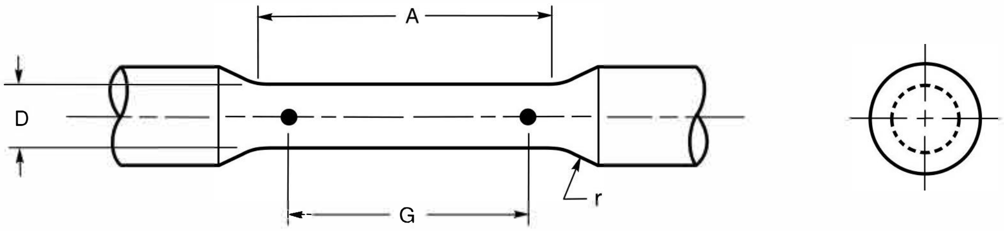


Dimensions in inches			
	Standard Specimen	Small-Size Specimens Proportional to Standard	
Nominal Diameter	0.500 in Round	0.350 in Round	0.250 in Round
G—Gage length	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005
D—Diameter (Footnote a)	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005
r—Radius of fillet, min.	3/8	1/4	3/16
A—Length of reduced section (Footnote b), min.	2-1/4	1-3/4	1-1/4

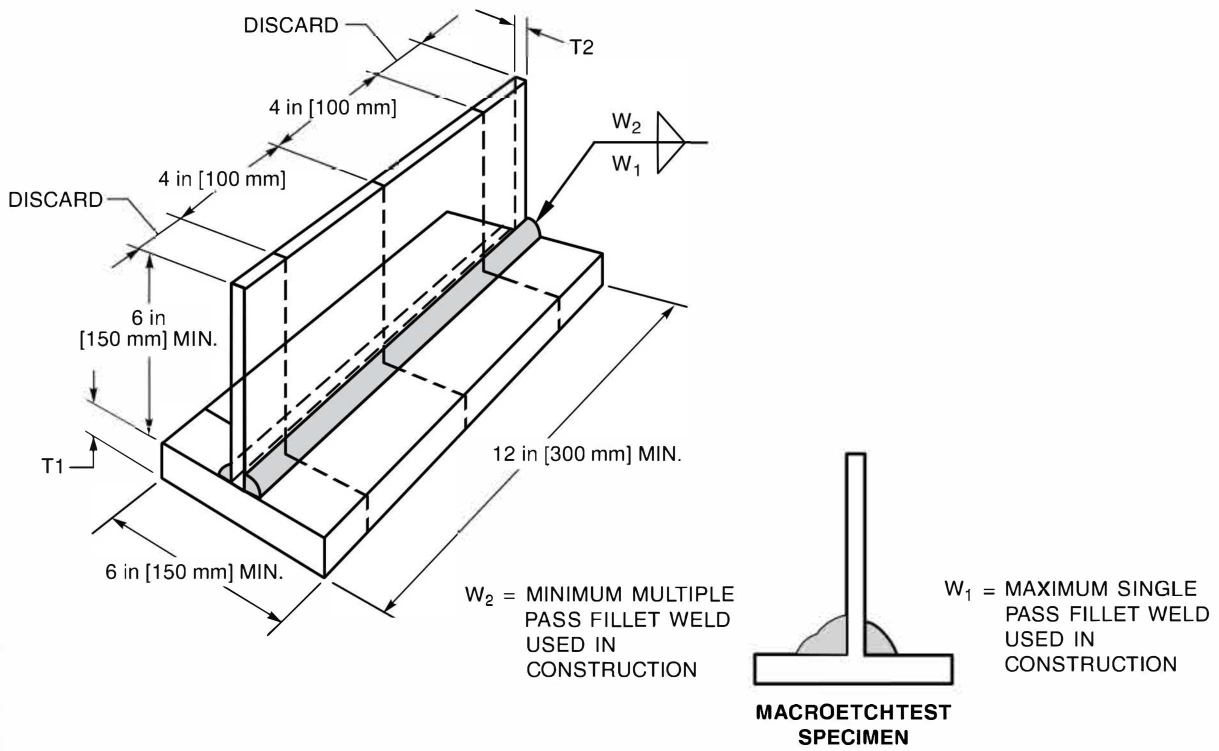
Dimensions (metric version per ASTM E8M)			
	Standard Specimen	Small-Size Specimens Proportional to Standard	
Nominal Diameter	12.5 mm Round	9 mm Round	6 mm Round
G—Gage length	62.5 ± 0.1	45.0 ± 0.1	30.0 ± 0.1
D—Diameter (Footnote a)	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1
r—Radius of fillet, min.	10	8	6
A—Length of reduced section (Footnote b), min.	75	54	36

[a] The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1% larger in diameter than the center (controlling dimension).

[b] If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should be spaced at the indicated gage length.

Note: The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

Figure 6.14—All-Weld Metal Tension Specimen (see 6.10.3.6)

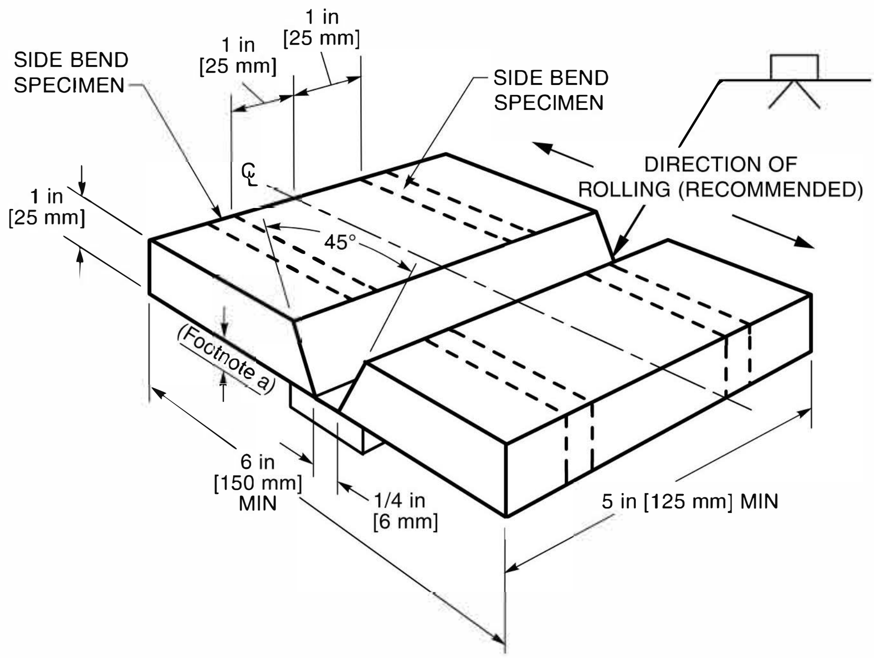


INCHES		
Weld Size	T1 min.	T2 min.
1/8	1/4	3/16
3/16	1/2	3/16
1/4	3/4	1/4
5/16	1	5/16
3/8	1	3/8
1/2	1	1/2
5/8	1	5/8
3/4	1	3/4
> 3/4	1	1

MILLIMETERS		
Weld Size	T1 min.	T2 min.
3	6	5
5	12	5
6	20	6
8	25	8
10	25	10
12	25	12
16	25	16
20	25	20
>20	25	25

Note: Where the maximum plate thickness used in production is less than the value shown above, the maximum thickness of the production pieces may be substituted for T1 and T2.

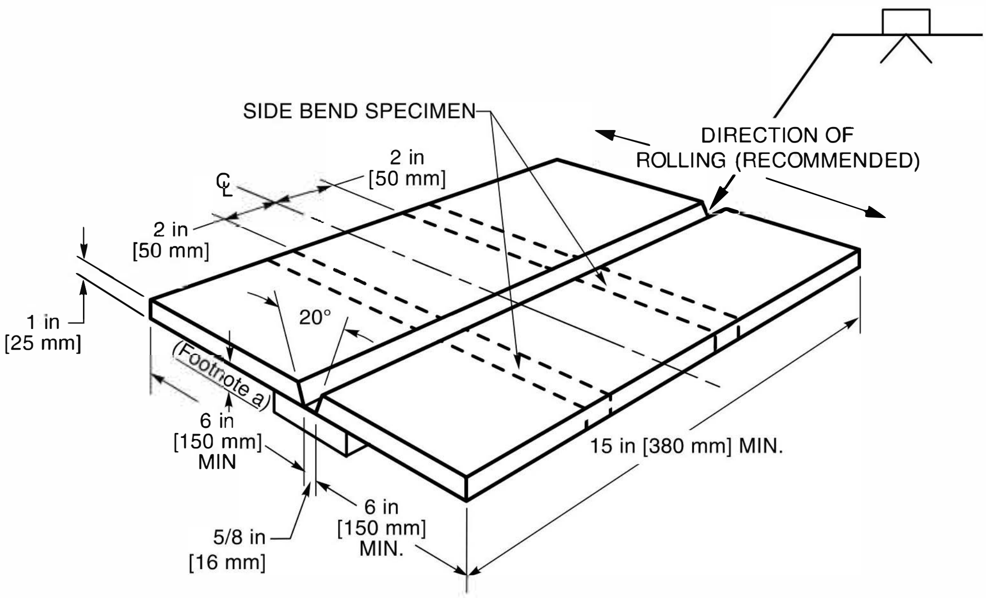
Figure 6.15—Fillet Weld Soundness Tests for WPS Qualification (see 6.13.2)



[a] The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for RT, otherwise 1 in [25 mm] min.

Note: When RT is used, no tack welds shall be in test area.

Figure 6.16—Test Plate for Unlimited Thickness—Welder Qualification and Fillet Weld Consumable Verification Tests (see 6.13.3.2 and 6.21.1)



[a] The backing thickness shall be 3/8 in [10 mm] min. to 1/2 in [12 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for RT, otherwise 1-1/2 in [40 mm] min.

Notes:
1. When RT is used, no tack welds shall be in test area.
2. The joint configuration of a qualified WPS may be used in lieu of the groove configuration shown here.

Figure 6.17—Test Plate for Unlimited Thickness—Welder Operator Qualification and Fillet Weld Consumable Verification Tests (see 6.13.3.2 and 6.21.2.2)

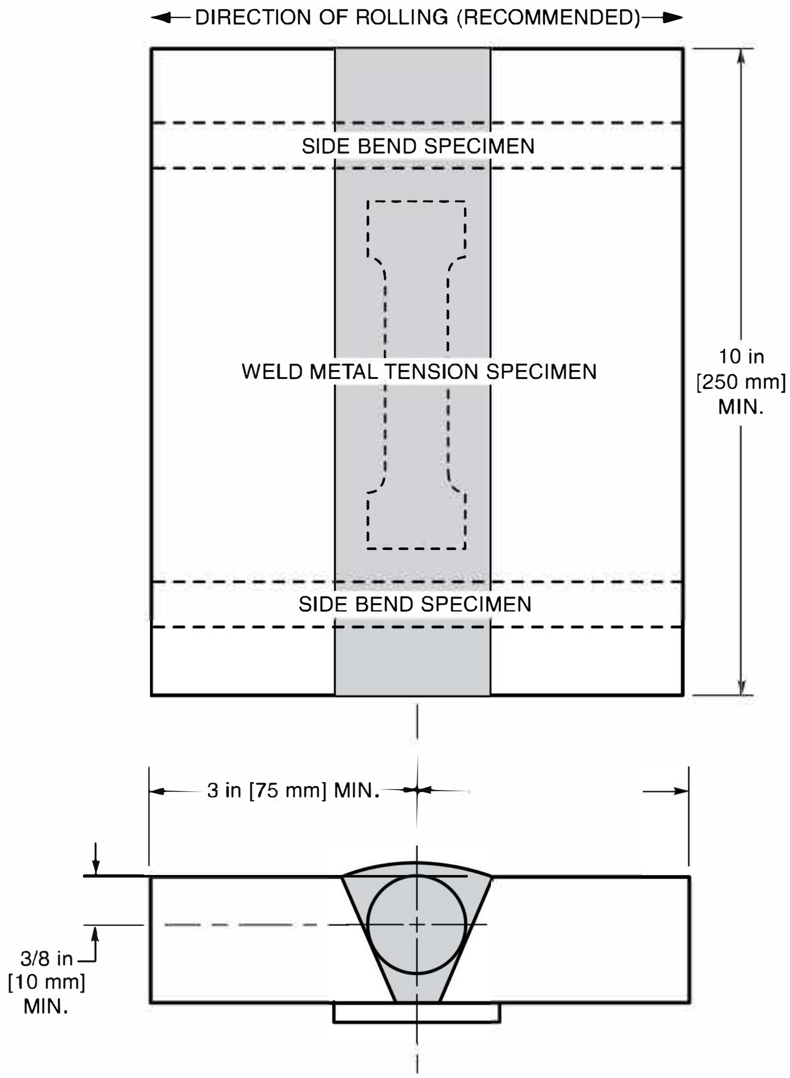
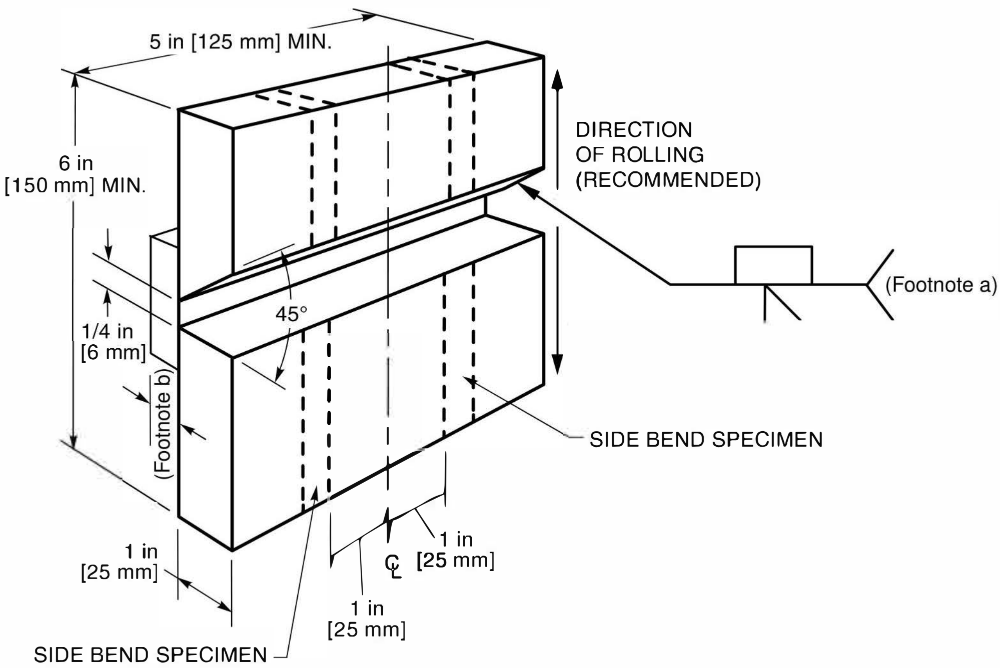


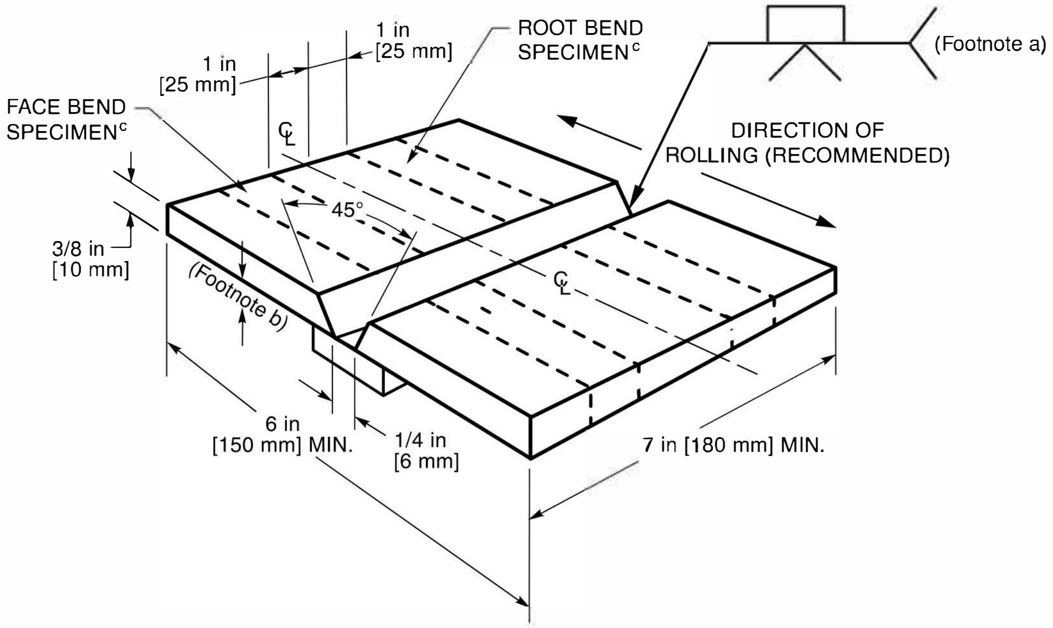
Figure 6.18—Location of Test Specimen on Welded Test Plate 1 in [25 mm] Thick—Consumables Verification for Fillet Weld WPS Qualification (see 6.13.3)



[a] When RT is used, no tack welds shall be in test area.

