p of 2.40.1.1.

(2) This requirement may be presumed to be met by the prequalified joint details of Figure 3.8 (complete penetration) and subsection 3.12.4 (partial penetration), when matching materials (Table 3.1) are used.

(3) Compatible strength of welds may also be presumed with the prequalified fillet weld details of Figure 3.2, when the following effective throat requirements are met:

(a) $E = 0.7 \ t_b$ for elastic working stress design of mild steel circular steel tubes ($F_y \leq 40$ ksi [280 MPa] joined with overmatched welds (classified strength F_{EXX} = 70 ksi [485 MPa])

(b) $E = 1.0 \ t_b$ for ultimate strength design (LRFD) of circular or box tube connections of mild steel, $F_y \leq$ 40 ksi (280 MPa), with welds satisfying the matching strength requirements of Table 3.1.

(c) E = lesser of t_c or $1.07 \ t_b$ for all other cases

(4) Fillet welds smaller than those required in Figure 3.2 to match connection strength, but sized only to resist design loads, shall at least be sized for the following multiple of stresses calculated per 2.39.3, to account for nonuniform distribution of load:

	ASD	LRFD
E60XX and E70XX—	1.35	1.5
Higher strengths—	1.6	1.8

2.40.1.4 Transitions. Flared connections and tube size transitions not excepted below shall be checked for local stresses caused by the change in direction at the transition. (See note 4 to Table 2.6.) Exception, for static loads:

Circular tubes having D/t less than 30, and

Transition slope less than 1:4.

2.40.1.5 Other Configurations and Loads

(1) The term "T-, Y-, and K-connections" is often used generically to describe tubular connections in which branch members are welded to a main member, or chord, at a structural node. Specific criteria are also given for cross (X-) connections (also referred to as double-tee) in 2.40.1.1 and 2.40.1.2. N-connections are a special case of K-connections in which one of the branches is perpendicular to the chord; the same criteria apply. See Commentary for multiplanar connections.

(2) Connection classifications as T-, Y-, K-, or cross should apply to individual branch members according to the load pattern for each load case. To be considered a K-connection, the punching load in a branch member should be essentially balanced by loads on other braces in the same plane on the same side of the joint. In T- and Y-connections the punching load is reacted as beam shear in the chord. In cross connections the punching load is carried through the chord to braces on the opposite side. For branch members which carry part of their load as K-connections, and part as T-, Y-, or cross

connections, interpolate based on the portion of each in total, or use computed alpha (see Commentary.)

(3) For multiplanar connections, computed alpha as given in Annex L may be used to estimate the beneficial or deleterious effect of the various branch member loads on main member ovalizing. However, for similarly loaded connections in adjacent planes, e.g., paired TT and KK connections in delta trusses, no increase in capacity over that of the corresponding uniplanar connections shall be taken.

2.40.1.6 Overlapping Connections. Overlapping joints, in which part of the load is transferred directly from one branch member to another through their common weld, shall include the following checks:

(1) The *allowable* individual member load component, $P_\perp$ perpendicular to the main member axis shall be taken as $P_\perp = (V_p\, t_c\, l_1) + (2V_w\, t_w\, l_2)$ where V_p is the allowable punching shear as defined in 2.40.1.1, and

t_c = the main member thickness

l_1 = actual weld length for that portion of the branch member which contacts the main member

V_p = allowable punching shear for the main member as K-connection ($\alpha = 1.0$)

V_w = allowable shear stress for the weld between branch members (Table 2.5)

t'_w = the lesser of the weld size (effective throat) or the thickness t_b of the thinner branch member

l_2 = the projected chord length (one side) of the overlapping weld, measured perpendicular to the main member.

These terms are illustrated in Figure 2.18.

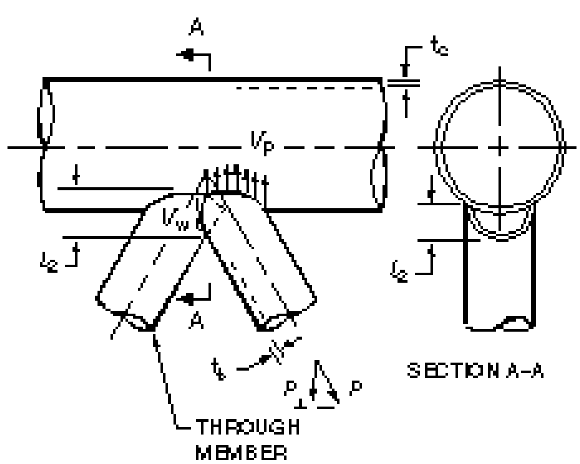


Figure 2.18—Detail of Overlapping Joint (see 2.40.1.6)

The *ultimate* limit state may be taken as 1.8 times the foregoing ASD allowable, with $\Phi = 0.8$.

