

2. Design of Welded Connections

2.0 Scope

This section covers the design requirements of Nontubular and Tubular welded connections, regardless of the product form or the type of loading.

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 Allowable Weld Stresses. The allowable stresses in welds shall not exceed those given in [Table 2.3](#).

2.1.4 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 construction.

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. Working drawings shall specify the groove depths (S) applicable for the weld size (E) required for the welding process.

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

2.2.4.1 Symbols. It is recommended that contract design drawings show complete joint penetration, partial joint penetration groove weld, or fillet weld requirements.

2.2.4.2 Special Details. When special groove or fillet 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 Effective Weld Size. 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](#).

2.3.4 Complete Joint Penetration Groove Welds.

2.3.4.1 Weld Size. The weld size of complete joint penetration groove welds shall be the thickness of the thinner part joined. No increase in the effective area for design calculations is permitted for weld reinforcement.

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 2](#) for formula governing the calculation of the effective throat for fillet welds in skewed T-joints. A tabulation of measured legs (W) and acceptable root openings (R) relate 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 the 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 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 ¼ 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 ¼ 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 (40 mm).

2.4.7 Fillet Weld Terminations.

2.4.7.1 Drawings. The length and deposition 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, 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 Slots. Minimum spacing and dimensions of slots when fillet welding is used shall conform to the requirements of [2.5](#). Fillet welds in slots in lap joints may be used to transfer shear or to prevent buckling or separations of lapped parts. These fillet welds may overlap, subject to the provisions of [2.4.2.2](#).

2.5 Slot Welds.

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

2.5.2 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.

2.5.3 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.

2.5.4 Prohibition in Q & T Steel. Slot welds are not permitted in quenched and tempered steels.

2.5.5 Limitation. 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, 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 D).

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 axes for end connections of single-angle, double angle, and similar type members is not required; such welded arrangements at the heel and toe of angle members may distributed to conform to the length of the various available edges. Similarly, Ts or beams framing into chords trusses, or similar joints, may be connected with unbraced fillet welds.

2.9 Skewed T-Joints

2.9.1 General.

2.9.2 Prequalified Minimum Weld Size.

2.9.3 Effective Throat.

2.9.3.1 Z Loss Reduction.

2.10 Partial Length Groove Weld Prohibition

2.11 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

2.11.1 Filler Plates Less Than ¼ in. (6mm)

Filler plates less than ¼ in. (6mm) 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).

2.11.2 Filler Plates ¼ in. (6 mm.) or Larger. Any filler plate ¼ 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).

2.12 Fillet Welds

2.12.1 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.

2.12.2 Intermittent Fillet Welds.

2.12.3 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).

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2.12.4 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:

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

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

2.12.5 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 or variable angle loaded welds is the following:

$$F_{vx} = \Sigma F_{vix}$$

$$F_{vy} = \Sigma F_{viy}$$

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

$$f(p) = [p(1.9 - 1.9p)]^{0.3}$$

$$M = \Sigma [F_{viy}(x) - F_{vix}(y)]$$

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

$\Delta_m = 0.209 (\Theta + 2)^{-0.32} W$, 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_v/r_I ratio, in. (mm)

2.13 Built-Up Members

If two or more plates or rolled shapes are used to build up a member, sufficient welding (of the fillet, 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.

2.14 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).

2.15 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 $4000/F_y$ for F_y in psi [$332/F_y$ 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 $8000/F_y$ (for F_y in ps [$664/F_y$ for F_y in Mpa.]

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

2.16 Tension Members.

In built-up tension members, the longitudinal spacing of intermittent welds connecting a plate component other components, or connecting two

plate component times the thickness of the thinner plate.

2.17 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 corner for a distance at least twice the normal size of the weld except as provided in 2.4.7.

2.18 Transitions of Thickness 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 and combination of these.

2.19 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 2.20 and the maximum combined stresses calculated therefrom shall be limited in accordance with the requirements of the applicable general specifications.

2.20 Cyclic Load Stress Range.

The allowable stress range (fatigue) for structures subject to cyclic loading shall be provided in Table 2.5, and Figures 2.8, 2.9, and 2.10 for the applicable condition and cycle life.

2.21 Corner and T-Joints

2.21.1 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).

2.21.2 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 the tensile stress at the root of any weld.

2.22 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.

2.22.1 Continuous Welds. 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.

2.23 Prohibited Joints and Welds

2.23.1 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.

2.23.2 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:

- (a) Secondary or non stress-carrying members and shoes or other non stressed appurtenances, and
- (b) Corner joints parallel to the direction of calculated stress, between components for built-up members designed primarily for axial stress.

2.23.3 Intermittent Groove Welds. Intermittent groove welds are prohibited.

2.23.4 Intermittent Fillet Welds. Intermittent fillet welds, except as provided in [2.30.1](#), are prohibited.

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

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

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

2.24 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 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.

2.25 Transition of Thickness and Widths

2.25.1 Tension Butt-Joint Thickness. But joints between parts having unequal thickness 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](#)).

2.25.2 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](#).

2.25.3 Tension Butt-Joint Width. Butt joints between parts having unequal width and subject to tensile shall have a smooth transition between offset edges 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 the butt joints (see [Figure 2.11](#)). A radius transition required for steels having a yield strength greater than equal to 90 ksi (620 Mpa).

2.26 Stiffeners

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

- (1) Minimum length of each weld shall be 1-1/2 (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 should 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, should be welded on both sides of the joint.

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

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

2.27 Connections or Splices in Compression Members with Milled Joints

If members subject to compression only are splice and full-milled bearing is provided, the splice materials 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.

2.28 Lap Joints

2.28.1 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 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.