[b] The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for RT, otherwise 1 in [25 mm] min.

Figure 6.19—Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification (see 6.21.1)

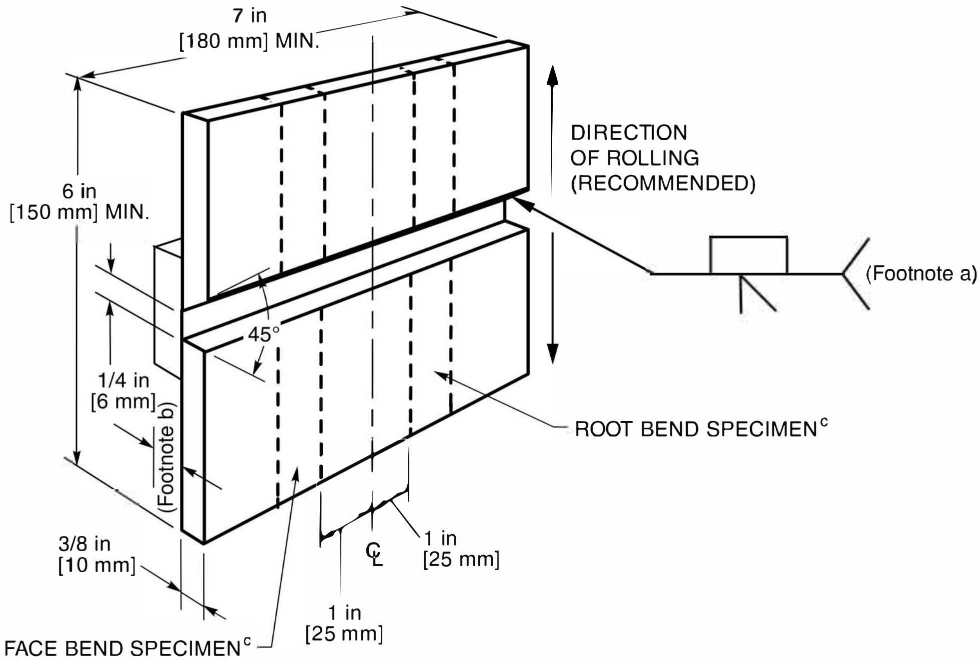


[a] When RT is used, no tack welds shall be in test area.

[b] The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for RT, otherwise 1 in [25 mm] min.

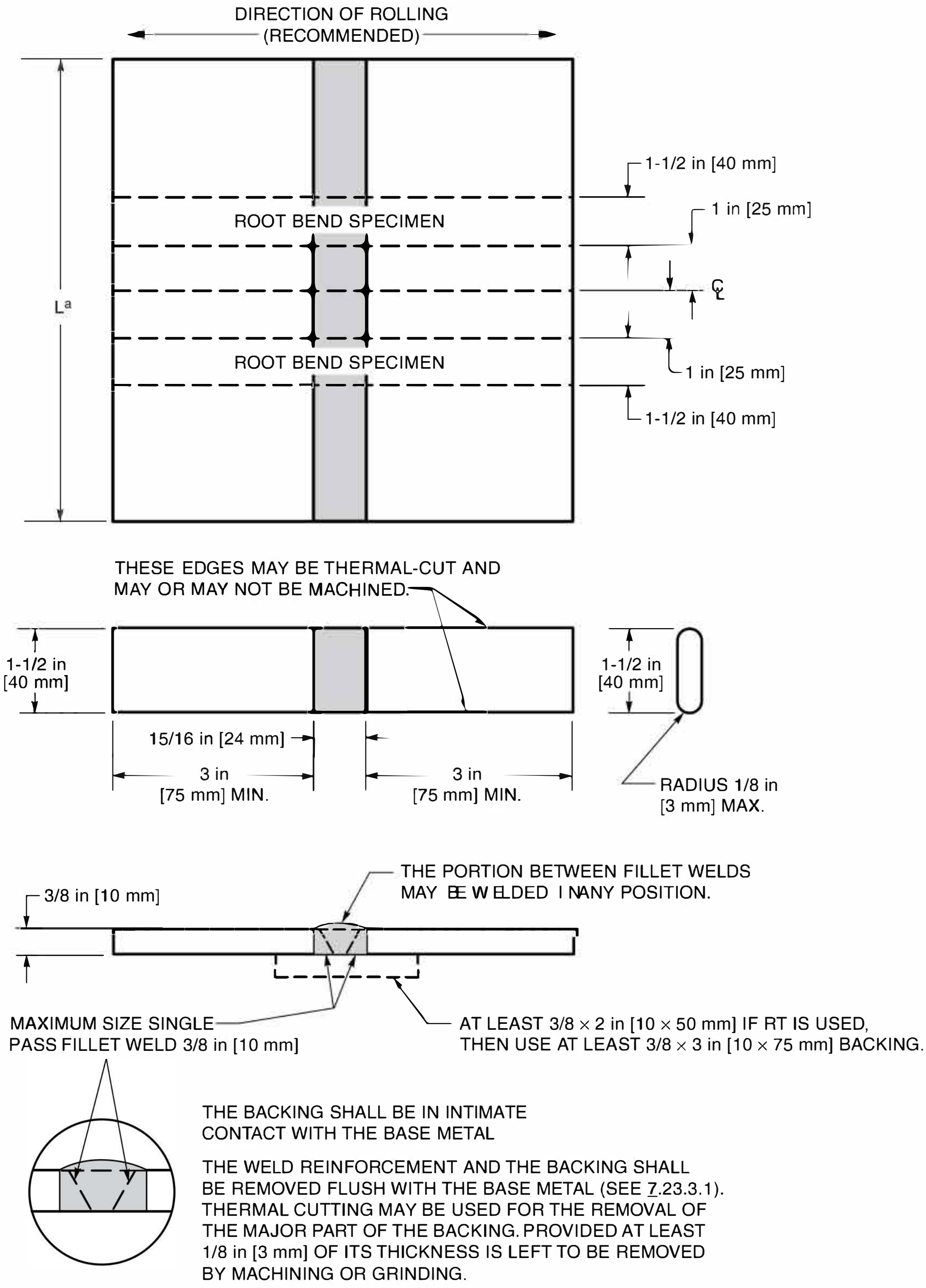
[c] For 3/8 in [10 mm] plate, a side-bend test may be substituted for each of the required face- and root-bend tests.

Figure 6.20—Test Plate for Limited Thickness—All Positions—Welder Qualification (see 6.21.1)



[a] When RT is used, no tack welds shall be in test area.
[b] The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for RT, otherwise 1 in [25 mm] min.
[c] For 3/8 in [10 mm] plate, a side-bend test may be substituted for each of the required face- and root-bend tests.

Figure 6.21—Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification (see 6.21.1)



[a] L = 7 in [175 mm] min. (welder), L = 15 in [380 mm] min. (welding operator).

Figure 6.22—Fillet Weld Root Bend Test Plate—Welder or Welding Operator Qualification—Option 2 (see 6.22.2 and Table 6.11 or 10.20 and Table 10.13)

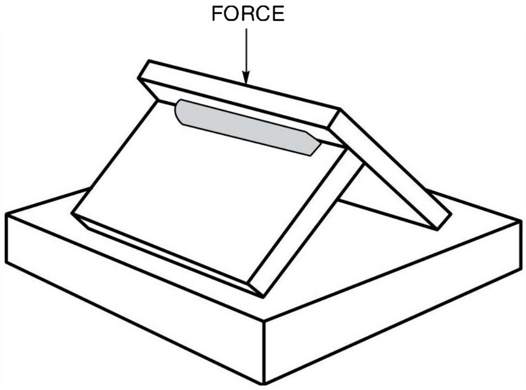
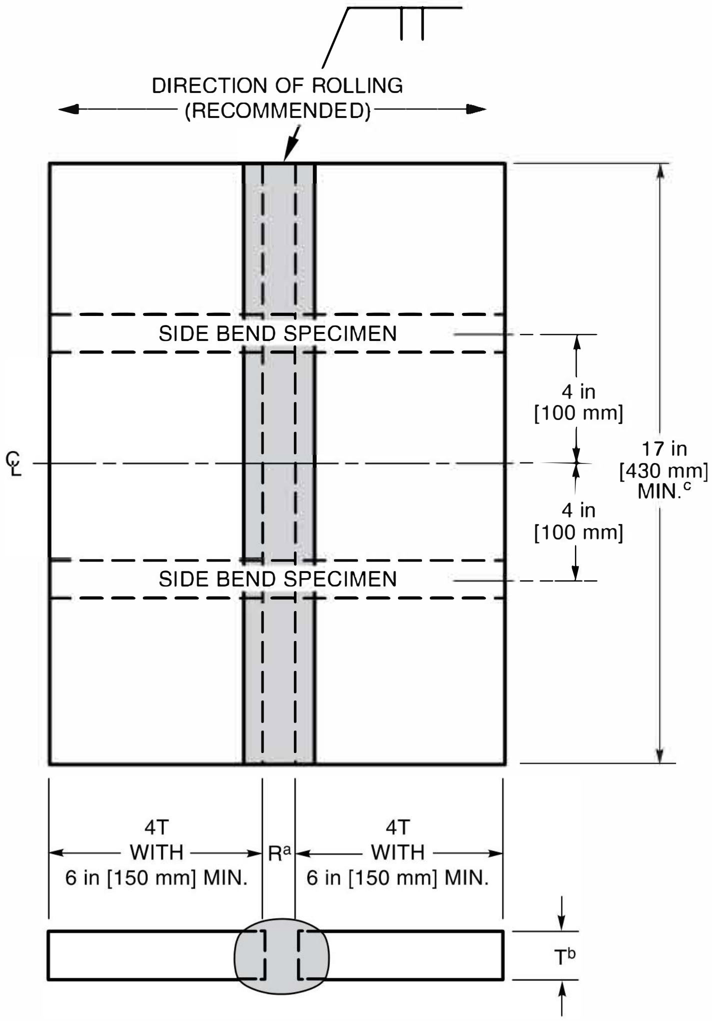
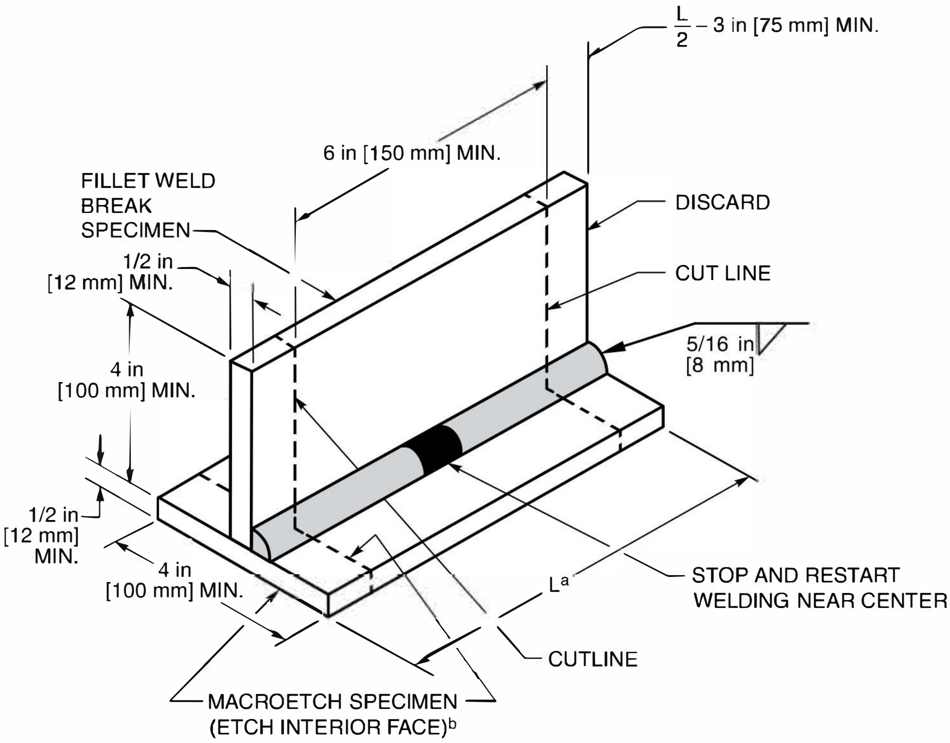


Figure 6.23—Method of Rupturing Specimen—Tack Welder Qualification (See 6.24)



[a] Root opening "R" established by WPS.
[b] T = maximum to be welded in construction but need not exceed 1-1/2 in [38 mm].
[c] Extensions need not be used if joint is of sufficient length to provide 17 in [430 mm] of sound weld.

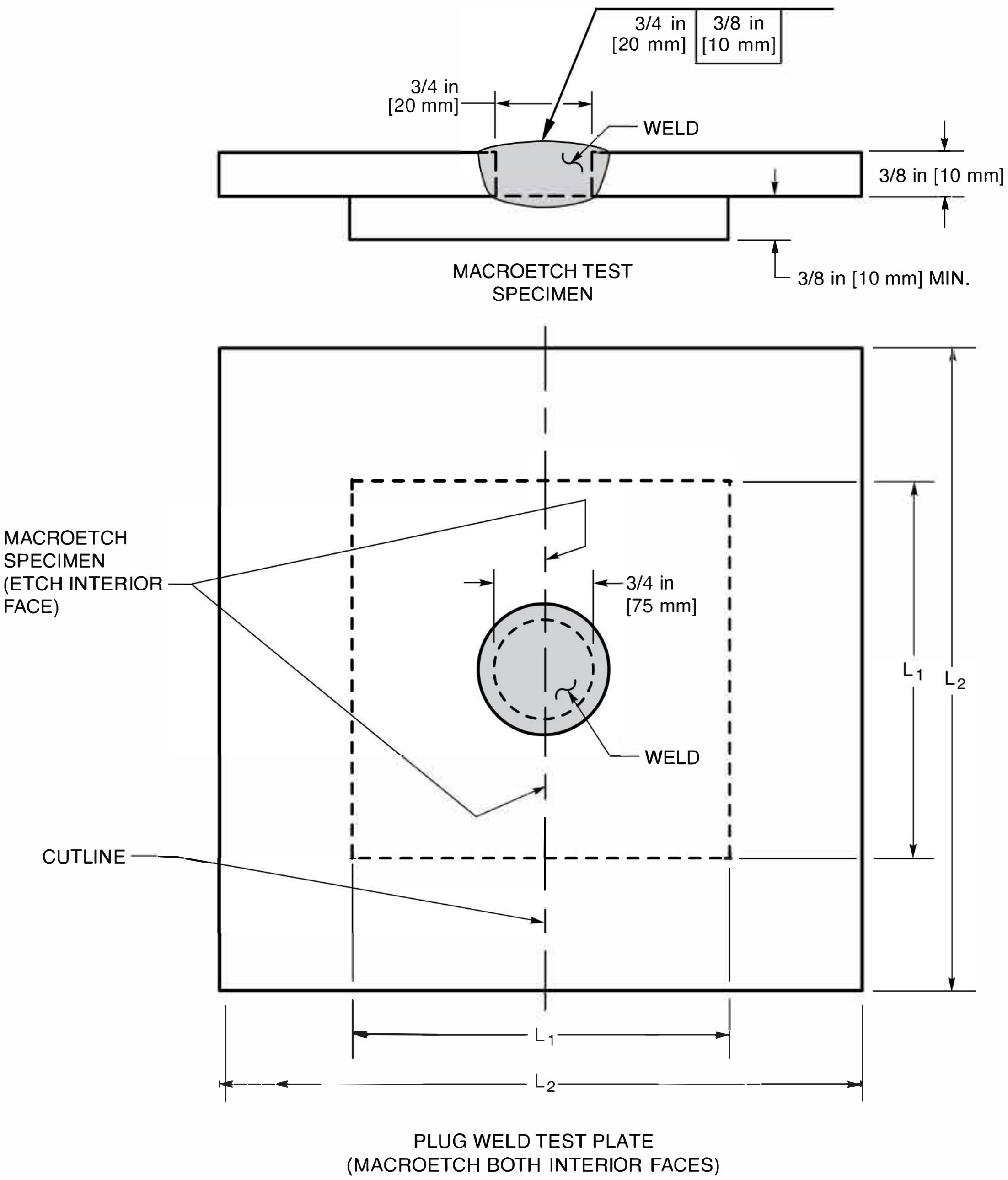
Figure 6.24—Butt Joint for Welding Operator Qualification—ESW and EGW (See 6.21.2.2)



[a] L = 8 in [200 mm] min. welder, 15 in [380 mm] min. (welding operator).

[b] Either end may be used for the required macroetch specimen. The other end may be discarded.

Figure 6.25—Fillet Weld Break and Macroetch Test Plate—Welder or Welding Operator Qualification—Option 1 (See 6.23.2.1)



Notes:
1. L1 = 2 in [50 mm] min. (welder), 3 in [75 mm] min. (welding operator);
2. L2 = 3 in [75 mm] min. (welder), 5 in [125 mm] min. (welding operator).