(2) The allowable combined load component parallel to the main member axis shall not exceed $V_w\, t_w\, \Sigma l_1$, where Σl_1 is the sum of the actual weld lengths for all braces in contact with the main member.

(3) The overlap shall preferably be proportioned for at least 50% of the acting $P_\perp$. In no case shall the branch member wall thickness exceed the main member wall thickness.

(4) Where the branch members carry substantially different loads, or one branch member has a wall thickness greater than the other, or both, the thicker or more heavily loaded branch member shall preferably be the through member with its full circumference welded to the main member.

(5) Net transverse load on the combined footprint shall satisfy 2.40.1.1 and 2.40.1.2.

(6) Minimum weld size for fillet welds shall provide effective throat of 1.0 t_b for $F_y < 40$ ksi (280 MPa), 1.2 t_b for $F_y > 40$ ksi (280 MPa).

2.40.2 Box T-, Y, and K-Connections (See 2.42.1.1). Criteria given in this section are all in ultimate load format, with the safety factor removed. Resistance factors for LRFD are given throughout. For ASD, the allowable capacity shall be the ultimate capacity, divided by a safety factor of $1.44/\Phi$. The choice of loads and load factors shall be in accordance with the governing design specification; see 2.1.2 and 2.36.5. Connections shall be checked for each of the failure modes described below.

These criteria are for connections between box sections of uniform wall thickness, in planar trusses where the branch members loads are primarily axial. If compact sections, ductile material, and compatible strength welds are used, secondary branch member bending may be neglected. (Secondary bending is that due to joint deformation or rotation in fully triangulated trusses. Branch member bending due to applied loads, sidesway of unbraced frames, etc., cannot be neglected and must be designed for. See 2.40.2.5.)

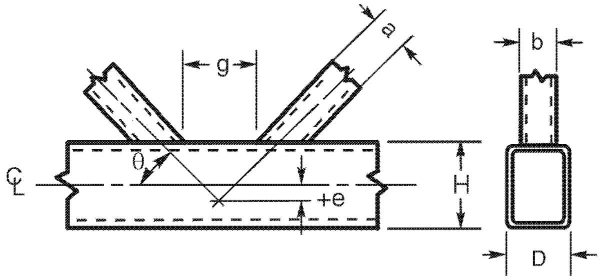
Criteria in this section are subject to the limitations shown in Figure 2.19.

2.40.2.1 Local Failure. Branch member axial load P_u at which plastic chord wall failure in the main member occurs is given by:

$$P_u \sin\theta = F_{yo}\, t_c^2 \left[\frac{2\eta}{1-\beta} + \frac{4}{\sqrt{(1-\beta)}}\right] Q_f$$

for cross, T-, and Y-connections with $0.25 \le \beta < 0.85$ and $\Phi = 1.0$.

Also, $P_u \sin\theta = F_{yo}\, t_c^2\ [9.8\, \beta_{eff} \sqrt{\gamma}]\, Q_f$



$-0.55H \leq e \leq 0.25H$
$\theta \geq 30°$
H/t_c AND $D/t_c \leq 35$ (40 FOR OVERLAP K- AND N-CONNECTIONS)
a/t_b AND $b/t_b \leq 35$
$F_{yo} \leq 52$ ksi (360 MPa)
$0.5 \leq H/D \leq 2.0$
$F_{yo}/F_{ult} \leq 0.8$

Figure 2.19—Limitations for Box T-, Y-, and K-Connections (see 2.40.2)

with $\Phi = 0.9$

for gap K- and N-connections with least

$$\beta_{eff} \geq 0.1 + \frac{\gamma}{50} \text{ and } g/D = \zeta \geq 0.5\ (1-\beta)$$

where F_{yo} is specified minimum yield strength of the main member, t_c is chord wall thickness, γ is $D/2t_c$ (D = chord face width); β, η, θ, and ζ are connection topology parameters as defined in Figure 2.14(M) and Figure C2.26; (β_{eff} is equivalent β defined below); and $Q_f = 1.3–0.4\overline{U}/\beta$ $(Q_f \leq 1.0)$; use $Q_f = 1.0$ (for chord in tension) with U being the chord utilization ratio.