2.28.2 Slot Spacing. When fillet welds in slots are used, the clear distance from the edge of the 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.

2.29 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.

2.30 Cover Plates

2.30.1 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.

2.30.2 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 the 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.

2.30.3 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.

2.31 Eccentricity

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

2.32 Allowable Stresses

2.32.1 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, and 2.40. The base-metal stresses shall be those specified in the applicable design specifications, with the following limitations:

2.32.2 Circular Section Limitations.

Limitations on diameter/thickness for circular sections, and largest flange 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:
 $D/t \leq 210/ F_y$ [for F_y in ksi], $80/ F_y$ [for F_y in Mpa] but no more than 35
- (3) box section overlap connections: $D/t \leq 190/ F_y$ [for F_y in ksi], $72/ F_y$ [for F_y in Mpa]

2.32.3 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.

2.32.4 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.

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

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

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.

2.32.6 Fatigue

2.32.6.1 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.

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

2.32.6.3 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.

2.32.6.4 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

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

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

2.32.6.5 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.

2.32.6.6 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 smoothes 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.

2.32.6.7 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 application 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.

2.33 Identification

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

2.34 Symbols

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

2.35 Weld Design

2.35.1 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.

2.35.1.2 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 $\vartheta \leq 1/3$ for circular connections, and $\vartheta \leq 0.8$ 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 ϑ may be required to keep the branch member and the weld on the flat face.

2.35.1.3 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](#).

2.35.2 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.

2.35.2.1 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 stress except where such calculations are waived [2.40.1.3\(2\)](#)

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

2.35.2.2 Prequalified Complete Joint Penetration Groove Weld Details Welded from One Side without Backing in T-, Y-, and K-Connections. See [3.13.4](#) the detail options. If fatigue behavior improvement is inquired, the details selected shall be based on the proper requirements of [2.36.6.6](#) and [Table 2.7](#).

2.35.3 Stresses in Welds. When weld allowable structure calculations are required for circular

section, the normal stress in the weld joining branch to chord in a simple T-, y-, or K-connection shall be computed as:

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

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 factor 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:

$$P_u - Q_w \bullet L_{\text{eff}}$$

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

For fillet welds,

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

with $\omega = 0.8$

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

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

$$K_a = x + y + 3 / (x^2 + y^2)$$

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

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

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:

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

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

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

2.35.5 Box Connection Lengths

2.35.5.1 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:

$$2a_x + 2b, \text{ for } \theta \leq 50^\circ$$

$$2a_x + b, \text{ for } \theta \leq 60^\circ$$

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

2.35.5.2 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:

$$2a_x + b, \text{ for } \theta \leq 50^\circ$$

$$2a_x, \text{ for } \theta \leq 60^\circ$$

For $50^\circ < \theta < 60^\circ$, interpolate

2.36 Limitations of the Strength of Welded Connections

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

2.36.1.1 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 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 acting

$$V_p = \tau f_n \sin \theta$$

The allowable punching shear stress is given by allow $V_p = Q_q \cdot Q_f \cdot F_{yo} / (0.6 \gamma)$

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

Terms used in the foregoing equations are define follows:

τ , θ , γ , β and other parameters of connection geom are defined in Figure 2.14 (M).

f_n is the nominal axial (f_a) or bending (f_b) stress in branch member (punching shear for each kept separated F_{y0} = The specified minimum yield strength of main member chord, but not more than 2/3 the ten strength.

Q_q , Q_f are geometry modifier and stress interact terms, respectively, give in Table 2.9.

For bending about two axes (e.g., y and z), the effective resultant bending stress in circular and square 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:

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

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

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

axial load: $P_u \sin \theta = t_c^2 F_{y0} [6\pi \beta Q_q] Q_f$
bending moment:

$$M_u \sin \theta = t_c^2 F_{y0} [d_b/4] [6\pi \beta Q_q] Q_f$$

with the resistance factor $\phi = 0.8$.

O_f should be computed with \hat{U}^2 redefined as $(P_c/AF_{y0})^2 + (M_c/SF_{y0})^2$ 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:

$$P_u \sin \theta \leq \pi d_b t_c F_{y0}/3$$

$$M_u \sin \theta \leq \pi d_b^2 t_c F_{y0}/3$$

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:

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

2.36.1.2 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

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

(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

$$P = P_{(1)} + [P_{(2)} - P_{(1)}]L/2.5D$$

for $L < 2.5/D$

$$P = P_{(2)}$$

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.

2.36.1.3 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 all be summed with the prequalified fillet weld details, see 3.2, when the following effective throat requirement:

- (a) $E = 0.7 t_b$ for elastic working stress mild steel circular steel tubes ($F_y \leq 40$ ksi joined with overmatched welds (classified strength 70 ksi [485 MPa])
- (b) $E = 1.0 t_b$ for ultimate strength design of circular or box tube connections of mild 40 ksi (280 MPa), with welds satisfying the strength requirements of Table 3.1.
- (c) $E =$ lesser of t_c or $1.07 t_b$ for all other

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

	ASD
E60XX and E70XX ---	1.35
Higher strengths----	1.6

2.36.1.4 Transitions. Flared connections sized transitions not excepted below shall be local stresses caused by the change in direction transition. See [note 4 to Table 2.6.](#) Exception, loads:

Circular tubes having D/t less than 30, and

Transition slope less than 1:4.