Figure 6.26—Plug Weld Macroetch Test Plate—Welder or Welding Operator Qualification (See 6.14) and WPS Qualification (see 6.22.3)

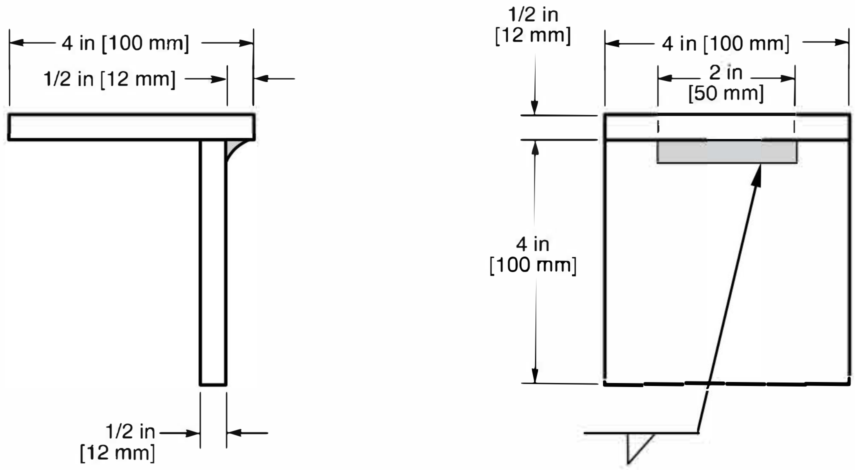
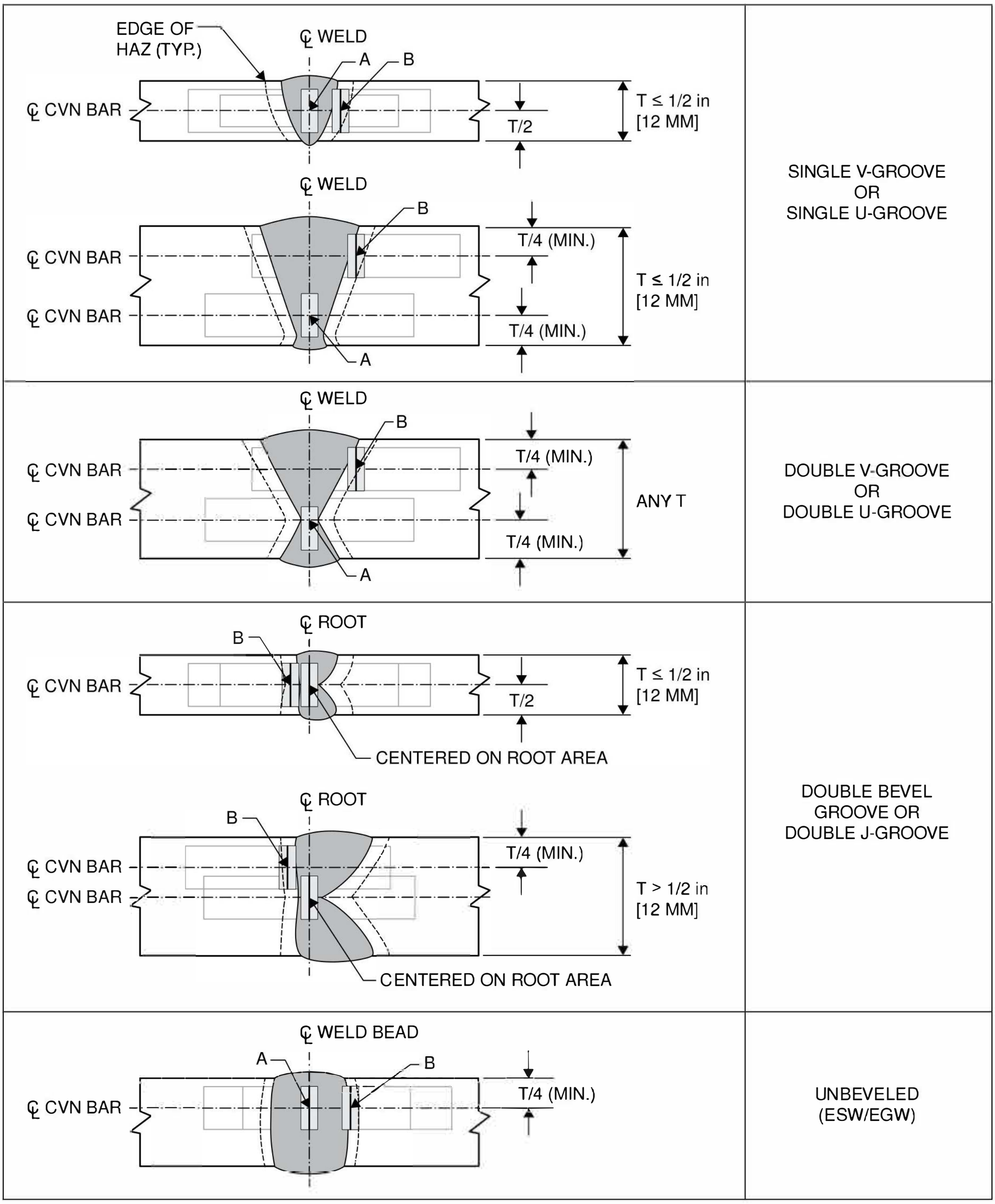
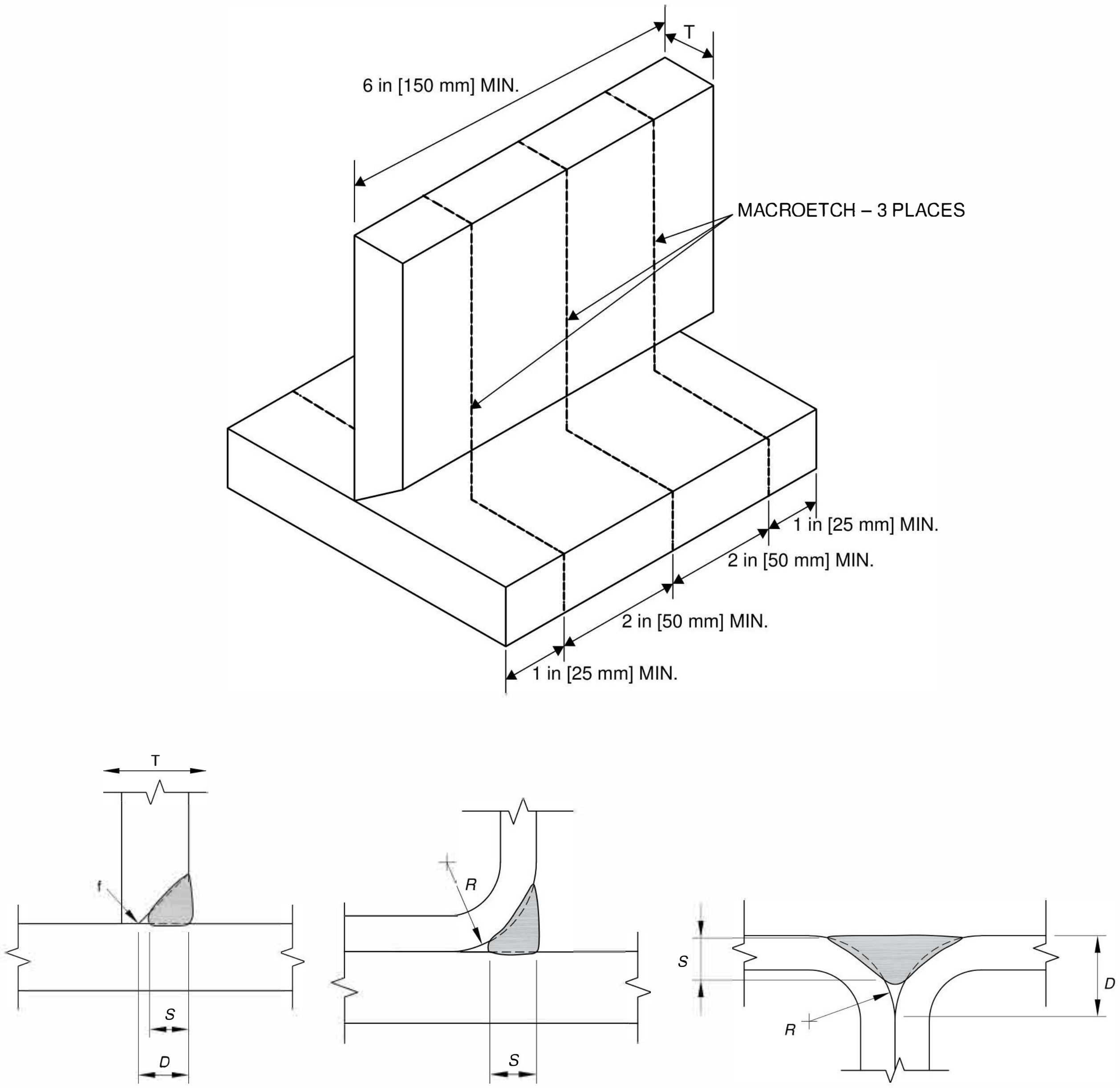


Figure 6.27—Fillet Weld Break Specimen—Tack Welder Qualification (See 6.17.2)



Notes:
1. A = Locate notch on weld centerline for V-, U- and square grooves. Locate notch on root centerline for bevel and J-grooves.
2. B = Locate notch in HAZ when CVNs in the HAZ are specified.
3. The Engineer may specify a notch location a specific distance from the fusion line in lieu of location B.

Figure 6.28—CVN Test Specimen Locations (see 6.27.1)



Notes:

1. Minimum Groove angle shown on WPS
2. Minimum Root Face (f) shown on WPS
3. Groove Type may vary

(A) Qualification Joint PJP (see 6.12.2)

Note:

1. Maximum corner Radius (R) shown on WPS

(B) Qualification Joint Flare-Bevel Groove (see 6.12.4)

Note:

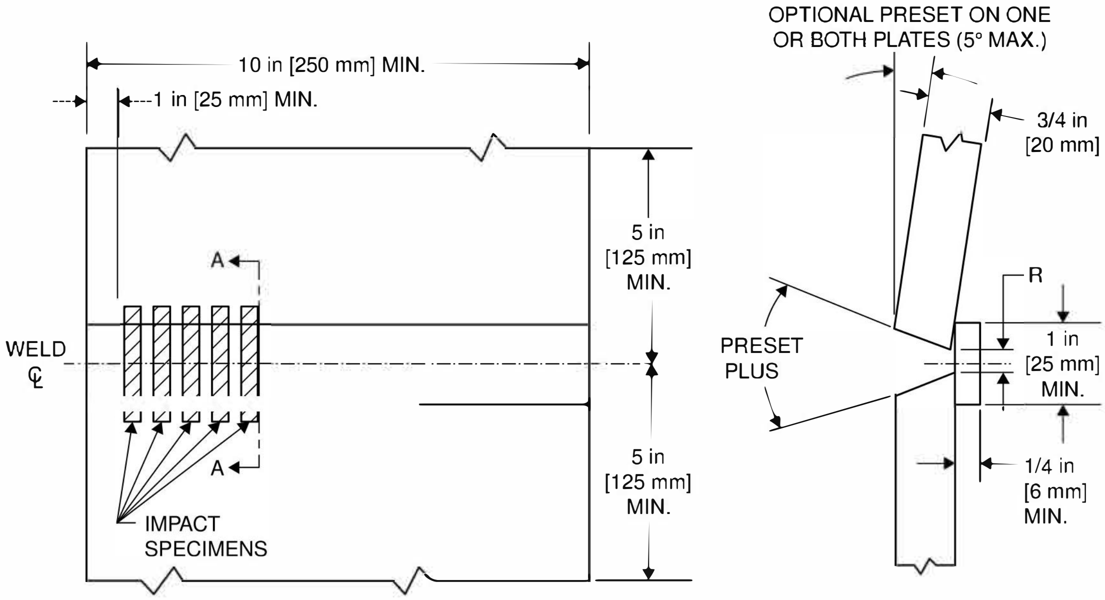
1. Maximum corner Radius (R) shown on WPS

(C) Qualification Joint Flare V-Groove (see 6.12.4)

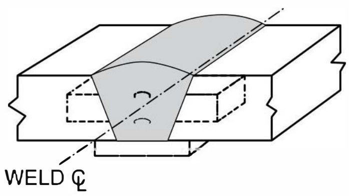
Notes:

1. Thickness (T) ≥ Maximum Groove Depth (D) used in Production. (D) need not exceed 1-in [25 mm]
2. S is weld size

Figure 6.29—Macroetch Test Assemblies for Determination of PJP Weld Size (see 6.12.2 or 6.12.4)



(A) TEST PLATE SHOWING LOCATION OF TEST SPECIMENS



SECTION A-A

(B) ORIENTATION OF IMPACT SPECIMEN

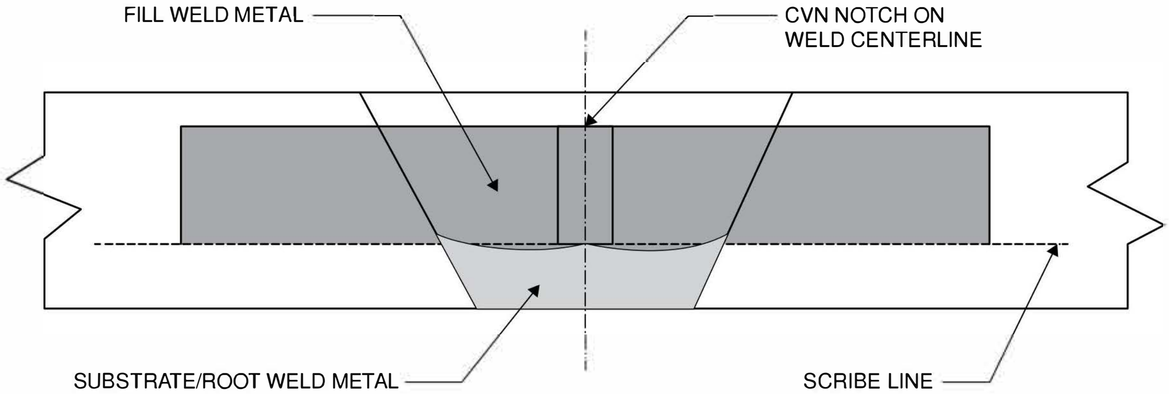
Note: See Figures 6.31 and 6.32 for positioning of CVN specimen.

	Root Opening (R)	Groove Angle (α)
OPTION 1	1/2 in [12 mm]	45°
OPTION 2	5/8 in [16 mm]	20°

Note: CVN specimen edge to be adjacent to intermix scribe (see Figure 6.32)

Source: Adapted from AWS D1.8/D1.8M:2016, *Structural Welding Code—Seismic*, Table Figure B.1, American Welding Society.

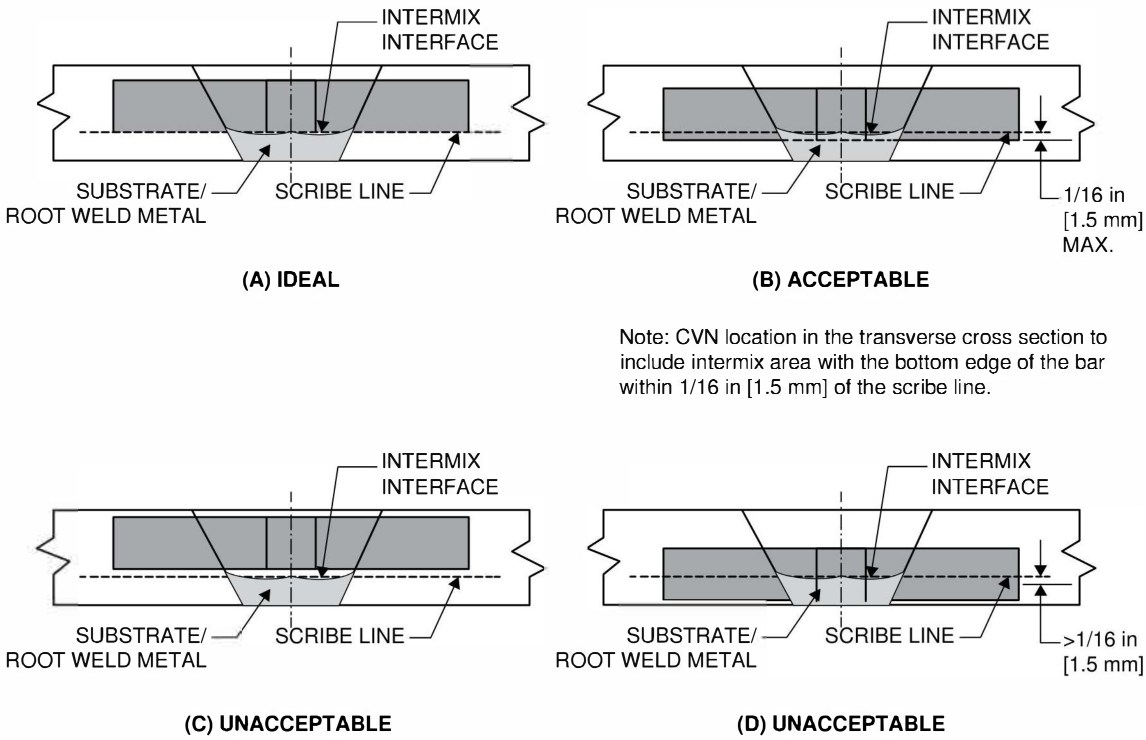
Figure 6.30—Intermix Test Plate (see 6.28.2)



Note: CVN specimen edge is on scribe line.