$$\overline{U} = \left|\frac{f_a}{F_{yo}}\right| + \left|\frac{f_b}{F_{yo}}\right|$$

$$\beta_{eff} = (b_{\substack{compression\\branch}} + a_{\substack{compression\\branch}} + b_{\substack{tension\\branch}} + a_{\substack{tension\\branch}})/4D$$

These loadings are also subject to the chord material shear strength limits of

$$P_u \sin\theta = (F_{yo}/\sqrt{3})\ t_c D\ [2\eta + 2\ \beta_{eop}]$$

for cross, T-, or Y-connections with $\beta > 0.85$, using $\Phi = 0.95$, and

$$P_u \sin\theta = (F_{yo}/\sqrt{3})\ t_c D\ [2\eta + \beta_{eop} + \beta_{gap}]$$

for gap K- and N-connections with $\beta \geq 0.1 + \gamma/50$, using $\Phi = 0.95$ (this check is unnecessary if branch members are square and equal width), where:

$\beta_{gap} = \beta$ for K- and N-connections with $\underline{\zeta \leq 1.5\ (1-\beta)}$
$\beta_{gap} = \beta_{eop}$ for all other connections
β_{eop} (effective outside punching) $= 5\beta/\gamma$
but not more than β

2.40.2.2 General Collapse. Strength and stability of a main member in a tubular connection, with any reinforcement, shall be investigated using available technology in accordance with the applicable design code.

(1) General collapse is particularly severe in cross connections and connections subjected to crushing loads. Such connections may be reinforced by increasing the main member thickness or by use of diaphragms, gussets, or collars.

For unreinforced matched box connections, the ultimate load normal to the main member (chord) due to branch axial load P shall be limited to:

$$P_u \sin\theta = 2t_c\ F_{yo}(a_x + 5\ t_c)$$

with $\Phi = 1.0$ for tension loads,
and $\Phi = 0.8$ for compression.

and

$$P_u \sin\theta = \frac{47\ t_c^3}{H - 4t_c}\sqrt{EF_{yo}}(Q_f)$$

with $\Phi = 0.8$ for cross connections, end post reactions, etc., in compression, and E = modulus of elasticity

or

$$P_u \sin\theta = 1.5\ t_c^2\ [1 + 3a_x/H]\ \sqrt{EF_{yo}}\ (Q_f)$$

with $\Phi = 0.75$ for all other compression branch loads

(2) For gap K- and N-connections, beam shear adequacy of the main member to carry transverse loads across the gap region shall be checked including interaction with axial chord forces. This check is not required for $U \leq 0.44$ in stepped box connections having $\beta + \eta \leq H/D$ (H is height of main member in plane of truss).

2.40.2.3 Uneven Distribution of Load (Effective Width). Due to differences in the relative flexibilities of the main member loaded normal to its surface and the branch member carrying membrane stresses parallel to its surface, transfer of load across the weld is highly nonuniform, and local yielding can be expected before the connection reaches its design load. To prevent progressive failure and ensure ductile behavior of the joint, both the branch members and the weld shall be checked, as follows:

(1) Branch Member Check. The effective width axial capacity P_u of the branch member shall be checked for all gap K- and N-connections, and other connections having $\beta > 0.85$. (Note that this check is unnecessary if branch members are square and equal width).

$P_u = F_y t_b [2a + b_{gap} + b_{eoi} - 4t_b]$

with $\Phi = 0.95$

where

F_y = specified minimum yield strength of branch
t_b = branch wall thickness
a, b = branch dimensions (see Figure 2.14(B))
b_{gap} = b for K- and N-connections with $\zeta \leq 1.5(1-\beta)$
$b_{gap} = b_{eoi}$ for all other connections

$$b_{eoi} = \left(\frac{5b}{\gamma\tau}\right)\frac{F_{yo}}{F_y} \leq b$$

Note: $\tau \leq 1.0$ and $F_y \leq F_{yo}$ are presumed.