2.36.1.5 Other Configurations and Loads

- (1) The term “T-, Y-, and K-connections” used generically to describe tubular connections branch members are welded to a main member, at a structural node. Specific criteria are also cross (X-) connections (also referred to as double 2.40.1.1 and 2.40.1.2. N-connections are a special of K-connections in which one of the branches is perpendicular to the chord; the same criteria apply.
- (2) Connection classifications as T-, Y-, K-, should apply to individual branch members according to the load pattern for each load case. To be considerable connection, the punching load in a branch should be essentially balanced by loads on others in the same plane on the same side of

the joint. In the Y-connections the punching load is reacted as shear in the chord. In cross connections the load is carried through the chord to braces on the site side. For branch members which carry part load as K-connections, and part as T-, Y-, or K-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 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

2.36.1.6 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 overlapping weld, measured perpendicular to the main member.

These terms are illustrated in [Figure 2.18](#).

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

- (3) The allowable combined load component parallel to the main member axis shall not exceed $V_x t_w \Sigma l_1$, where Σl_1 is the sum of the actual weld lengths for all braces in contact with the main member.
- (4) 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.
- (5) 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.
- (6) Net transverse load on the combined footprint shall satisfy 2.40.1.1 and 2.40.1.2.
- (7) 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).

2.36.2 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.

The 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, sideways 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.

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

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

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

with $\Phi = 0.9$

for gap K- and N-connection with least

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

where F_{yo} 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 ξ are connection topology parameters as defined in Figure 2.14 (M) and Figure C2.26; (β_{eff} is equivalent β defined below); and $Q_f = 1.3 - 0.4U/\beta$ ($Q_f \leq 1.0$); use $Q_f = 1.0$ (for chord in tension) with U being the chord utilization ratio.

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

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

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

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

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;

$$\beta_{\text{gap}} = \beta \text{ for K- and N-connections with } \xi \leq \frac{(1-\beta)}{(1-\beta)}$$

$$\beta_{\text{gap}} = \beta_{\text{eop}} \text{ for all other connections}$$

β_{eop} (effective outside punching) = $5\beta/\gamma$ but not more than β

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

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

For unreinforced matched box connections, the mate load normal to the main member (chord) due 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

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

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

or

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

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 load 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).

2.36.2.3 Uneven Distribution of Load (Effective Width). Due to differences in the relative flexibilities or the main member loaded normal to its surface and the branch member carrying membranes 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 progression 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).

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

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_{eoi} for all other connections

$b_{eoi} = \frac{5b}{\gamma\tau} F_{yo} \leq b$

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.

2.36.2.4 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. 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 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.

$$b_{et} = \frac{5b}{\gamma(\tau)_t} \leq b$$

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

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

and other terms are used 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.

2.36.2.4 Bending. Primary bending moment, M , due to applied load, cantilever beams, sideway 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 $\eta D/4$ for in-plane bending, and as $\beta D/4$ 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.

2.36.2.4 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% 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 $0.4 \leq \beta \leq 0.8$).

2.37 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](#)).

2.38 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 joints-cans designed for punching shear. See [Commentary C2.42.2.2](#).

2.38.1 Limitations

2.38.1.1 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).

2.38.1.2 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.

2.38.1.3 Reduced Effective Yield. Reduced effective yield shall be used as F_{y0} in the design of tubular connections (see **Note 2 of Table 2.9**) for the following steels:

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

2.38.1.4 Suitable 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

2.38.1.5 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.

2.38.2 Tubular Base-Metal Notch Toughness.

2.38.2.1 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. (50mm) 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.

2.38.2.2 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:

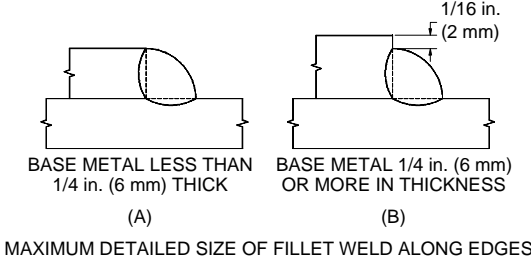
(1) Base-metal thickness of 2 in (50mm) or greater.
 (3) Base-metal thickness of 1 in. (25 mm) or greater with a specified yield strength of 50 ksi (345 MPa) or greater.

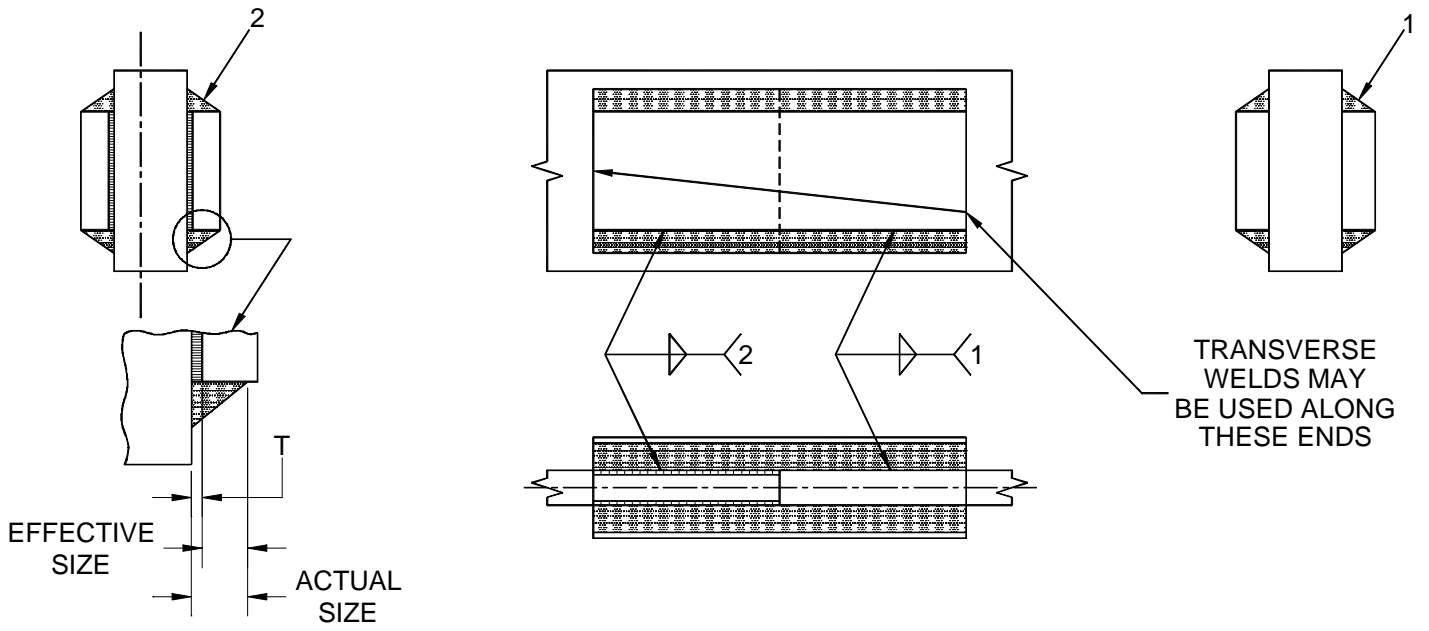
When the LAST is not specified, or the structure is not governed by cyclic or fatigue loading, testing shall be at a temperature not greater than 40°F (4°C). Charpy V-notch testing shall normally represent the as-furnished tubulars, and be tested in accordance with ASTM A 673 Frequency H (heat lot).