Source: Adapted from AWS D1.8/D1.8M:2016, *Structural Welding Code—Seismic*, Figure B.2, American Welding Society.

Figure 6.31—Interface Scribe Line Location [see 6.28.5(2)]



Source: Adapted from AWS D1.8/D1.8M:2016, *Structural Welding Code—Seismic*, Figure B.3, American Welding Society.

Figure 6.32—Intermix CVN Test Specimen Location [see 6.28.5(3)]

7. Fabrication

7.1 Scope

This clause contains requirements for the fabrication and erection of welded assemblies and structures produced by any process acceptable under this code (see 5.5 and 6.15) related to:

(1) Materials – Clauses 7.2 and 7.3

(2) Processes and WPSs – Clauses 7.4, 7.5, 7.6, 7.7, 7.10, 7.11, 7.20, 7.24, 7.26, and 7.29

(3) Weld Details – Clauses 7.9, 7.13, 7.14, 7.15, 7.16, 7.17, 7.18, 7.21, and 7.30

(4) Weld Quality and Repairs – Clauses 7.12, 7.13, 7.23, and 7.25

(5) Member Dimensional Tolerances – Clause 7.22

(6) Post Welding Operations – Clauses 7.3, 7.8, 7.27, 7.28, 7.29, and 7.30

7.2 Base Metal

7.2.1 Specified Base Metal. The contract documents shall designate the specification and classification of base metal to be used. When welding is involved in the structure, approved base metals, listed in Table 5.3 or Table 6.9, should be used wherever possible.

7.2.2 Base Metal for Weld Tabs, Backing, and Spacers

7.2.2.1 Weld Tabs. Weld tabs used in welding shall conform to the following requirements:

(1) When used in welding with an approved steel listed in Table 5.3 or Table 6.9, they may be any of the steels listed in Table 5.3 or Table 6.9.

(2) When used in welding with a steel qualified in conformance with 6.8.3 they may be:

(a) The steel qualified, or

(b) Any steel listed in Table 5.3 or Table 6.9

7.2.2.2 Backing and Shelf Bars. Steel for backing and shelf bars shall conform to the requirements of 7.2.2.1 or ASTM A109 T3 or T4, except that 100 ksi [690 MPa] minimum yield strength steel as backing shall be used only with 100 ksi [690 MPa] minimum yield strength steels.

7.2.2.3 Spacers. Spacers shall be of the same material as the base metal.

7.3 Welding Consumables and Electrode Requirements

7.3.1 General

7.3.1.1 Certification for Electrodes or Electrode Flux Combinations. When requested by the Engineer, the Contractor or fabricator shall furnish certification that the electrode or electrode-flux combination conforms to the requirements of the classification.

7.3.1.2 Suitability of Classification. The classification and size of electrode, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances attending the work. Welding current shall be within the range recommended by the electrode manufacturer.

7.3.1.3 Shielding Gas. A gas or gas mixture used for shielding shall conform to the requirements of AWS A5.32M/A5.32, *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*. When requested by the Engineer, the Contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture conforms to the dew point requirements of AWS A5.32/A5.32M. When mixed at the welding site, suitable meters shall be used for proportioning the gases. Percentage of gases shall conform to the requirements of the WPS.

7.3.1.4 Storage. Welding consumables that have been removed from the original package shall be protected and stored so that the welding properties are not affected.

7.3.1.5 Condition. Electrodes shall be dry and in suitable condition for use.

7.3.2 SMAW Electrodes. Electrodes for SMAW shall conform to the requirements of the latest edition of AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, or to the requirements of AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

7.3.2.1 Low-Hydrogen Electrode Storage Conditions. All electrodes having low-hydrogen coverings conforming to AWS A5.1 and AWS A5.5 shall be purchased in hermetically sealed containers or shall be baked by the user in conformance with 7.3.2.4 prior to use. After opening the hermetically sealed container, electrodes not immediately issued for use shall be stored in ovens held at a temperature of at least 250°F [120°C]. Electrodes shall be rebaked no more than once. Electrodes that have been wet shall not be used.

7.3.2.2 Approved Atmospheric Time Periods. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere shall not exceed the values shown in column A, Table 7.1, for the specific electrode classification with optional supplemental designators, where applicable. Electrodes exposed to the atmosphere for periods less than those allowed by column A, Table 7.1 may be returned to a holding oven maintained at 250°F [120°C] min.; after a minimum hold period of four hours at 250°F [120°C] min. the electrodes may be reissued.

7.3.2.3 Alternative Atmospheric Exposure Time Periods Established by Tests. The alternative exposure time values shown in column B in Table 7.1 may be used provided testing establishes the maximum allowable time. The testing shall be performed in conformance with AWS A5.5 for each electrode classification and each electrode manufacturer. Such tests shall establish that the maximum moisture content values of AWS A5.5 are not exceeded. Additionally, E70XX or E70XX-X (AWS A5.1 or A5.5) low-hydrogen electrode coverings shall be limited to a maximum moisture content not exceeding 0.4% by weight. These electrodes shall not be used at relative humidity temperature combinations that exceed either the relative humidity or moisture content in the air that prevailed during the testing program.

For proper application of this subclause, see Annex D for the temperature-moisture content chart and its examples. The chart shown in Annex D, or any standard psychometric chart, shall be used in the determination of temperature-relative humidity limits.

7.3.2.4 Baking Electrodes. Electrodes exposed to the atmosphere for periods greater than those allowed in Table 7.1 shall be baked as follows:

(1) All electrodes having low-hydrogen coverings conforming to AWS A5.1 shall be baked for at least two hours between 500°F and 800°F [260°C and 430°C], or

(2) All electrodes having low-hydrogen coverings conforming to AWS A5.5 shall be baked for at least one hour at temperatures between 700°F and 800°F [370°C and 430°C].

All electrodes shall be placed in a suitable oven at a temperature not exceeding one half the final baking temperature for a minimum of one half hour prior to increasing the oven temperature to the final baking temperature. Final baking time shall start after the oven reaches final baking temperature.

7.3.2.5 Low-Hydrogen Electrode Restrictions for ASTM A514 or A517 Steels. When used for welding ASTM A514 or A517 steels, low-hydrogen electrodes shall meet the following requirements, as applicable:

(1) When welding with E90XX-X or higher tensile strength electrodes, the electrode may be used without baking, provided the electrode is furnished in hermetically sealed containers.

(2) When welding with E90XX-X or higher tensile strength electrodes not furnished in hermetically sealed containers, or when welding with E80XX-X or lower tensile strength electrodes whether furnished in hermetically sealed containers or otherwise, the electrodes shall be baked for a minimum of one hour at temperatures between 700°F and 800°F [370°C and 430°C] before being used, except as provided in (3).

(3) When welding with E7018M electrodes, or electrodes with the optional H4R designator, the electrode may be used without baking.

7.3.3 SAW Electrodes and Fluxes. SAW may be performed with one or more single electrodes, one or more parallel electrodes, or combinations of single and parallel electrodes. The spacing between arcs shall be such that the slag cover over the weld metal produced by a leading arc does not cool sufficiently to prevent the proper weld deposit of a following electrode. SAW with multiple electrodes may be used for any groove or fillet weld pass.

7.3.3.1 Electrode-Flux Combination Requirements. The bare electrodes and flux used in combination for SAW of steels shall conform to the requirements in the latest edition of AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, or to the requirements of the latest edition of AWS A5.23/A5.23M, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*.

7.3.3.2 Condition of Flux. Flux used for SAW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 500°F [260°C] for one hour before use. Flux shall be placed in the dispensing system immediately upon opening a package, or if used from an opened package, the top one inch shall be discarded. Flux that has been wet shall not be used.

7.3.3.3 Flux Reclamation. SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, catch pans, sweeping, or other means. The welding fabricator shall have a system for collecting unmelted flux, adding new flux, and welding with the mixture of these two, such that the flux composition and particle size distribution at the weld puddle are relatively constant.

7.3.3.4 Crushed Slag. Crushed slag may be used provided it has its own marking, using the crusher's name and trade designation. In addition, each dry batch or dry blend (lot) of flux, as defined in AWS A5.01M/A5.01, *Welding and Brazing Consumables—Procurement of Filler Metals and Fluxes*, shall be tested in conformance with Schedule I of AWS A5.01M/A5.01 and classified by the Contractor or crusher per AWS A5.17/A5.17M or AWS A5.23/A5.23M, as applicable.

7.3.4 GMAW/FCAW Electrodes. The electrodes for GMAW or FCAW shall conform to the requirements of the following:

(1) AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*;

(2) AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*;

(3) AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*;

(4) AWS A5.29/A5.29M, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*; or

(5) AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*.

7.3.5 GTAW

7.3.5.1 Tungsten Electrodes. Welding current shall be compatible with the diameter and type or classification of electrode. Tungsten electrodes shall be in conformance with AWS A5.12M/A5.12, *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*.

7.3.5.2 Filler Metal. The filler metal shall conform to all the requirements of the latest edition of AWS A5.18/A5.18M or AWS A5.28/A5.28M or AWS A5.30/A5.30M, *Specification for Consumable Inserts*, as applicable.

7.4 ESW and EGW Processes

7.4.1 Process Limitations. The ESW and EGW processes shall be restricted to use of Table 5.3, Group I, II, and III steels, except that ESW and EGW of ASTM A710 shall not be permitted.

7.4.2 Condition of Electrodes and Guide Tubes. Electrodes and consumable guide tubes shall be dry, clean, and in suitable condition for use.

7.4.3 Condition of Flux. Flux used for ESW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from packages damaged in transit or in handling shall be discarded or shall be dried at a minimum temperature of 250°F [120°C] for one hour before use. Flux that has been wet shall not be used.

7.4.4 Weld Starts and Stops. Welds shall be started in such a manner as to allow sufficient heat buildup for complete fusion of the weld metal to the groove faces of the joint. Welds which have been stopped at any point in the weld joint for a sufficient amount of time for the slag or weld pool to begin to solidify may be restarted and completed, provided the completed weld is examined by UT for a minimum of 6 in [150 mm] on either side of the restart and, unless prohibited by joint geometry, also confirmed by RT. All such restart locations shall be recorded and reported to the Engineer.

7.4.5 Preheating. Because of the high-heat input characteristic of these processes, preheating is not normally required. However, no welding shall be performed when the temperature of the base metal at the point of welding is below 32°F [0°C].

7.4.6 Repairs. Welds having discontinuities prohibited by Clause 8, Part C or Clause 10, Part F shall be repaired as allowed by 7.25 utilizing a qualified welding process, or the entire weld shall be removed and replaced.

7.4.7 Weathering Steel Requirements. For ESW and EGW of exposed, bare, unpainted applications of ASTM A588/A588M steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode-flux combination shall be in conformance with 6.15.1.3(2), and the filler metal chemical composition shall conform to Table 5.6.

7.5 WPS Variables

The welding variables shall be in conformance with a written WPS (see Annex J, Form J–2, as an example). Each pass will have complete fusion with the adjacent base metal, and such that there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in the roots of joints under restraint. All welders, welding operators, and tack welders shall be informed in the proper use of the WPS, and the applicable WPS shall be readily available and shall be followed during the performance of welding.

7.6 Preheat and Interpass Temperatures

Base metal shall be preheated, if required, to a temperature not less than the minimum value listed on the WPS (see 5.2.1 for prequalified WPS limitations and Table 6.5 for qualified WPS essential variable limitations).

Preheat and all subsequent minimum interpass temperatures shall be maintained during the welding operation for a distance at least equal to the thickness of the thickest welded part (but not less than 3 in [75 mm]) in all directions from the point of welding.

Minimum interpass temperature requirements shall be considered equal to the preheat requirements, unless otherwise indicated on the WPS.

Preheat and interpass temperature shall be checked just prior to initiating the arc for each pass.

For combinations of base metals, the minimum preheat shall be based on the highest minimum preheat.

7.7 Heat Input Control for Quenched and Tempered Steels

When quenched and tempered steels are welded, the heat input shall be restricted in conjunction with the maximum preheat and interpass temperatures required. Such considerations shall include the additional heat input produced in simultaneous welding on the two sides of a common member. The preceding limitations shall be in conformance with the producer's recommendations. The heat input limitations of this clause shall not apply to ASTM A913/A913M.

7.8 Stress-Relief Heat Treatment

Where required by the contract documents, welded assemblies shall be stress relieved by heat treating. Final machining after stress relieving shall be considered when needed to maintain dimensional tolerances.

7.8.1 Requirements. The stress-relief treatment shall conform to the following requirements:

(1) The temperature of the furnace shall not exceed 600°F [315°C] at the time the welded assembly is placed in it.

(2) Above 600°F [315°C], the rate of heating in °F [°C] per hour shall not exceed 400 [560] divided by the maximum metal thickness of the thicker part, in inches [centimeters], but in no case more than 400°F [220°C] per hour. During the heating period, variations in temperature throughout the portion of the part being heated shall be no greater than 250°F [140°C] within any 15 ft [5 m] interval of length. The rates of heating and cooling need not be less than 100°F [55°C] per hour. However, in all cases, consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

(3) After a maximum temperature of 1100°F [600°C] is reached on quenched and tempered steels, or a mean temperature range between 1100°F and 1200°F [600°C and 650°C] is reached on other steels, the temperature of the assembly shall be held within the specified limits for a time not less than specified in Table 7.2, based on weld thickness. When the specified stress relief is for dimensional stability, the holding time shall be not less than specified in Table 7.2, based on the thickness of the thicker part. During the holding period there shall be no difference greater than 150°F [65°C] between the highest and lowest temperature throughout the portion of the assembly being heated.

(4) Above 600°F [315°C], cooling shall be done in a closed furnace or cooling chamber at a rate no greater than 500°F [260°C] per hour divided by the maximum metal thickness of the thicker part in inches [mm], but in no case more than 500°F [260°C] per hour. From 600°F [315°C], the assembly may be cooled in still air.

7.8.2 Alternative PWHT. Alternatively, when it is impractical to PWHT to the temperature limitations stated in 7.8.1, welded assemblies may be stress-relieved at lower temperatures for longer periods of time, as given in Table 7.3.

7.8.3 Steels Not Recommended for PWHT. Stress relieving of weldments of ASTM A514/A514M, ASTM A517/ A517M, ASTM A709/A709M Grade HPS 100W [HPS 690W] and ASTM A710/A710M steels is not generally recommended. Stress relieving may be necessary for those applications where weldments are required to retain dimensional stability during machining or where stress corrosion cracking may be involved, neither condition being unique to weldments involving ASTM A514/A514M, ASTM A517/A517M, ASTM A709/A709M Grade HPS 100W [HPS 690W] and ASTM A710/A710M steels. However, the results of notch toughness tests have shown that PWHT may actually impair weld metal and HAZ toughness, and intergranular cracking may sometimes occur in the grain-coarsened region of the weld HAZ.

7.9 Backing

7.9.1 Attachment of Steel Backing. Steel backing shall conform to the following requirements:

7.9.1.1 Fusion. Groove welds made with steel backing shall have the weld thoroughly fused to the backing.

7.9.1.2 Full-Length Backing. Except as permitted below, steel backing shall be made continuous for the full length of the weld. All joints in steel backing shall be CJP groove weld joints meeting all the requirements of Clause 7 of this code.

For statically loaded applications, backing for welds to the ends of closed sections, such as hollow structural section (HSS), are permitted to be made from one or two pieces with unspliced discontinuities where all of the following conditions are met:

(1) The closed section nominal wall thickness does not exceed 5/8 in [16 mm].

(2) The closed section outside perimeter does not exceed 64 in [1625 mm].

(3) The backing is transverse to the longitudinal axis of the closed section.

(4) The interruption in the backing does not exceed 1/4 in [6 mm].

(5) The weld with discontinuous backing is not closer than the HSS diameter or major cross section dimension from other types of connections.

(6) The interruption in the backing is not located in the corners.

For statically loaded box columns, discontinuous backing is permitted in the CJP welded corners, at field splices and at connection details. Discontinuous backing is permitted in other closed sections where approved by the Engineer.

7.9.1.3 Backing Thickness. Steel backing shall be of sufficient thickness to prevent melt-through.

7.9.1.4 Cyclically Loaded Nontubular Connections. Steel backing in cyclically loaded nontubular structures shall comply with the following:

(1) Steel backing of welds that are transverse to the direction of computed stress shall be removed, and the joints shall be ground or finished smooth except for joints designed in accordance with Table 4.5 (5.5).

(2) Steel backing of welds that are parallel to the direction of stress or are not subject to computed stress need not be removed, unless so specified by the Engineer.

(3) Where external welds are used to attach longitudinal steel backing that is to remain in place, the welds shall be fillet welds that are continuous for the entire length on both sides of the backing.

7.9.1.5 Statically Loaded Connections. Steel backing for welds in statically loaded structures (tubular and nontubular) need not be welded full length and need not be removed unless specified by the Engineer.

7.9.2 Backing Welds. Backing welds may be used for backing of groove or fillet welds. When SMAW is used, low-hydrogen electrodes shall be used.

7.9.3 Non-Steel Backing. Roots of groove welds may be backed by copper, flux, glass tape, ceramic, iron powder, or similar materials to prevent melt-through.