(2) Weld Checks. The minimum welds provided in simple T-, Y-, or K-connections shall be capable of developing at their ultimate breaking strength, the lesser of the branch member yield strength or local strength of the main member.

This requirement may be presumed to be met by the prequalified joint details of Figure 3.6 (complete penetration and partial penetration), when matching materials (Table 3.1) are used,

(3) Fillet welds shall be checked as described in 2.39.5.

2.40.2.4 Overlapping Connections. Lap joints reduce the design problems in the main member by transferring most of the transverse load directly from one branch member to the other. See Figure 2.20.

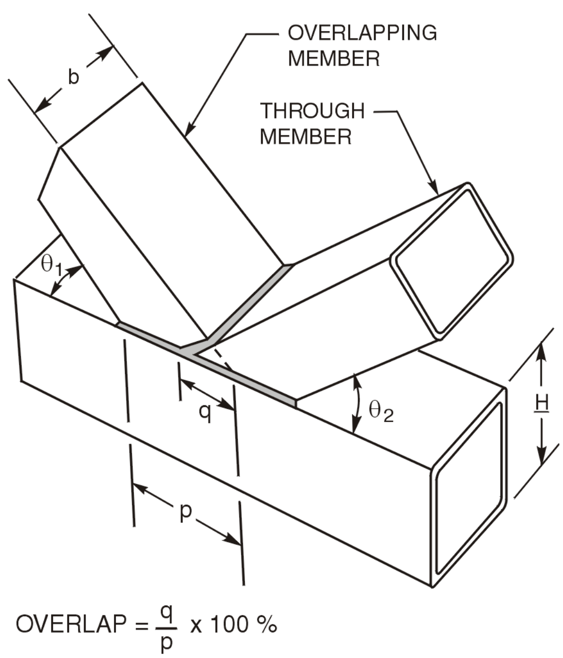


Figure 2.20—Overlapping K-Connections (see 2.40.2.4)

The criteria of this section are applicable to statically loaded connections meeting the following limitations:

(1) The larger, thicker branch is the thru member.

(2) $\beta \geq 0.25$.

(3) The overlapping branch member is 0.75 to 1.0 times the size of the through member with at least 25% of its side faces overlapping the through member.

(4) Both branch members have the same yield strength.

(5) All branch and chord members are compact box tubes with width/thickness ≤ 35 for branches, and ≤ 40 for chord.

The following checks shall be made:

(1) Axial capacity P_u of the overlapping tube, using

$\Phi = 0.95$ with

$P_u = F_y\, t_b\, [Q_{OL}\,(2a - 4t_b) + b_{eo} + b_{et}]$

for 25% to 50% overlap, with

$$Q_{OL} = \frac{\%\ \text{overlap}}{50\%}$$

$P_u = F_y\, t_b\, [(2a - 4t_b) + b_{eo} + b_{et}]$

for 50% to 80% overlap.

$P_u = F_y\, t_b\, [(2a - 4t_b) + b + b_{et}]$

for 80% to 100% overlap.

$P_u = F_y t_b\, [(2a - 4t_b) + 2b_{et}]$

for more than 100% overlap

where b_{eo} is effective width for the face welded to the chord,

$$b_{eo} = \frac{(5b)F_{yo}}{\gamma(\tau)F_y} \leq b$$

and b_{et} is effective width for the face welded to the through brace.

$$b_{et} = \frac{5b}{\gamma_t \tau_t} \leq b$$

$\gamma_t = b/(2t_b)$ of the through brace

$\tau_t = t_{overlap}/t_{through}$

and other terms are as previously defined.

(2) Net transverse load on the combined footprint, treated as a T- or Y-connection.

(3) For more than 100% overlap, longitudinal shearing shall be checked, considering only the sidewalls of the thru branch footprint to be effective.

2.40.2.5 Bending. Primary bending moment, M, due to applied load, cantilever beams, sidesway of unbraced frames, etc., shall be considered in design as an additional axial load, P:

$$P = \frac{M}{JD \sin \theta}$$

In lieu of more rational analysis (see Commentary), JD may be taken as η D/4 for in-plane bending, and as βD/4 for out-of-plane bending. The effects of axial load, in-plane bending and out-of-plane bending shall be considered as additive. Moments are to be taken at the branch member footprint.