2.38.2.3 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.

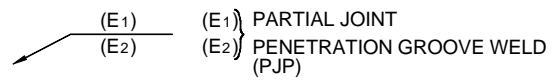
Figure 2.1





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.

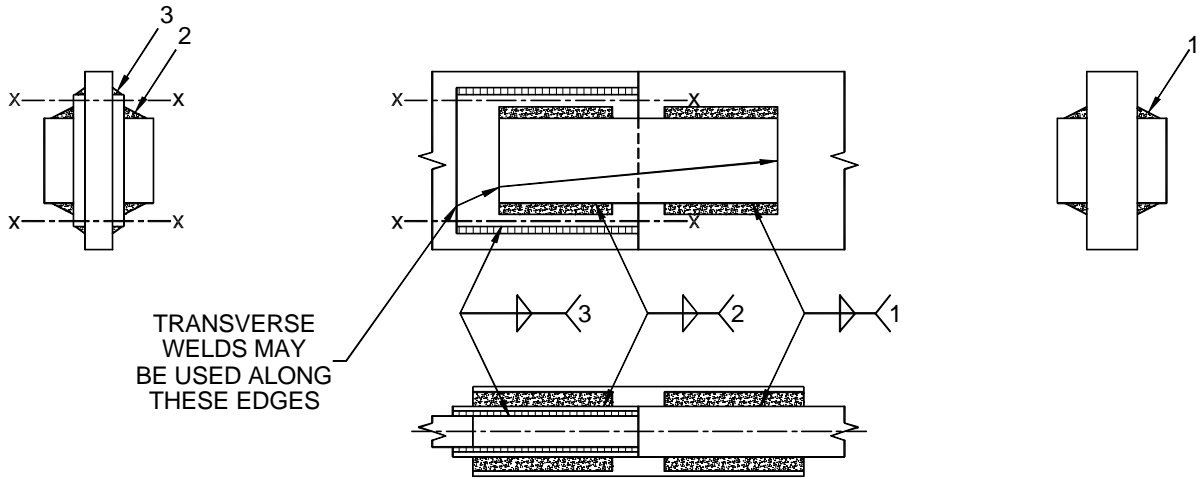
Figure 2.2



WHERE

(E1) = WELD SIZE, OTHER SIDE
(E2) = WELD SIZE, ARROW SIDE

Figure for paragraph 2.2.4



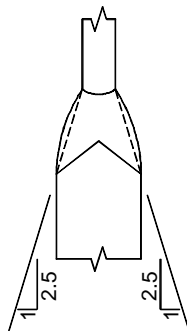
NOTE:

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 PLANES.

Figure 2.3

WELDED FROM 2 SIDES

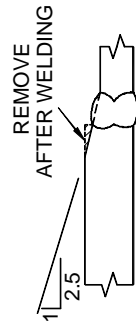
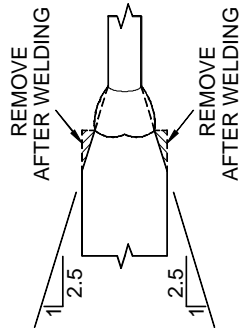
CENTERLINE ALIGNMENT



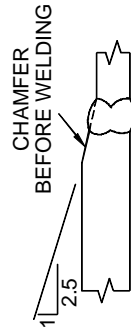
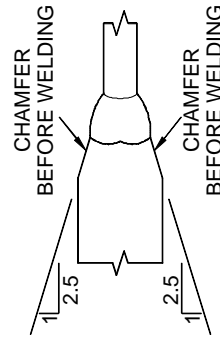
OFFSET ALIGNMENT



(A) TRANSITION BY SLOPING WELD SURFACE



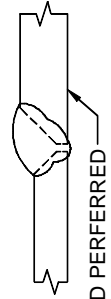
(B) TRANSITION BY SLOPING WELD SURFACE AND CHAMFERING



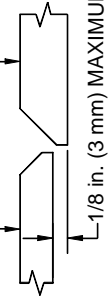
(C) TRANSITION BY CHAMFERING THICKER PART