7.10 Welding and Cutting Equipment

All welding and thermal cutting equipment shall be so designed and manufactured, and shall be in such condition, as to enable designated personnel to follow the procedures and attain the results described elsewhere in this code.

7.11 Welding Environment

7.11.1 Maximum Wind Velocity. GMAW, GTAW, EGW, or FCAW-G shall not be done in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of 5 miles per hour [8 kilometers per hour].

7.11.2 Minimum Ambient Temperature. Welding shall not be done

(1) when the ambient temperature is lower than 0°F [–20°C], or

(2) when surfaces are wet or exposed to rain, snow, or

(3) high wind velocities, or

(4) when welding personnel are exposed to inclement conditions.

NOTE: Zero°F does not mean the ambient environmental temperature, but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0°F [–20°C], but a heated structure or shelter around the area being welded may maintain the temperature adjacent to the weldment at 0°F [–20°C] or higher.

7.12 Conformance with Design

The sizes and lengths of welds shall be no less than those specified by design requirements and detail drawings, except as allowed in Table 8.1 or Table 10.15. The location of welds shall not be changed without approval of the Engineer.

7.13 Minimum Fillet Weld Sizes

The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 7.7. The minimum fillet weld size shall apply in all cases, unless the design drawings specify welds of a larger size.

7.14 Preparation of Base Metal

7.14.1 General. Base metal shall be sufficiently clean to permit welds to be made that will meet the quality requirements of this code.

7.14.2 Mill-Induced Surface Defects. Welds shall not be placed on surfaces that contain fins, tears, cracks, slag, or other base metal defects as defined in the base metal specifications.

7.14.3 Scale and Rust. Loose scale, thick scale, and thick rust shall be removed from the surfaces to be welded, and from surfaces adjacent to the weld. Welds may be made on surfaces that contain mill scale and rust if the mill scale and rust can withstand vigorous hand wire brushing and if the applicable quality requirements of this code are met with the following exception: for girders in cyclically loaded structures, all mill scale shall be removed from the surfaces on which flange-to-web welds are to be made.

7.14.4 Foreign Materials

7.14.4.1 Surfaces to be welded, and surfaces adjacent to the weld, shall be cleaned to remove excessive quantities of the following:

(1) Water

(2) Oil

(3) Grease

(4) Other hydrocarbon based materials

Welding on surfaces containing residual amounts of foreign materials is permitted provided the quality requirements of this code are met.

7.14.4.2 Welds are permitted to be made on surfaces with surface protective coatings or anti-spatter compounds, except those that are prohibited in 7.14.4.1, provided the quality requirements of this code can be met.

7.14.5 Mill-Induced Discontinuities. The limits of acceptability and the repair of visually observed cut surface discontinuities shall be in conformance with Table 7.4, in which the length of discontinuity is the visible long dimension on the cut surface of material and the depth is the distance that the discontinuity extends into the material from the cut surface. All welded repairs shall be in conformance with this code. Removal of the discontinuity may be done from either surface of the base metal. The aggregate length of welding shall not exceed 20% of the length of the plate surface being repaired except with approval of the Engineer.

7.14.5.1 Acceptance Criteria. For discontinuities greater than 1 in [25 mm] in length and depth discovered on cut surfaces, the following procedures shall be observed.

(1) Where discontinuities such as W, X, or Y in Figure 7.1 are observed prior to completing the joint, the size and shape of the discontinuity shall be determined by UT. The area of the discontinuity shall be determined as the area of total loss of back reflection, when tested in conformance with the procedure of ASTM A435/A435M, *Specification for Straight-Beam Ultrasonic Examination of Steel Plates.*

(2) For acceptance of W, X, or Y discontinuities, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4% of the cut material area (length times width) with the following exception: if the length of the discontinuity, or the aggregate width of discontinuities on any transverse section, as measured perpendicular to the cut material length, exceeds 20% of the cut material width, the 4% cut material area shall be reduced by the percentage amount of the width exceeding 20%. (For example, if a discontinuity is 30% of the cut material width, the area of discontinuity cannot exceed 3.6% of the cut material area.) The discontinuity on the cut surface of the cut material shall be removed to a depth of 1 in [25 mm] beyond its intersection with the surface by chipping, gouging, or grinding, and blocked off by welding with a low-hydrogen process in layers not exceeding 1/8 in [3 mm] in thickness for at least the first four layers.

(3) Repair shall not be required if a discontinuity Z, not exceeding the allowable area in 7.14.5.1(2), is discovered after the joint has been completed and is determined to be 1 in [25 mm] or more away from the face of the weld, as measured on the cut base metal surface. If the discontinuity Z is less than 1 in [25 mm] away from the face of the weld, it shall be removed to a distance of 1 in [25 mm] from the fusion zone of the weld by chipping, gouging, or grinding. It shall then be blocked off by welding with a low-hydrogen process in layers not exceeding 1/8 in [3 mm] in thickness for at least the first four layers.

(4) If the area of the discontinuity W, X, Y, or Z exceeds the allowable in 7.14.5.1(2), the cut material or subcomponent shall be rejected and replaced, or repaired at the discretion of the Engineer.

7.14.5.2 Repair. In the repair and determination of limits of mill induced discontinuities visually observed on cut surfaces, the amount of metal removed shall be the minimum necessary to remove the discontinuity or to determine that the limits of Table 7.4 are not exceeded. However, if weld repair is required, sufficient base metal shall be removed to provide access for welding. Cut surfaces may exist at any angle with respect to the rolling direction. All welded repairs of discontinuities shall be made by:

(1) Suitably preparing the repair area

(2) Welding with an approved low-hydrogen process and observing the applicable provisions of this code

(3) Grinding the completed weld smooth and flush (see 7.23.3.1) with the adjacent surface.

NOTE: The requirements of 7.14.5.2 may not be adequate in cases of tensile load applied through the thickness of the material.

7.14.6 Joint Preparation. Machining, thermal cutting, gouging (including plasma arc cutting and gouging), chipping, or grinding may be used for joint preparation, or the removal of unacceptable work or metal, except that oxygen gouging shall only be permitted for use on as-rolled steels.

7.14.7 Material Trimming. For cyclically loaded structures, material thicker than specified in the following list shall be trimmed if and as required to produce a satisfactory welding edge wherever a weld is to carry calculated stress:

(1) Sheared material thicker than 1/2 in [12 mm]

(2) Rolled edges of plates (other than universal mill plates) thicker than 3/8 in [10 mm]

(3) Toes of angles or rolled shapes (other than wide flange sections) thicker than 5/8 in [16 mm]

(4) Universal mill plates or edges of flanges of wide flange sections thicker than 1 in [25 mm]

(5) The preparation for butt joints shall conform to the requirements of the detail drawings

7.14.8 Thermal Cutting Processes. Electric arc cutting and gouging processes (including plasma arc cutting and gouging) and oxyfuel gas cutting processes are recognized under this code for use in preparing, cutting, or trimming materials. The use of these processes shall conform to the applicable requirements of Clause 7.

7.14.8.1 Other Processes. Other thermal cutting and gouging processes may be used under this code, provided the Contractor demonstrates to the Engineer an ability to successfully use the process.

7.14.8.2 Profile Accuracy. Steel and weld metal may be thermally cut, provided a smooth and regular surface free from cracks and notches is secured, and provided that an accurate profile is secured by the use of a mechanical guide. For cyclically loaded structures, freehand thermal cutting shall be done only where approved by the Engineer.

7.14.8.3 Roughness Requirements. In thermal cutting, the equipment shall be so adjusted and manipulated as to avoid cutting beyond (inside) the prescribed lines. The reference standard for evaluation of cut surfaces shall be the surface roughness gauge included in AWS C4.1–77 set, *Criteria for Describing Oxygen-Cut Surfaces and Oxygen Cutting Surface Roughness Gauge*. The roughness of thermal cut surfaces shall be evaluated by visually comparing the cut surface to the roughness represented on the roughness gauge. Surface roughness shall be no greater than that represented by Sample 3, except that for the ends of members not subject to calculated stress, copes in beams with the flange thickness not exceeding 2 in [50 mm], and for materials over 4 in to 8 in [100 mm to 200 mm] thick, surface roughness shall not exceed that represented by Sample 2.

7.14.8.4 Gouge or Notch Limitations. Roughness exceeding these values and notches or gouges not more than 3/16 in [5 mm] deep on otherwise satisfactory surfaces shall be removed by machining or grinding. Notches or gouges exceeding 3/16 in [5 mm] deep may be repaired by grinding if the nominal cross-sectional area is not reduced by more than 2%. Ground or machined surfaces shall be faired to the original surface with a slope not exceeding one in ten. Cut surfaces and adjacent edges shall be left free of slag. In thermal cut surfaces, occasional notches or gouges may, with approval of the Engineer, be repaired by welding.

7.15 Reentrant Corners

Reentrant corners of cut material shall be formed to provide a gradual transition with a radius of not less than 1 in [25 mm] except corners in connection material and beam copes. Adjacent surfaces shall meet without offset or cutting past the point of tangency. The reentrant corners may be formed by thermal cutting, followed by grinding, if necessary, in conformance with the surface requirements of 7.14.8.3.

7.16 Weld Access Holes, Beam Copes, and Connection Material

Weld access holes, beam copes, and cut surfaces in connection materials shall be free of notches. Beam copes and cut surfaces in connection materials shall be free of sharp reentrant corners. Weld access holes shall provide a smooth transition that does not cut past the points of tangency between adjacent surfaces and shall meet the surface requirements of 7.14.8.3.

7.16.1 Weld Access Hole Dimensions. All weld access holes shall have a length from the edge of the weld joint preparation at the inside surface not less than 1–1/2 times the thickness of the material in which the hole is made. The minimum height of the access hole shall be the thickness of the material with the access hole (t_w) but not less than 3/4 in [20 mm] nor does the height need to exceed 2 in [50 mm]. The access hole shall be detailed to provide room for weld backing as needed and provide adequate access for welding.

7.16.1.1 Weld Access Holes in Rolled Sections. The edge of the web shall be sloped or curved from the surface of the flange to the reentrant surface of the access hole. No corner of the weld access hole shall have a radius less than 3/8 in [10 mm].

7.16.1.2 Weld Access Holes in Built-up Sections. For built-up sections where the weld access hole is made after the section is welded, the edge of the web shall be sloped or curved from the surface of the flange to the re-entrant surface of the access hole. No corner of the weld access hole shall have a radius less than 3/8 in [10 mm]. For built-up sections where the access hole is made before the section is welded, the access hole may terminate perpendicular to the flange, providing the weld is terminated at least a distance equal to the weld size away from the access hole. Fillet welds shall not be returned through the access hole (see Figure 7.2).

7.16.2 Shapes to be Galvanized. Weld access holes and beam copes in shapes that are to be galvanized shall be ground to bright metal. If the curved transition portion of weld access holes and beam copes are formed by predrilled or sawed holes, that portion of the access hole or cope need not be ground.

7.16.3 Copes and Access Holes in Heavy Shapes. For rolled shapes with a flange thickness exceeding 2 in [50 mm] and welded sections with plate thickness exceeding 2 in [50 mm]:

(1) If the curved surface of the access hole is thermally cut, a minimum preheat of 150°F [65°C] extending 3 in [75 mm] from the area where the curve is to be cut shall be applied prior to thermal cutting.

(2) The thermally cut surfaces of beam copes and weld access holes shall be ground to bright metal and visually inspected to ensure the surface is free of cracks prior to welding.

7.17 Tack Welds and Construction Aid Welds

7.17.1 General Requirements

(1) Tack welds and construction aid welds shall be made with a qualified or prequalified WPS and by qualified personnel.

(2) Tack welds that are not incorporated in final welds, and construction aid welds that are not removed, shall meet visual inspection requirements before a member is accepted.

7.17.2 Exclusions. Tack welds and construction aid welds are permitted except that:

(1) In tension zones of cyclically loaded structures, there shall be no tack welds not incorporated into the final weld except as permitted by 4.17.2, nor construction aid welds. Locations more than 1/6 of the depth of the web from tension flanges of beams or girders are considered outside the tension zone.

(2) On members made of quenched and tempered steel with specified yield strength greater than 70 ksi [485 MPa], tack welds outside the final weld and construction aid welds shall require the approval of the Engineer.

7.17.3 Removal. At locations other than 7.17.2, tack welds and construction aid welds not incorporated into final welds shall be removed when required by the Engineer.

7.17.4 Additional Tack Weld Requirements

(1) Tack welds incorporated into final welds shall be made with electrodes meeting the requirements of the final welds. These welds shall be cleaned prior to incorporation.

(2) Multipass tack welds shall have cascaded ends or be otherwise prepared for incorporation into the final weld.

(3) Tack welds incorporated into final welds that are qualified with notch toughness or are required to be made with filler metal classified with notch toughness shall be made with compatible filler metals.

7.17.5 Additional Requirements for Tack Welds Incorporated into SAW Welds. The following shall apply in addition to 7.17.4 requirements.

(1) Preheat is not required for single pass tack welds remelted by continuous SAW welds. This is an exception to the qualification requirements of 7.17.1.

(2) Fillet tack welds shall not exceed 3/8 in [10 mm] in size and shall not produce objectionable changes in the appearance of the weld surface.

(3) Tack welds in the roots of joints requiring specific root penetration shall not result in decreased penetration.

(4) Tack welds not conforming to the requirements of (2) and (3) shall be removed or reduced in size by any suitable means before welding.

(5) Tack welds in the root of a joint with steel backing less than 5/16 in [8 mm] thick shall be removed or made continuous for the full length of the joint using SMAW with low-hydrogen electrodes, GMAW, or FCAW-G.

7.18 Camber in Built-Up Members

7.18.1 Camber. Edges of built-up beam and girder webs shall be cut to the prescribed camber with suitable allowance for shrinkage due to cutting and welding. However, moderate variation from the specified camber tolerance may be corrected by a careful application of heat.

7.18.2 Correction. Corrections of errors in camber of quenched and tempered steel shall require approval by the Engineer.

7.19 Splices

7.19.1 Subassembly Splices. All welded subassembly splices in each component part of a cover-plated beam or built-up member shall be made before the component part is welded to other component parts of the member.

7.19.1.1 Shop Splice Location. Shop splices of webs and flanges in built-up girders may be located in a single transverse plane or multiple transverse planes.

7.19.1.2 Cyclically Loaded Splices. For cyclically loaded members, the fatigue stress provisions of the general specifications shall apply.

7.19.2 Member Splices. Long girders or girder sections may be made by welding subassemblies. Splices between sections of rolled beams or built-up girders shall be made in a single transverse plane, when practicable.

7.20 Control of Distortion and Shrinkage

7.20.1 Procedure and Sequence. In assembling and joining parts of a structure or of built-up members and in welding reinforcing parts to members, the procedure and sequence shall be such as will minimize distortion and shrinkage.

7.20.2 Sequencing. Insofar as practicable, all welds shall be made in a sequence that will balance the applied heat of welding while the welding progresses.

7.20.3 Contractor Responsibility. On members or structures where excessive shrinkage or distortion could be expected, the Contractor shall prepare a written welding sequence for that member or structure which meets the quality requirements specified. The welding sequence and distortion control program shall be submitted to the Engineer, for information and comment, before the start of welding on the member or structure in which shrinkage or distortion is likely to affect the adequacy of the member or structure.

7.20.4 Weld Progression. The direction of the general progression in welding on a member shall be from points where the parts are relatively fixed in position with respect to each other toward points having a greater relative freedom of movement.

7.20.5 Minimized Restraint. In assemblies, joints expected to have significant shrinkage should usually be welded before joints expected to have lesser shrinkage. They should also be welded with as little restraint as possible.

7.20.6 Temperature Limitations. In making welds under conditions of severe external shrinkage restraint, once the welding has started, the joint shall not be allowed to cool below the minimum specified preheat until the joint has been completed or sufficient weld has been deposited to ensure freedom from cracking.

7.21 Tolerance of Joint Dimensions

7.21.1 Fillet Weld Assembly. The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening shall not exceed 3/16 in [5 mm] except in cases involving either shapes or plates 3 in [75 mm] or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in [8 mm] may be used, provided suitable backing is used. Backing may be of flux, glass tape, iron powder, or similar materials, or welds using a low-hydrogen process compatible with the filler metal deposited. If the separation is greater than 1/16 in [2 mm], the legs of the fillet weld shall be increased by the amount of the root opening, or the Contractor shall demonstrate that the required effective throat has been obtained.

7.21.1.1 Faying Surface. The separation between faying surfaces of plug and slot welds, and of butt joints landing on a backing, shall not exceed 1/16 in [2 mm]. Where irregularities in rolled shapes occur after straightening do not allow contact within the above limits, the procedure necessary to bring the material within these limits shall be subject to the approval of the Engineer. The use of filler plates shall be prohibited except as specified on the drawings or as specially approved by the Engineer and made in conformance with 4.11.

7.21.2 PJP Groove Weld Assembly. The parts to be joined by PJP groove welds parallel to the length of the member shall be brought into as close contact as practicable. The root opening between parts shall not exceed 3/16 in [5 mm] except in cases involving rolled shapes or plates 3 in [75 mm] or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in [8 mm] may be used, provided suitable backing is used and the final weld meets the requirements for weld size. Tolerances for bearing joints shall be in conformance with the applicable contract specifications.