2.40.2.6 Other Configurations. Cross T-, Y-, gap K-, and gap N-connections with compact circular branch tubes framing into a box section main member may be designed using 78.5% of the capacity given in 2.40.2.1 and 2.40.2.2, by replacing the box dimension "a" and "b" in each equation by branch diameter, d_b (limited to compact sections with $0.4 \leq \beta \leq 0.8$).

2.41 Thickness Transition

Tension butt joints in axially aligned primary members of different material thicknesses or size shall be made in such a manner that the slope through the transition zone does not exceed 1 in 2-1/2. The transition shall be accomplished by chamfering the thicker part, sloping the weld metal, or by any combination of these methods (see Figure 2.4).

2.42 Material Limitations

Tubular connections are subject to local stress concentrations which may lead to local yielding and plastic strains at the design load. During the service life, cyclic loading may initiate fatigue cracks, making additional demands on the ductility of the steel, particularly under dynamic loads. These demands are particularly severe in heavy-wall joint-cans designed for punching shear. See Commentary C2.42.2.2.

2.42.1 Limitations

2.42.1.1 Yield Strength. The design provisions of 2.40 for welded tubular connections are not intended for use with circular tubes having a specified minimum yield, F_y, over 60 ksi (415 MPa) or for box sections over 52 ksi (360 MPa).

2.42.1.2 ASTM A 500 Precaution. Products manufactured to this specification may not be suitable for those applications such as dynamically loaded elements in welded structures, etc., where low-temperature notch toughness properties may be important. Special investigation or heat treatment may be required if this product is applied to tubular T-,Y-, and K-connections.

2.42.1.3 Reduced Effective Yield. Reduced effective yield shall be used as F_{yo} in the design of tubular connections (see Note 2 of Table 2.9) for the following steels:

ASTM A 514	ASTM A 618, Grades II and III
ASTM A 517	(Grade I if the properties
ASTM A 537	are suitable for welding)
ASTM A 572	ASTM A 633
ASTM A 588	ASTM A 709
ASTM A 595	ASTM A 710, Grade A
	ASTM A 808
	API 5L, Grades X42 and X52

2.42.1.4 Suitability for Tubular Connections. In the absence of a notch toughness requirement, the following steels may be unsuitable for use as the main member in a tubular connection (see 2.42.2.2):

ASTM A 514
ASTM A 517
ASTM A 572
ASTM A 588
ASTM A 595
ASTM A 709
API 5L, Grades X42 and X52

2.42.1.5 Box T-, Y-, and K-Connections. The designer should consider special demands which are placed on the steel used in box T-, Y-, and K-connections.

2.42.2 Tubular Base-Metal Notch Toughness

2.42.2.1 Charpy V-Notch Requirements. Welded tubular members in tension shall be required to demonstrate Charpy V-notch absorbed energy of 20 ft·lb at 70°F (27 J at 20°C) for the following conditions:

(1) Base-metal thickness of 2 in. (50 mm) or greater with a specified minimum yield strength of 40 ksi (280 MPa) or greater.

Charpy V-notch testing shall be in accordance with ASTM A 673 (Frequency H, heat lot). For the purposes of this subsection, a tension member is defined as one having more than 10 ksi (70 MPa) tensile stress due to design loads.

2.42.2.2 LAST Requirements. Tubulars used as the main member in structural nodes, whose design is governed by cyclic or fatigue loading (e.g., the joint-can in T-, Y-, and K-connections) shall be required to demonstrate Charpy V-notch absorbed energy of 20 ft·lb (27 J) at the Lowest Anticipated Service Temperature (LAST) for the following conditions:

(1) Base-metal thickness of 2 in. (50 mm) or greater.

(2) Base-metal thickness of 1 in. (25 mm) or greater with a specified yield strength of 50 ksi (345 MPa) or greater.

When the LAST is not specified, or the structure is not governed by cyclic or fatigue loading, testing shall be at a temperature not greater than 40°F (4°C). Charpy V-notch testing shall normally represent the as-furnished tubulars, and be tested in accordance with ASTM A 673 Frequency H (heat lot).

2.42.2.3 Alternative Notch Toughness. Alternative notch toughness requirements shall apply when specified in contract documents. The Commentary gives additional guidance for designers. Toughness should be considered in relation to redundancy versus criticality of structure at an early stage in planning and design.