WELDED FROM 1 SIDE

CONSTANT ID PREFERRED

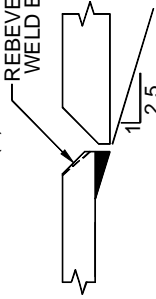


OD OF TUBE

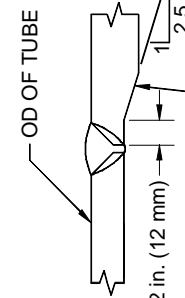
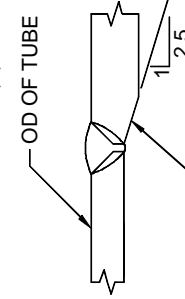


1/8 in. (3 mm) MAXIMUM DIFFERENCE IN RADIUS BEFORE TAPER WELD IS REQUIRED

(A) REBEVEL AFTER WELD BUILDUP



(C) TRANSITION BY TAPER WELD

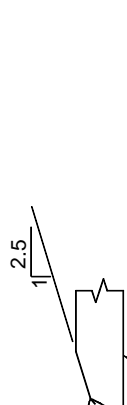


MACHINE, GRIND, OR THERMAL CUT SMOOTH BEFORE WELDING

MACHINE BEFORE WELDING

(D) TRANSITION BY TAPER BORE OF THICKER TUBE

(E) TRANSITION BY STRAIGHT AND TAPER BORE AT THICKER TUBE



CONSTANT ID PREFERRED

(F) TRANSITION BY TAPER OD OF THICKER TUBE

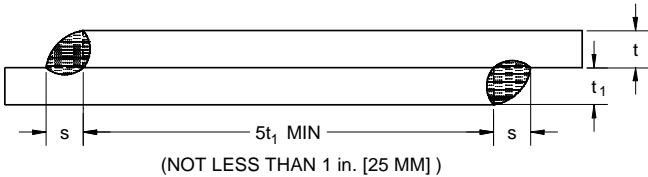
Figure 2.4

NOTES:

1. GROOVE MAY BE OF ANY PERMITTED OR QUALIFIED TYPE AND DETAIL.
2. TRANSITION SLOPES SHOWN ARE 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.

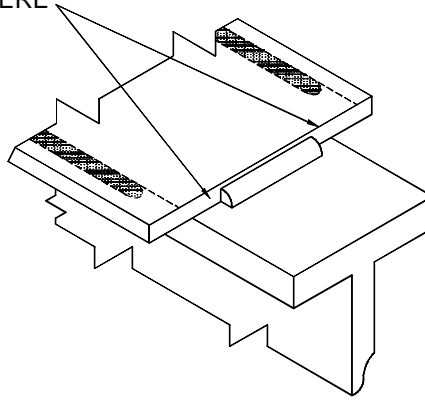
Figure 2.5

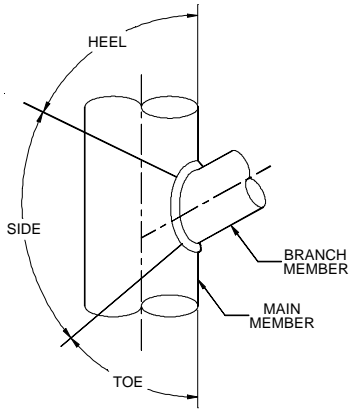


- NOTES:
1. $s = \text{AS REQUIRED}$
2. $t > t_1$

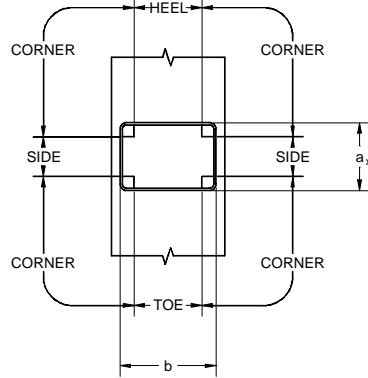
Figure 2.12

DO NOT TIE WELDS
TOGETHER HERE

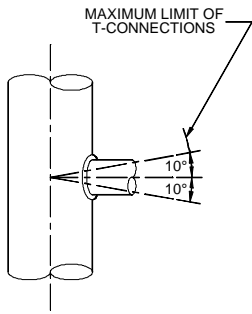
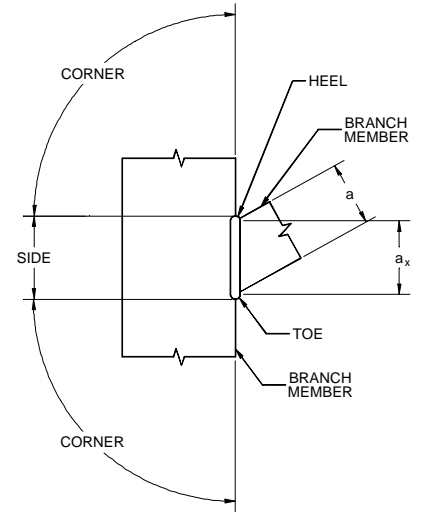




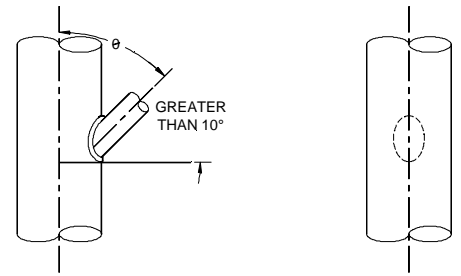
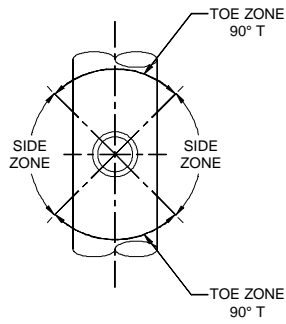
(A) CIRCULAR SECTIONS