7.21.3 Butt Joint Alignment. Parts to be joined at butt joints shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, the offset from the theoretical alignment shall not exceed 10% of the thickness of the thinner part joined, or 1/8 in [3 mm], whichever is smaller. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 1/2 in [12 mm] in 12 in [300 mm]. Measurement of offset shall be based upon the centerline of parts unless otherwise shown on the drawings.

7.21.4 Groove Dimensions

7.21.4.1 Nontubular Cross-Sectional Variations. With the exclusion of ESW and EGW, and with the exception of 7.21.4.2 for root openings in excess of those allowed in Figure 7.3, the dimensions of the cross section of the groove welded joints which vary from those shown on the detail drawings by more than these tolerances shall be referred to the Engineer for approval or correction.

7.21.4.2 Correction. Root openings greater than those allowed in 7.21.4.1, but not greater than twice the thickness of the thinner part or 3/4 in [20 mm], whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding.

7.21.4.3 Engineer's Approval. Root openings greater than allowed by 7.21.4.2 may be corrected by welding only with the approval of the Engineer.

7.21.5 Gouged Grooves. Grooves produced by gouging shall be in substantial conformance with groove profile dimensions as specified in Figure 5.1 and Figure 5.2 and provisions of 5.4.1 and 5.4.2. Suitable access to the root shall be maintained.

7.21.6 Alignment Methods. Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practicable. Suitable allowances shall be made for warpage and shrinkage.

7.22 Dimensional Tolerance of Welded Structural Members

The dimensions of welded structural members shall conform to the tolerances of (1) the general specifications governing the work, and (2) the special dimensional tolerances in 7.22.1 to 7.22.12. (Note that a tubular column is interpreted as a compression tubular member.)

7.22.1 Straightness of Columns and Trusses. For welded columns and primary truss members, regardless of cross section, the maximum variation in straightness shall be

Lengths of less than 30 ft [9 m]:

$$1/8 \text{ in} \times \frac{[\text{No. of ft of total length}]}{10}$$

1 mm × [No. of meters of total length]

Lengths of 30 ft [9 m] to 45 ft [15 m] = 3/8 in [10 mm]

Lengths over 45 ft [15 m]:

$$3/8 \text{ in} + 1/8 \text{ in} \times \frac{[\text{No. of ft of total length} - 45]}{10}$$

$$10 \text{ mm} + 3 \text{ mm} \times \frac{[\text{No. of meters of total length} - 15]}{3}$$

7.22.2 Beam and Girder Straightness (No Camber Specified). For welded beams or girders, regardless of cross section, where there is no specified camber, the maximum variation in straightness shall be

$$1/8 \text{ in} \times \frac{\text{No. of ft of total length}}{10}$$

1 mm × No. of meters of total length

7.22.3 Beam and Girder Camber (Typical Girder). For welded beams or girders, other than those whose top flange is embedded in concrete without a designed concrete haunch, regardless of cross section, the maximum variation from required camber at shop assembly (for drilling holes for field splices or repairing field welded splices) shall be

at midspan –0, +1–1/2 in [40 mm] for spans ≥ 100 ft [30 m]
–0, + 3/4 in [20 mm] for spans < 100 ft [30 m]

at supports, 0 for end supports
± 1/8 in [3 mm] for interior supports

$$\text{at intermediate points, } -0, + \frac{4(a)b(1 - a/S)}{S}$$

Where

a = distance in feet (meters) from inspection point to nearest support
S = span length in feet (meters)
b = 1–1/2 in [40 mm] for spans ≥ 100 ft [30 m]
b = 3/4 in [20 mm] for spans < 100 ft [30 m]

See Table 7.5 for tabulated values.

7.22.4 Beam and Girder Camber (without Designed Concrete Haunch). For members whose top flange is embedded in concrete without a designed concrete haunch, the maximum variation from required camber at shop assembly (for drilling holes for field splices or preparing field welded splices) shall be

at midspan, ±3/4 in [20 mm] for spans ≥ 100 ft [30 m]
± 3/8 in [10 mm] for spans < 100 ft [30 m]

at supports, 0 for end supports
± 1/8 in [3 mm] for interior supports

$$\text{at intermediate points, } \pm \frac{4(a)b(1 - a/S)}{S}$$

where a and S are as defined above

b = 3/4 in [20 mm] for spans ≥ 100 ft [30 m]
b = 3/8 in [10 mm] for spans < 100 ft [30 m]

See Table 7.6 for tabulated values.

Regardless of how the camber is shown on the detail drawings, the sign convention for the allowable variation is plus (+) above, and minus (–) below, the detailed camber shape. These provisions also apply to an individual member when no field splices or shop assembly is required. Camber measurements shall be made in the no load condition.

7.22.5 Beam and Girder Sweep. The maximum variation from straightness or specified sweep at the midpoint shall be

$$\pm 1/8 \text{ in} \times \frac{\text{No. of ft of total length}}{10}$$

$$\pm 1 \text{ mm} \times [\text{No. of meters of total length}]$$

provided the member has sufficient lateral flexibility to allow the attachment of diaphragms, cross-frames, lateral bracing, etc., without damaging the structural member or its attachments.

7.22.6 Variation in Web Flatness

7.22.6.1 Measurements. Variations from flatness of girder webs shall be determined by measuring the offset from the actual web centerline to a straight edge whose length is greater than the least panel dimension and placed on a plane parallel to the nominal web plane. Measurements shall be taken prior to erection (see Commentary).

7.22.6.2 Statically Loaded Nontubular Structures. Variations from flatness of webs having a depth, D, and a thickness, t, in panels bounded by stiffeners or flanges, or both, whose least panel dimension is d shall not exceed the following:

Intermediate stiffeners on both sides of web
where D/t < 150, maximum variation = d/100
where D/t ≥ 150, maximum variation = d/80

Intermediate stiffeners on one side only of web
where D/t < 100, maximum variation = d/100
where D/t ≥ 100, maximum variation = d/67

No intermediate stiffeners
where D/t ≥ 100, maximum variation = D/150
(See Annex E for tabulation.)

7.22.6.3 Cyclically Loaded Nontubular Structures. Variation from flatness of webs having a depth, D, and a thickness, t, in panels bounded by stiffeners or flanges, or both, whose least panel dimension is d shall not exceed the following:

Intermediate stiffeners on both sides of web

Interior girders—
where D/t < 150—maximum variation = d/115
where D/t ≥ 150—maximum variation = d/92

Fascia girders—
where D/t < 150—maximum variation = d/130
where D/t ≥ 150—maximum variation = d/105

Intermediate stiffeners on one side only of web

Interior girders—
where D/t < 100—maximum variation = d/100
where D/t ≥ 100—maximum variation = d/67

Fascia girders—
where D/t < 100—maximum variation = d/120
where D/t ≥ 100—maximum variation = d/80

No intermediate stiffeners—maximum variation = D/150

(See Annex F for tabulation.)

7.22.6.4 Excessive Distortion. Web distortions of twice the allowable tolerances of 7.22.6.2 or 7.22.6.3 shall be satisfactory when occurring at the end of a girder which has been drilled, or sub-punched and reamed; either during assembly or to a template for a field bolted splice; provided, when the splice plates are bolted, the web assumes the proper dimensional tolerances.

7.22.6.5 Architectural Consideration. If architectural considerations require tolerances more restrictive than described in 7.22.6.2 or 7.22.6.3, specific reference shall be included in the bid documents.

7.22.7 Variation Between Web and Flange Centerlines. For built-up H or I members, the maximum variation between the centerline of the web and the centerline of the flange at contact surface shall not exceed 1/4 in [6 mm].

7.22.8 Flange Warpage and Tilt. For welded beams or girders, the combined warpage and tilt of flange shall be determined by measuring the offset at the toe of the flange from a line normal to the plane of the web through the intersection of the centerline of the web with the outside surface of the flange plate. This offset shall not exceed 1% of the total flange width or 1/4 in [6 mm], whichever is greater, except that welded butt joints of abutting parts shall fulfill the requirements of 7.21.3.

7.22.9 Depth Variation. For welded beams and girders, the maximum allowable variation from specified depth measured at the web centerline shall be

For depths up to 36 in [1 m] incl.	± 1/8 in [3 mm]
For depths over 36 in [1 m] to 72 in [2 m] incl.	± 3/16 in [5 mm]
For depths over 72 in [2 m]	+ 5/16 in [8 mm] – 3/16 in [5 mm]

7.22.10 Bearing at Points of Loading. The bearing ends of bearing stiffeners shall be square with the web and shall have at least 75% of the stiffener bearing cross-sectional area in contact with the inner surface of the flanges. The outer surface of the flanges when bearing against a steel base or seat shall fit within 0.010 in [0.25 mm] for 75% of the projected area of web and stiffeners and not more than 1/32 in [1 mm] for the remaining 25% of the projected area. Girders without stiffeners shall bear on the projected area of the web on the outer flange surface within 0.010 in [0.25 mm] and the included angle between web and flange shall not exceed 90° in the bearing length (see Commentary).

7.22.11 Tolerance on Stiffeners

7.22.11.1 Fit of Intermediate Stiffeners. Where tight fit of intermediate stiffeners is specified, it shall be defined as allowing a gap of up to 1/16 in [2 mm] between stiffener and flange.

7.22.11.2 Straightness of Intermediate Stiffeners. The out-of-straightness variation of intermediate stiffeners shall not exceed 1/2 in [12 mm] for girders up to 6 ft [1.8 m] deep, and 3/4 in [20 mm] for girders over 6 ft [1.8 m] deep, with due regard for members which frame into them.

7.22.11.3 Straightness and Location of Bearing Stiffeners. The out-of-straightness variation of bearing stiffeners shall not exceed 1/4 in [6 mm] up to 6 ft [1.8 m] deep or 1/2 in [12 mm] over 6 ft [1.8 m] deep. The actual centerline of the stiffener shall lie within the thickness of the stiffener as measured from the theoretical centerline location.

7.22.12 Other Dimensional Tolerances. Twist of box members and other dimensional tolerances of members not covered by 7.22 shall be individually determined and mutually agreed upon by the Contractor and the Owner with proper regard for erection requirements.

7.23 Weld Profiles

All welds shall meet the visual acceptance criteria of Tables 8.1 or 10.15, and shall be free from cracks, overlaps, and the unacceptable profile discontinuities exhibited in Figure 7.4, Table 7.8, and Table 7.9, except as otherwise allowed in 7.23.1, 7.23.2, and 7.23.3.

7.23.1 Fillet Welds. The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figure 7.4 and as allowed by Tables 7.8, 7.9, 8.1, and 10.15.

7.23.2 Exception for Intermittent Fillet Welds. Except for undercut, as allowed by the code, the profile requirements of Figure 7.4 shall not apply to the ends of intermittent fillet welds outside their effective length.

7.23.3 Groove Welds. Groove weld reinforcement shall comply with Tables 7.8 and 7.9 and with the provisions below. Welds shall have a gradual transition to the plane of the base metal surfaces.

7.23.3.1 Flush Surfaces. Welds required to be flush shall be finished so as to not reduce the thicknesses of the thinner base metal or weld metal by more than 1/32 in [1 mm]. Remaining reinforcement shall not exceed 1/32 in [1 mm] in height and shall blend smoothly into the base metal surfaces with transition areas free from undercut. However, all reinforcement shall be removed where the weld forms part of a faying or contact surface.

7.23.3.2 Finish Methods and Values. Where surface finishing is required, surface roughness values (see ASME B46.1) shall not exceed 250 microinches [6.3 micrometers]. Chipping and gouging may be used provided these are followed by grinding or machining. For cyclically loaded structures, finishing shall be parallel to the direction of primary stress, except final roughness of 125 microinches [3.2 micrometers] or less may be finished in any direction.

7.23.4 Shelf Bars. Shelf bars shall conform to the requirements of 7.9.1.1 through 7.9.1.5. Shelf bars may be left in place only for statically loaded members.

7.24 Technique for Plug and Slot Welds

7.24.1 Plug Welds. The technique used to make plug welds when using SMAW, GMAW (except GMAW-S), and FCAW processes shall be as follows:

7.24.1.1 Flat Position. For welds to be made in the flat position, each pass shall be deposited around the root of the joint and then deposited along a spiral path to the center of the hole, fusing and depositing a layer of weld metal in the root and bottom of the joint. The arc shall then be moved to the periphery of the hole and the procedure repeated, fusing and depositing successive layers to fill the hole to the required depth. The slag covering the weld metal should be kept molten until the weld is finished. If the arc is broken or the slag is allowed to cool, the slag must be completely removed before restarting the weld.

7.24.1.2 Vertical Position. For welds to be made in the vertical position, the arc is started at the root of the joint at the lower side of the hole and is carried upward, fusing into the face of the inner plate and to the side of the hole. The arc is stopped at the top of the hole, the slag is cleaned off, and the process is repeated on the opposite side of the hole. After cleaning slag from the weld, other layers should be similarly deposited to fill the hole to the required depth.

7.24.1.3 Overhead Position. For welds to be made in the overhead position, the procedure is the same as for the flat position, except that the slag should be allowed to cool and should be completely removed after depositing each successive bead until the hole is filled to the required depth.

7.24.2 Slot Welds. Slot welds shall be made using techniques similar to those specified in 7.24.1 for plug welds, except that if the length of the slot exceeds three times the width, or if the slot extends to the edge of the part, the technique requirements of 7.24.1.3 shall apply.

7.25 Repairs

The removal of weld metal or portions of the base metal may be done by machining, grinding, chipping, or gouging. It shall be done in such a manner that the adjacent weld metal or base metal is not nicked or gouged. Oxygen gouging shall only be permitted for use on as-rolled steels. Unacceptable portions of the weld shall be removed without substantial removal of the base metal. The surfaces shall be cleaned thoroughly before welding. Weld metal shall be deposited to compensate for any deficiency in size.

7.25.1 Contractor Options. The Contractor has the option of either repairing an unacceptable weld or removing and replacing the entire weld, except as modified by 7.25.3. The repaired or replaced weld shall be retested by the method originally used, and the same technique and quality acceptance criteria shall be applied. If the Contractor elects to repair the weld, it shall be corrected as follows:

7.25.1.1 Overlap, Excessive Convexity, or Excessive Reinforcement. Excessive weld metal shall be removed.

7.25.1.2 Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting. The surfaces shall be prepared (see 7.29) and additional weld metal deposited.

7.25.1.3 Incomplete Fusion, Excessive Weld Porosity, or Slag Inclusions. Unacceptable portions shall be removed (see 7.25) and rewelded.

7.25.1.4 Cracks in Weld or Base Metal. The extent of the crack shall be ascertained by use of acid etching, MT, PT, or other equally positive means; the crack and sound metal 2 in [50 mm] beyond each end of the crack shall be removed, and rewelded.

7.25.2 Localized Heat Repair Temperature Limitations. Members distorted by welding shall be straightened by mechanical means or by application of a limited amount of localized heat. The temperature of heated areas as measured by approved methods shall not exceed 1100°F [600°C] for quenched and tempered steel nor 1200°F [650°C] for other steels. The part to be heated for straightening shall be substantially free of stress and from external forces, except those stresses resulting from a mechanical straightening method used in conjunction with the application of heat.

7.25.3 Engineer's Approval. Prior approval of the Engineer shall be obtained for repairs to base metal (other than those required by 7.14), repair of major or delayed cracks, repairs to ESW and EGW with internal defects, or for a revised design to compensate for deficiencies. The Engineer shall be notified before welded members are cut apart.

7.25.4 Inaccessibility of Unacceptable Welds. If, after an unacceptable weld has been made, work is performed which has rendered that weld inaccessible or has created new conditions that make correction of the unacceptable weld dangerous or ineffectual, then the original conditions shall be restored by removing welds or members, or both, before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed conforming to an approved revised design.

7.25.5 Welded Restoration of Base Metal with Mislocated Holes. Mislocated holes may be left open or filled with bolts except when welding is necessary to fulfill contract requirements or when required by the Engineer. Base metal with mislocated holes may be restored by welding provided the Contractor prepares and follows a qualified or prequalified WPS and meets the requirements of (1) through (4) below. The groove geometry shall be considered prequalified.:

(1) Base metal not in tension zones of cyclically loaded members shall be restored by welding, provided the repair weld soundness is verified by the same NDT process specified in the contract documents for groove welds. If the contract documents did not originally specify NDT, the restored base metal shall be evaluated using a method and acceptance criteria specified by the Engineer.

(2) Base metal in tension zones of cyclically loaded members may be restored by welding provided:

(a) The Engineer approves repair by welding and the WPS for the repair.

(b) The WPS is followed in the work and the soundness of the restored base metal is verified by the NDT method(s) specified in the contract documents for examination of tension groove welds or as approved by the Engineer.

(3) In addition to the requirements of (1) and (2), when holes in quenched and tempered base metals are restored by welding:

(a) Appropriate filler metal, heat input, and PWHT (when PWHT is required) shall be used.

(b) Sample welds shall be made using the repair WPS.

(c) RT of the sample welds shall verify that weld soundness conforms to the requirements of 8.12.2.1.

(d) One reduced section tension test (weld metal); two side bend tests (weld metal); and three CVN tests of the HAZ (coarse grained area) removed from sample welds shall be used to demonstrate that the mechanical properties of the repaired area conform to the specified requirements of the base metal (see Clause 6, Part D for CVN testing requirements).