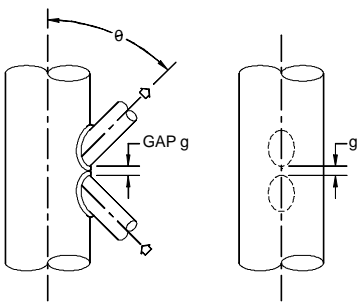
(B) BOX SECTIONS



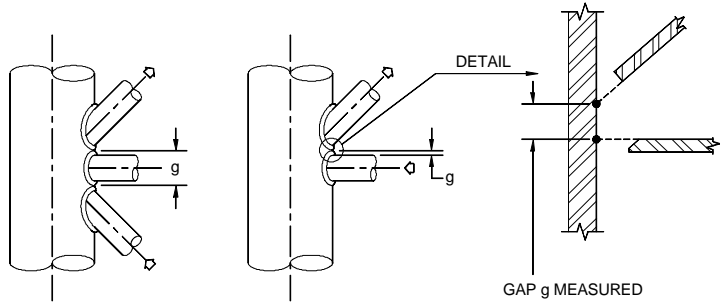
(C) T-CONNECTION



(D) Y-CONNECTION



(E) K-CONNECTION

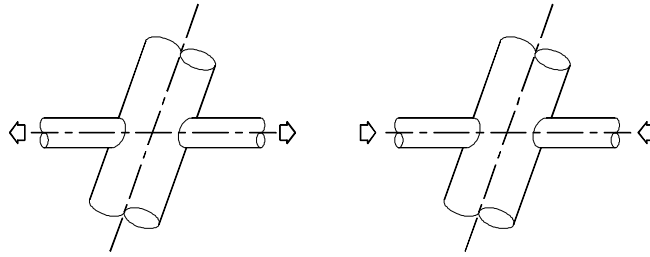


(F) K- COMBINATION CONNECTION

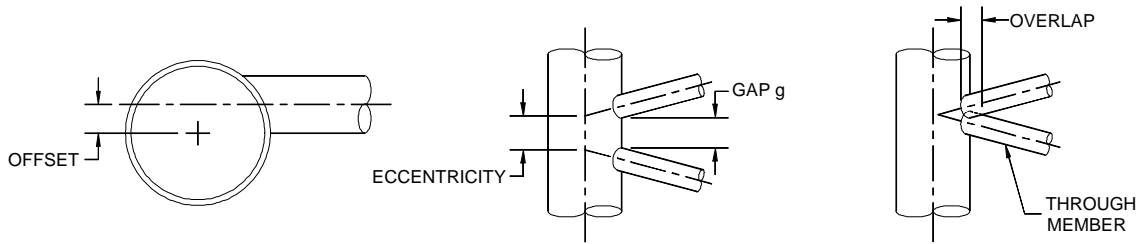
GAP g MEASURED ALONG THE SURFACE OF THE CHORD BETWEEN PROJECTIONS OF THE BRANCH MEMBER OUTSIDE SURFACE AT THE NEAREST APPROACH

NOTE: RELEVANT GAP IS BETWEEN BRACES WHOSE LOADS ARE ESSENTIALLY BALANCED. TYPE (2) IS ALSO REFERRED TO AS AN N-CONNECTION.

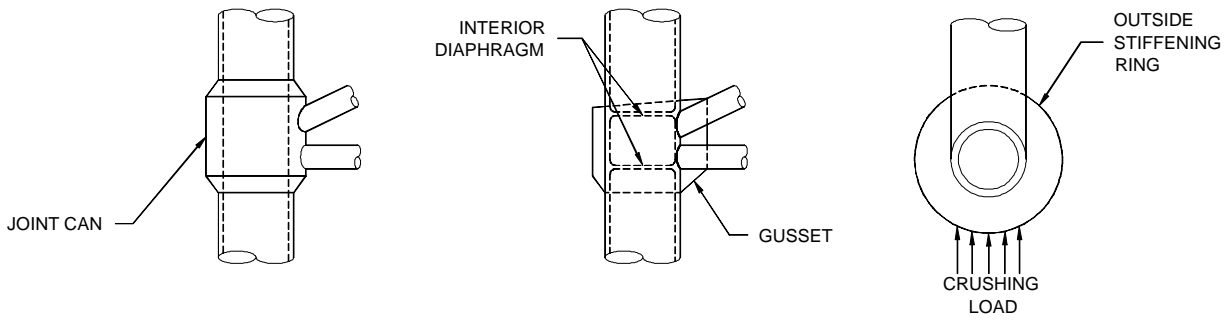
Figure 2.14



(G) CROSS CONNECTIONS

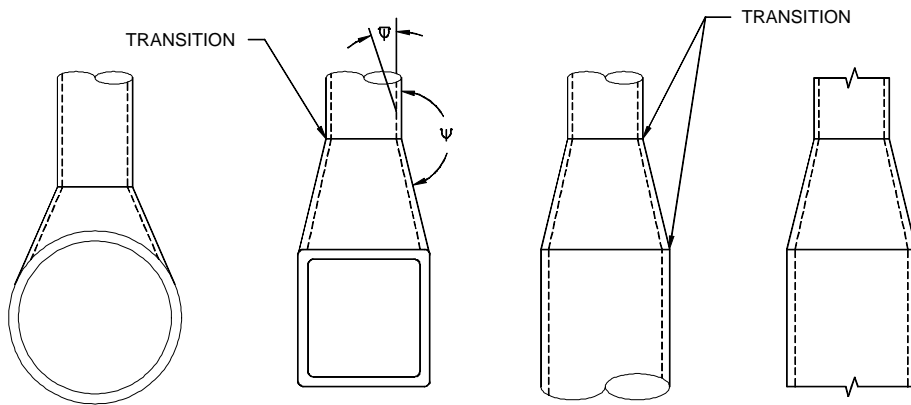


(H) DEVIATIONS FROM CONCENTRIC CONNECTIONS

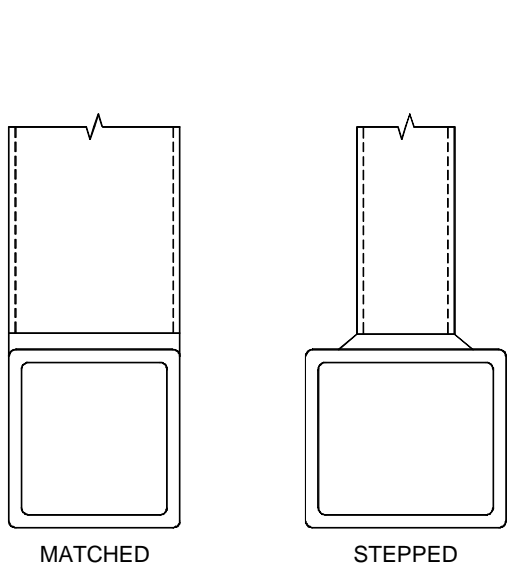


(I) SIMPLE TUBULAR CONNECTION

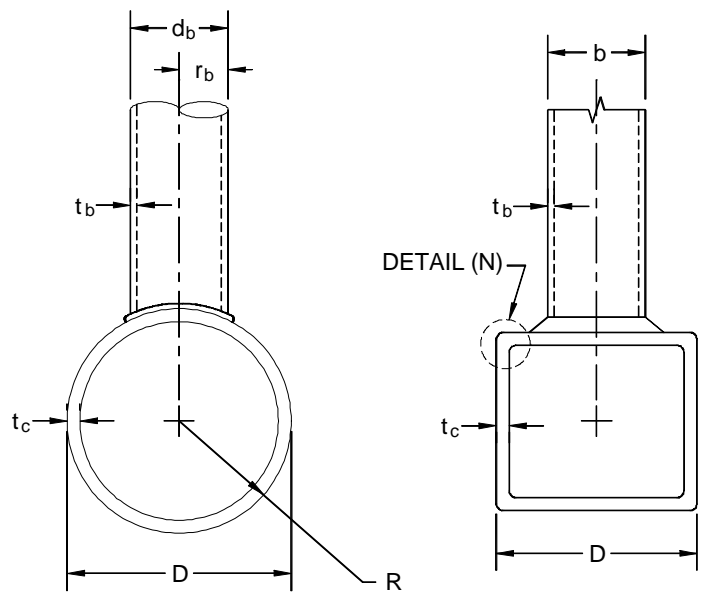
(J) EXAMPLES OF COMPLEX REINFORCED CONNECTIONS



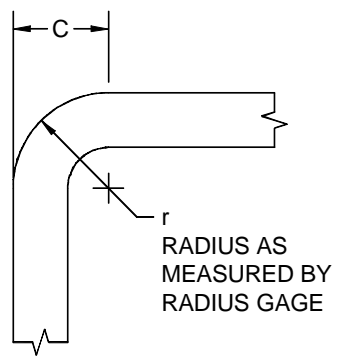
(K) FLARED CONNECTIONS AND TRANSITIONS



(L) CONNECTION TYPES FOR BOX SECTIONS



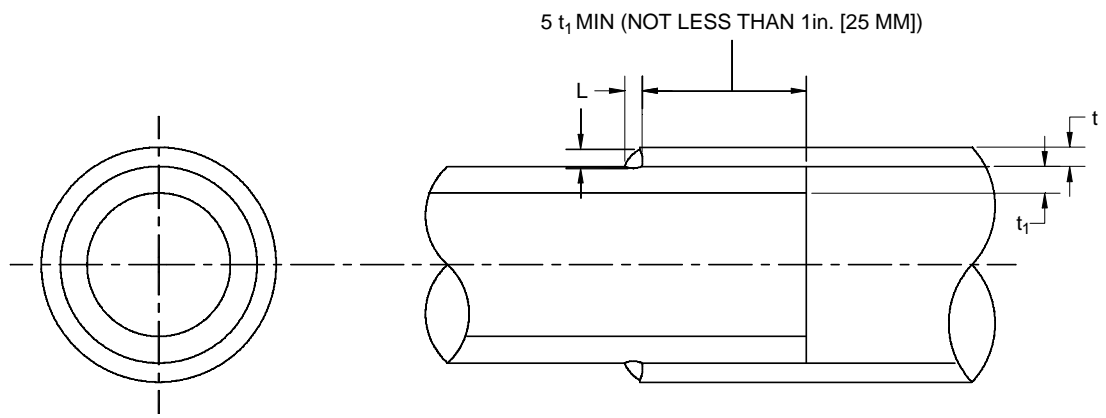
(M) GEOMETRIC PARAMETERS



(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 (concluded)