(4) Weld surfaces shall be finished as specified in 7.23.3.1.

7.26 Peening

Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking or distortion, or both. No peening shall be done on the root or surface layer of the weld or the base metal at the edges of the weld except as provided in 10.2.3.6(3) for tubulars. Care should be taken to prevent overlapping or cracking of the weld or base metal.

7.26.1 Tools. The use of manual slag hammers, chisels, and lightweight vibrating tools for the removal of slag and spatter is allowed and shall not be considered peening.

7.27 Caulking

Caulking shall be defined as plastic deformation of weld and base metal surfaces by mechanical means to seal or obscure discontinuities. Caulking shall be prohibited for base metals with minimum specified yield strength greater than 50 ksi [345 MPa].

For base metals with minimum specified yield strength of 50 ksi [345 MPa] or less, caulking may be used, provided:

(1) all inspections have been completed and accepted

(2) caulking is necessary to prevent coating failures

(3) the technique and limitations on caulking are approved by the Engineer

7.28 Arc Strikes

Arc strikes outside the area of permanent welds should be avoided on any base metal. Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and checked to ensure soundness.

7.29 Weld Cleaning

7.29.1 In-Process Cleaning. Before welding over previously deposited weld metal, all slag shall be removed and the weld and adjacent base metal shall be cleaned by brushing or other suitable means. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption. It shall not, however, restrict the welding of plug and slot welds in conformance with 7.24.

7.29.2 Cleaning of Completed Welds. Slag shall be removed from all completed welds, and the weld and adjacent base metal shall be cleaned by brushing or other suitable means. Tightly adherent spatter remaining after the cleaning operation is acceptable, unless its removal is required for the purpose of NDT. Welded joints shall not be painted until after welding has been completed and the weld accepted.

7.30 Weld Tabs (See 7.2.2)

7.30.1 Use of Weld Tabs. Welds shall be terminated at the end of a joint in a manner that will ensure sound welds. Whenever necessary, this shall be done by use of weld tabs aligned in such a manner to provide an extension of the joint preparation.

7.30.2 Removal of Weld Tabs for Statically Loaded Nontubular Structures. For statically loaded nontubular structures, weld tabs need not be removed unless required by the Engineer.

7.30.3 Removal of Weld Tabs for Cyclically Loaded Nontubular Structures. For cyclically loaded nontubular structures, weld tabs shall be removed upon completion and cooling of the weld, and the ends of the weld shall be made smooth and flush with the edges of abutting parts.

7.30.4 Ends of Welded Butt Joints. Ends of welded butt joints required to be flush shall be finished so as not to reduce the width beyond the detailed width or the actual width furnished, whichever is greater, by more than 1/8 in [3 mm] or so as not to leave reinforcement at each end that exceeds 1/8 in [3 mm]. Ends of welded butt joints shall be faired at a slope not to exceed 1 in 10.

Table 7.1
Allowable Atmospheric Exposure of Low-Hydrogen Electrodes
(See 7.3.2.2 and 7.3.2.3)

Electrode	Column A (hours)	Column B (hours)
A5.1		
E70XX	4 max.	
E70XXR	9 max.	Over 4 to 10 max.
E70XXHZR	9 max.	
E7018M	9 max.	
A5.5		
E70XX-X	4 max.	Over 4 to 10 max.
E80XX-X	2 max.	Over 2 to 10 max.
E90XX-X	1 max.	Over 1 to 5 max.
E100XX-X	1/2 max.	Over 1/2 to 4 max.
E110XX-X	1/2 max.	Over 1/2 to 4 max.

Notes:
1. Column A: Electrodes exposed to atmosphere for longer periods than shown shall be baked before use.
2. Column B: Electrodes exposed to atmosphere for longer periods than those established by testing shall be baked before use.
3. Electrodes shall be issued and held in quivers, or other small open containers. Heated containers are not mandatory.
4. The optional supplemental designator, R, designates a low-hydrogen electrode which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level allowed in AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*.

Table 7.2
Minimum Holding Time (See 7.8.1)

1/4 in [6 mm] or Less	Over 1/4 in [6 mm] Through 2 in [50 mm]	Over 2 in [50 mm]
15 min.	15 min. for each 1/4 in [6 mm] or fraction thereof	2 hrs plus 15 min. for each additional in [25 mm] or fraction thereof over 2 in [50 mm]

Table 7.3
Alternate Stress-Relief Heat Treatment (See 7.8.2)

Decrease in Temperature below Minimum Specified Temperature		Minimum Holding Time at Decreased Temperature, Hours per Inch [25 mm] of Thickness
Δ°F	Δ°C	
50	30	2
100	60	4
150	90	10
200	120	20

Table 7.4
Limits on Acceptability and Repair of Mill Induced Laminar Discontinuities in Cut Surfaces (See 7.14.5)

Description of Discontinuity	Repair Required
Any discontinuity 1 in [25 mm] in length or less	None, need not be explored
Any discontinuity over 1 in [25 mm] in length and 1/8 in [3 mm] maximum depth	None, but the depth should be explored[a]
Any discontinuity over 1 in [25 mm] in length with depth over 1/8 in [3 mm] but not greater than 1/4 in [6 mm]	Remove, need not weld
Any discontinuity over 1 in [25 mm] in length with depth over 1/4 in [6 mm] but not greater than 1 in [25 mm]	Completely remove and weld
Any discontinuity over 1 in [25 mm] in length with depth greater than 1 in [25 mm]	See 7.14.5.1

[a] A spot check of 10% of the discontinuities on the cut surface in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 in [3 mm], then all of the discontinuities over 1 in [25 mm] in length remaining on that cut surface shall be explored by grinding to determine depth. If none of the discontinuities explored in the 10% spot check have a depth exceeding 1/8 in [3 mm], then the remainder of the discontinuities on that cut surface need not be explored.

Table 7.5
Camber Tolerance for Typical Girder (See 7.22.3)

	Camber Tolerance (in inches)				
Span \ a/S	0.1	0.2	0.3	0.4	0.5
≥ 100 ft	9/16	1	1–1/4	1–7/16	1–1/2
< 100 ft	1/4	1/2	5/8	3/4	3/4
	Camber Tolerance (in millimeters)				
Span \ a/S	0.1	0.2	0.3	0.4	0.5
≥ 30 m	14	25	34	38	40
< 30 m	7	13	17	19	20

Table 7.6
Camber Tolerance for Girders without a Designed Concrete Haunch (See 7.22.4)

Camber Tolerance (in inches)					
a/S Span	0.1	0.2	0.3	0.4	0.5
≥ 100 ft	1/4	1/2	5/8	3/4	3/4
< 100 ft	1/8	1/4	5/16	3/8	3/8
Camber Tolerance (in millimeters)					
a/S Span	0.1	0.2	0.3	0.4	0.5
≥ 30 m	7	13	17	19	20
< 30 m	4	6	8	10	10

Table 7.7
Minimum Fillet Weld Sizes (See 7.13)

Base Metal Thichness (T)[a]		Minimum Size of Fillet Weld[b]	
in	mm	in	mm
T ≤ 1/4	T ≤ 6	1/8[c]	3[c]
1/4 < T ≤ 1/2	6 < T ≤ 12	3/16	5
1/2 < T ≤ 3/4	12 < T ≤ 20	1/4	6
3/4 < T	20 < T	5/16	8

[a] For nonlow-hydrogen processes without preheat calculated in conformance with 6.8.4, T equals thickness of the thicker part joined; single-pass welds shall be used.
For nonlow-hydrogen processes using procedures established to prevent cracking in conformance with 6.8.4 and for low-hydrogen processes, T equals thickness of the thinner part joined; single-pass requirement shall not apply.
[b] Except that the weld size need not exceed the thickness of the thinner part joined.
[c] Minimum size for cyclically loaded structures shall be 3/16 in [5 mm].

Table 7.8
Weld Profiles[a] (see 7.23)

Weld Type	Joint Type					
	Butt	Corner-Inside	Corner-Outside	T-Joint	Lap	Butt with Shelf Bar
Groove (CJP or PJP)	Figure 7.4A	Figure 7.4B[b]	Figure 7.4C	Figure 7.4D[b]	N/A	Figure 7.4G
	Schedule A	Schedule B	Schedule A	Schedule B	N/A	See Footnote c
Fillet	N/A	Figure 7.4E	Figure 7.4F	Figure 7.4E	Figure 7.4E	N/A
	N/A	Schedule C	Schedule C or D[d]	Schedule C	Schedule C	N/A

[a] Schedules A through D are given in Table 7.9.
[b] For reinforcing fillet welds required by design, the profile restrictions apply to each groove and fillet, separately.
[c] Welds made using shelf bars and welds made in the horizontal position between vertical bars of unequal thickness are exempt from R and C limitations. See Figures 7.4G and 7.4H for typical details.
[d] See Figure 7.4F for a description of where Schedule C and D apply.

Table 7.9
Weld Profile Schedules (see 7.23)

Schedule A	(t = thickness of thicker plate joined for CJP; t = weld size for PJP)			
	t	R min.	R max.	
	≤ 1 in [25 mm]	0	1/8 in [3 mm]	
	> 1 in [25 mm], ≤ 2 in [50 mm]	0	3/16 in [5 mm]	
	> 2 in [50 mm]	0	1/4 in [6 mm][a]	
Schedule B	(t = thickness of thicker plate joined for CJP; t = weld size for PJP; C = allowable convexity or concavity)			
	t	R min.	R. max.	C max[b]
	< 1 in [25 mm	0	unlimited	1/8 in [3 mm]
	≥ 1 in [25 mm]	0	unlimited	3/16 in [5 mm]
Schedule C	(W = width of weld face or individual surface bead; C = allowable convexity)			
	W		C max[b]	
	≤ 5/16 in [8 mm]		1/16 in [2 mm]	
	>5/16 in [8 mm], <1 in [25 mm]		1/8 in [3 mm]	
	≥ 1 in [25 mm]		3/16 in [5 mm]	
Schedule D	(t = thickness of thinner of the exposed edge dimensions; C = allowable convexity; See Figure 7.4F)			
	t		C max[b]	
	any value of t		t/2	

[a] For cyclically loaded structures, R max. for materials > 2 in [50 mm] thick is 3/16 in [5 mm].
[b] There is no restriction on concavity as long as minimum weld size (considering both leg and throat) is achieved.

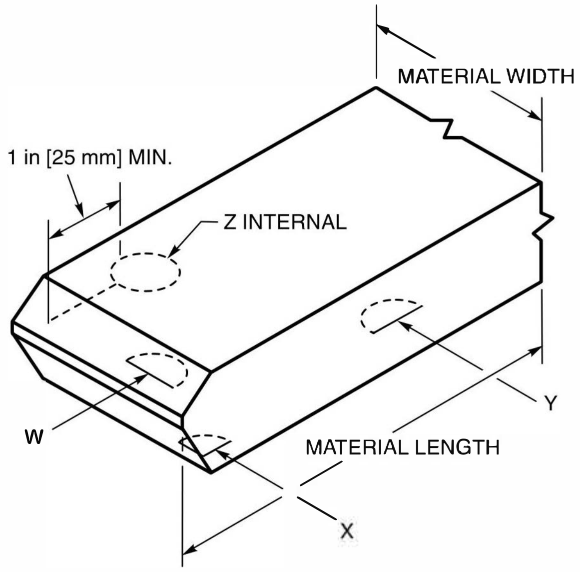
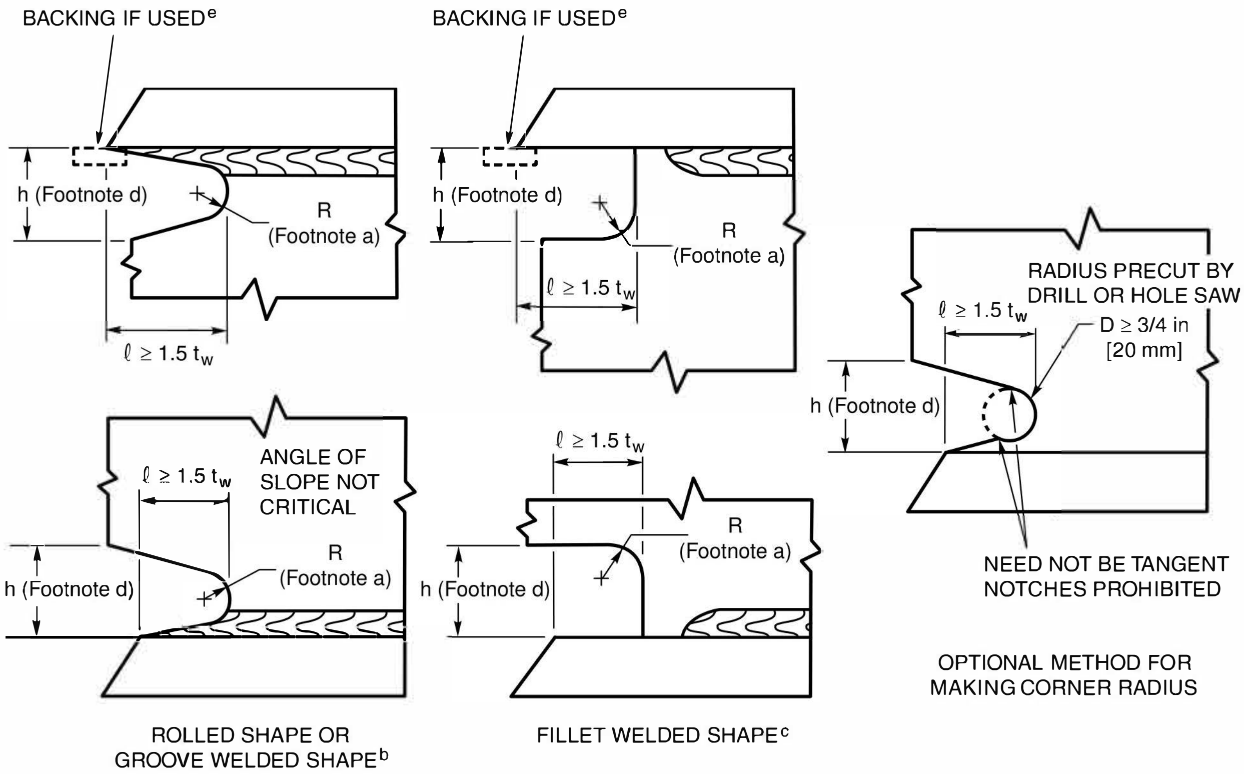
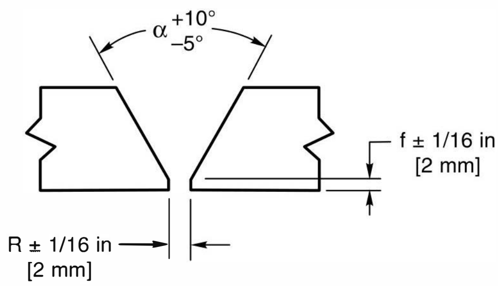


Figure 7.1—Edge Discontinuities in Cut Material (see 7.14.5.1)

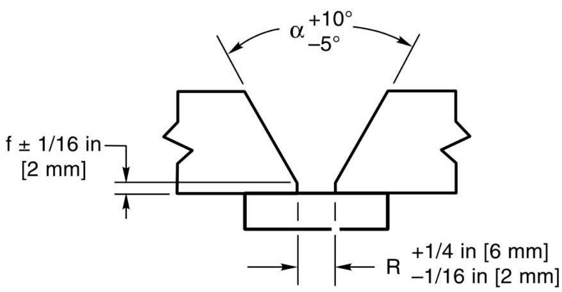


[a] Radius shall provide smooth notch-free transition; R≥ 3/8 in [10 mm] (Typical 1/2 in [12 mm]).
[b] Access hole made after welding web to flange.
[c] Access hole made before welding web to flange. The web to flange weld shall not be returned through hole.
[d] h_{min} = 3/4 in [20 mm] or t_w (web thickness), whichever is greater, h_{min} need not exceed 2 in [50 mm].
[e] These are typical details for joints welded from one side against steel backing. Alternative joint designs should be considered.

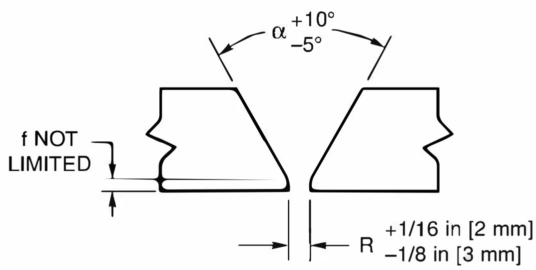
Figure 7.2—Weld Access Hole Geometry (see 7.16.1.2)



(A) GROOVE WELD WITHOUT BACKING— ROOT NOT BACKGOUGED



(B) GROOVE WELD WITH BACKING— ROOT NOT BACKGOUGED



(C) GROOVE WELD WITHOUT BACKING— ROOT BACKGOUGED

	Root Not Backgouged		Root Backgouged	
	in	mm	in	mm
(1) Root face of joint	±1/16	2	Not Limited	
(2) Root opening of joints without backing	±1/16	2	+1/16 −1/8	2 3
Root opening of joint with backing	+1/4 −1/16	6 2	Not applicable	
(3) Groove angle of joint	+10° −5°		+10° −5°	

Note: See 10.23.2.1 for tolerences for CJP tubular groove welds made from one side without backing.