NOTE: L = SIZE AS REQUIRED

Figure 2.15

Figure 2.16

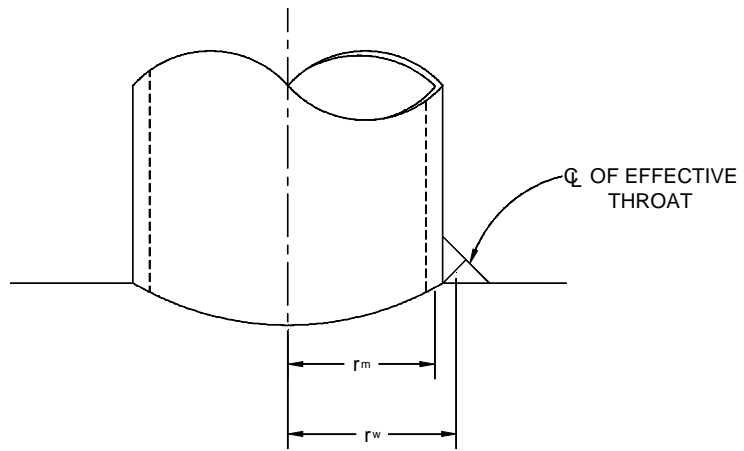


Figure 2.17

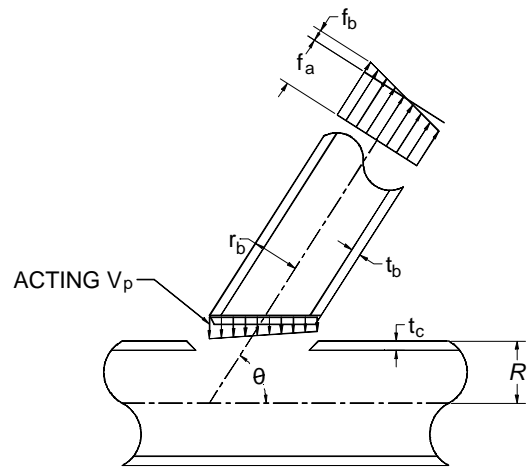


Figure 2.18

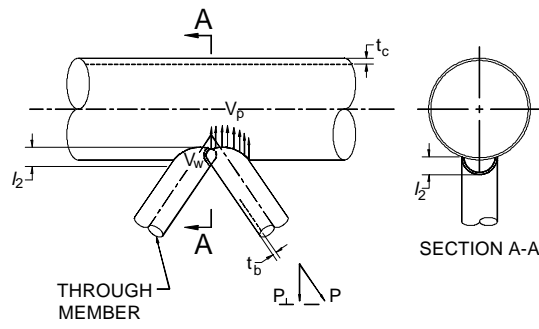
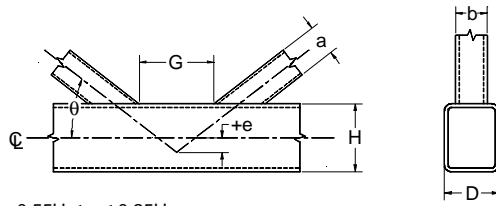


Figure 2.19



$$-0.55H \leq e \leq 0.25H$$

$$\theta \geq 30^\circ$$

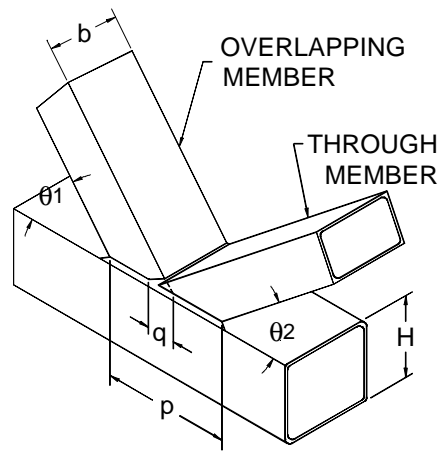
$$H/t_c \text{ AND } D/t_c \leq 35 \text{ (40 FOR OVERLAP K- AND N-CONNECTIONS)}$$

$$a/t_b \text{ AND } b/t_b \leq 35$$

$$F_{y0} \leq 52 \text{ ksi (360 MPa)}$$

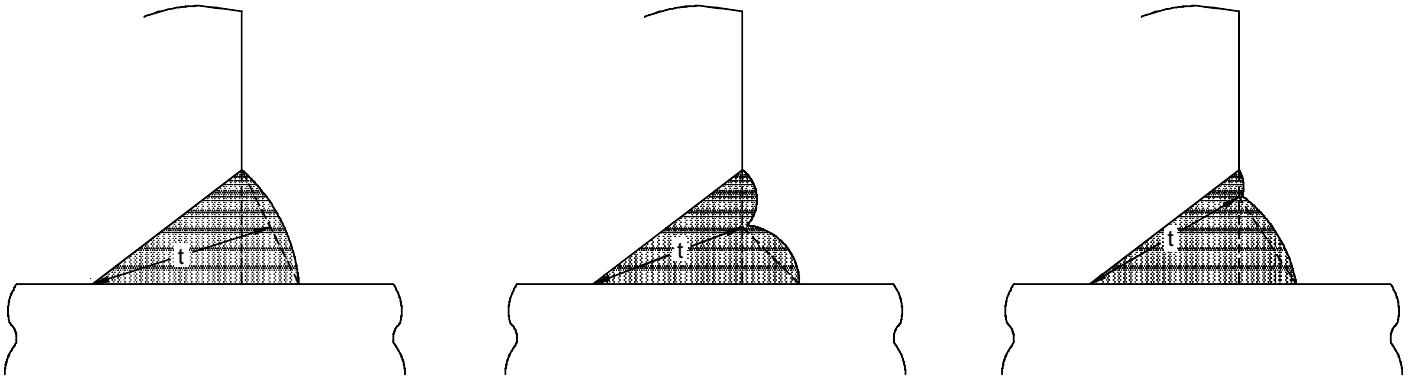
$$0.5 \leq H/D \leq 2.0$$

$$F_{y0} / F_{ult} \leq 0.8$$



$$\text{OVERLAP} = \frac{q}{p} \times 100\%$$

Figure 2.20



NOTE: THE EFFECTIVE THROAT OF A WELD IS THE MINIMUM DISTANCE FROM THE ROOT OF THE JOINT TO ITS FACE, WITH OR WITHOUT A DEDUCTION OF 1/8 in. (3 mm), LESS ANY CONVEXITY.

Figure for Annex 1