Figure 7.3—Workmanship Tolerances in Assembly of Groove Welded Joints (see 7.21.4.1)

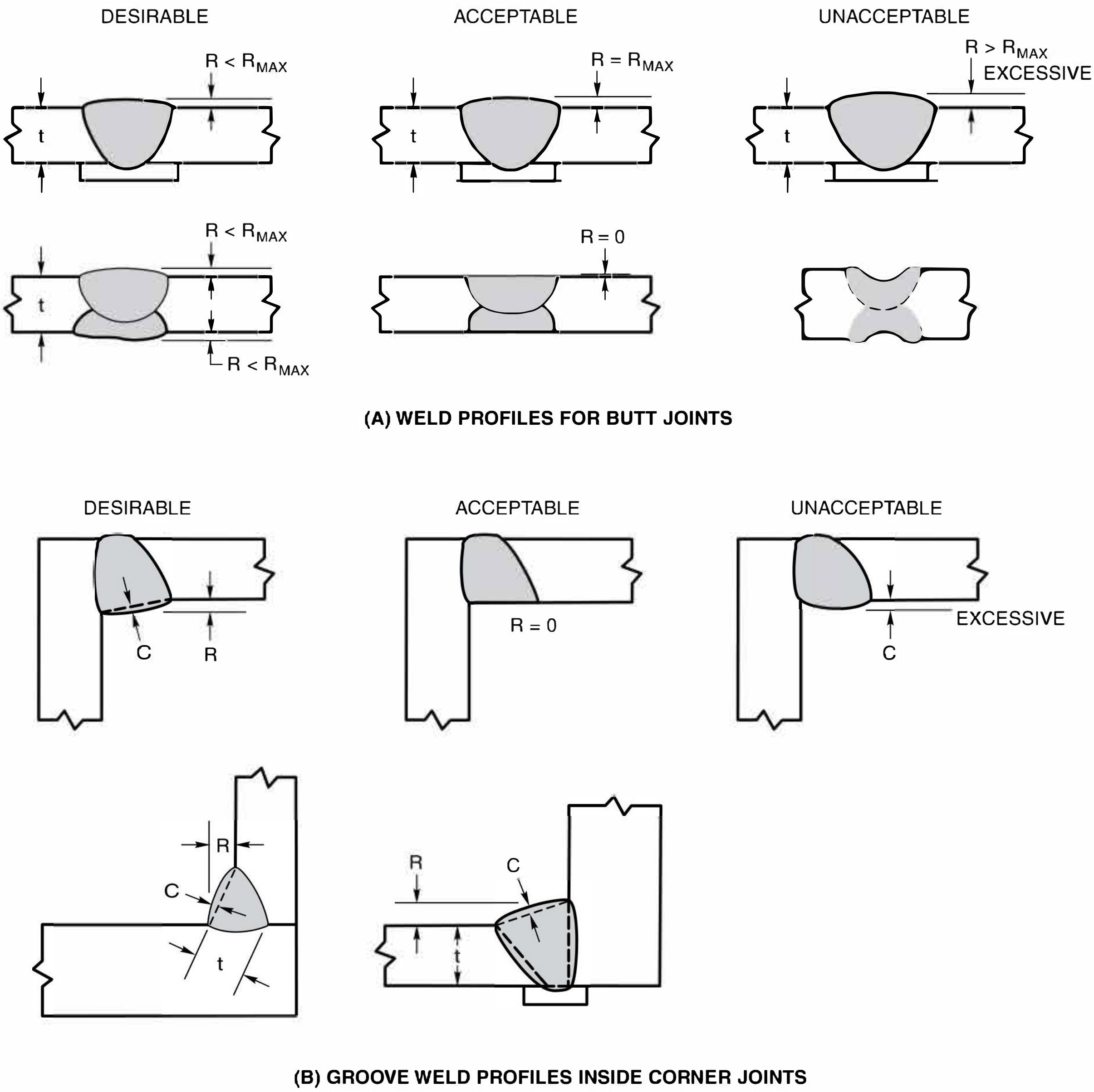
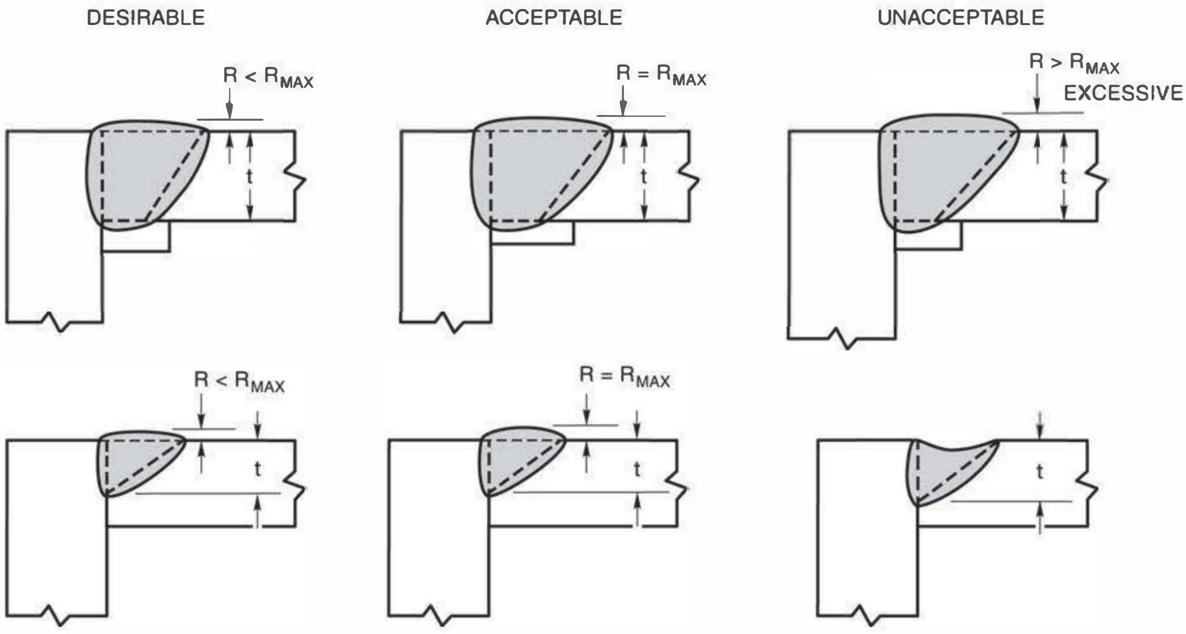
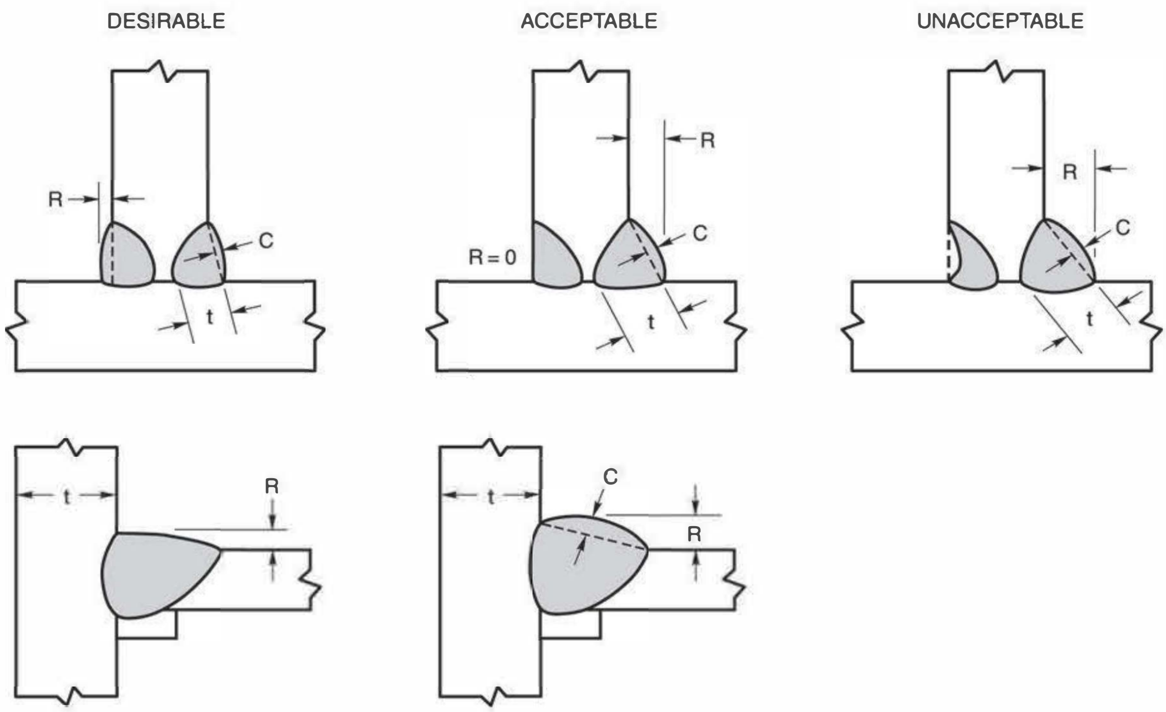


Figure 7.4—Requirements for Weld Profiles (see Tables 7.8 and 7.9)



(C) GROOVE WELD PROFILES OUTSIDE CORNER JOINTS



(D) GROOVE WELD PROFILES IN T-JOINTS

Figure 7.4 (Continued)—Requirements for Weld Profiles (see Tables 7.8 and 7.9)

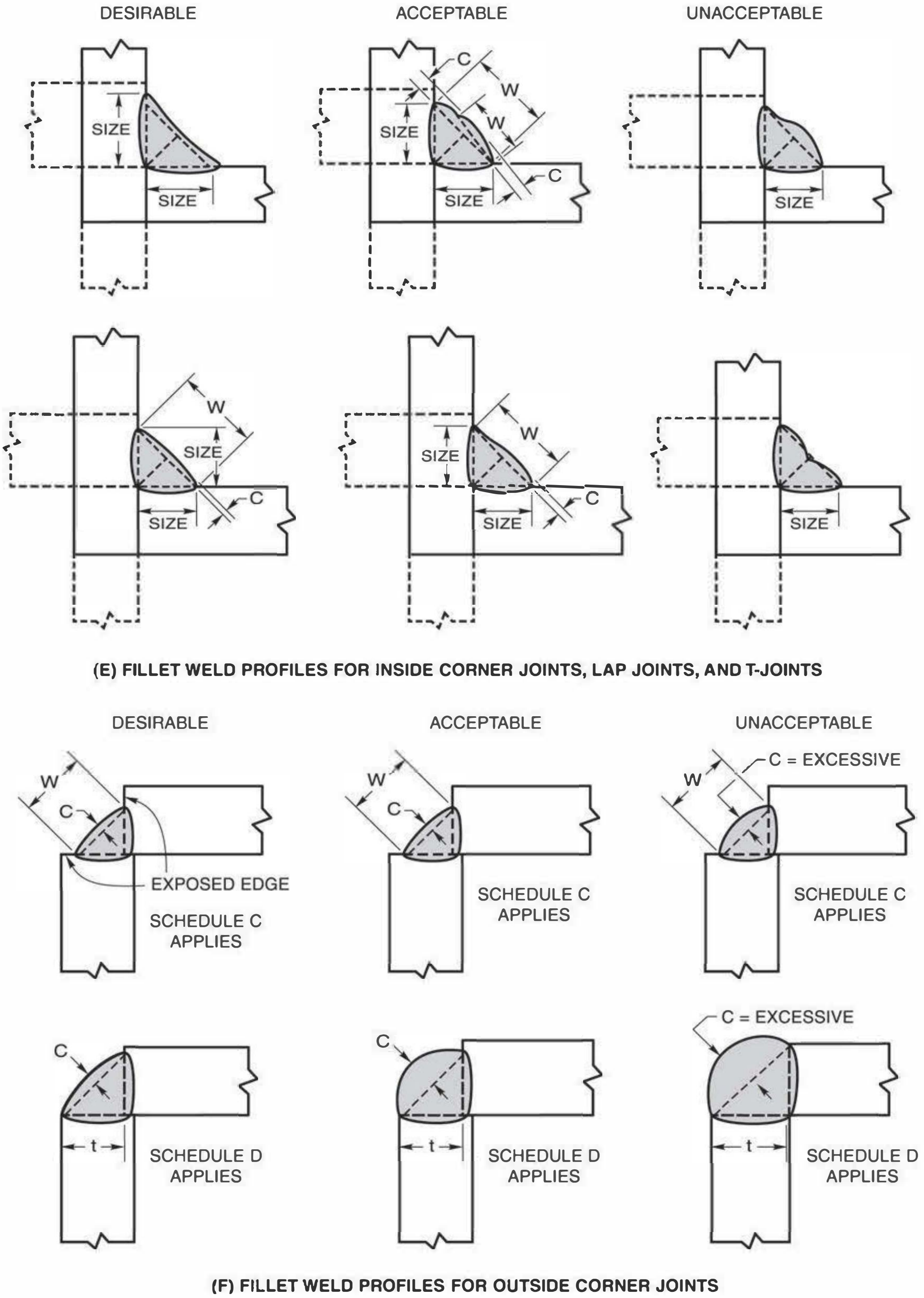
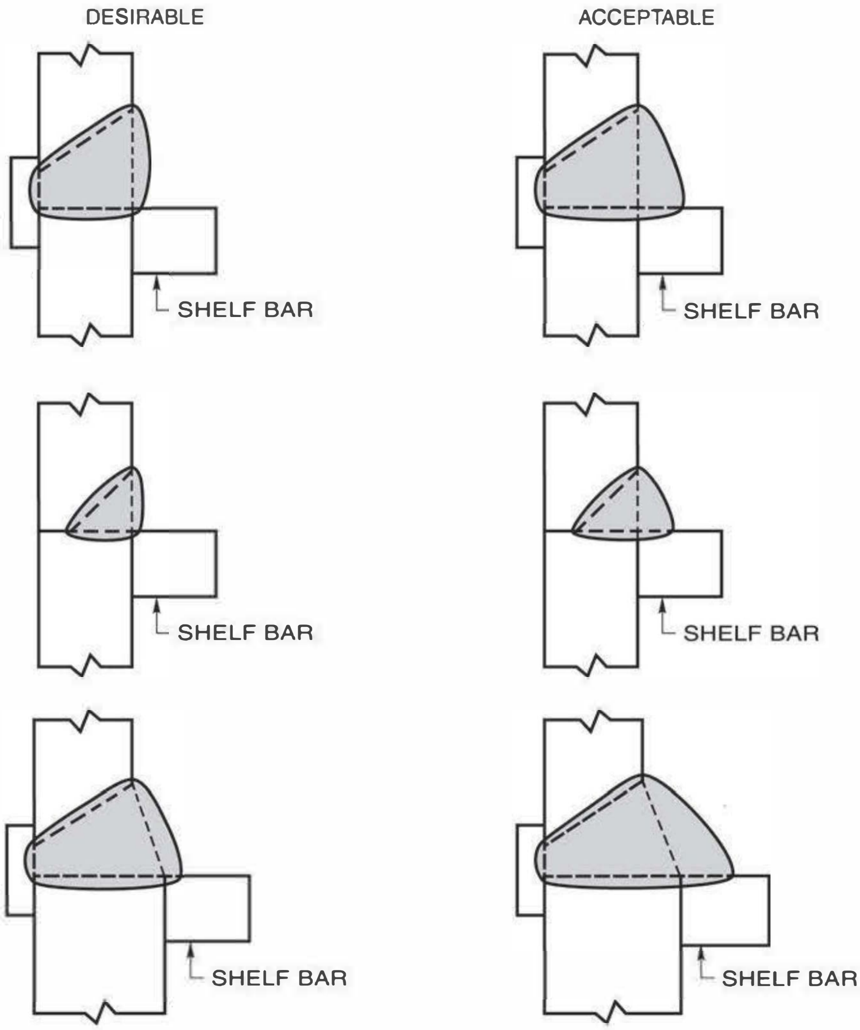
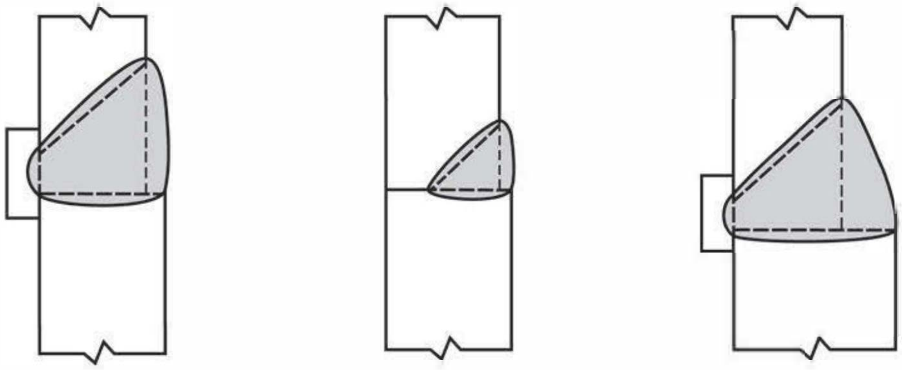


Figure 7.4 (Continued)—Requirements for Weld Profiles (see Tables 7.8 and 7.9)



(G) TYPICAL SHELF BAR DETAILS



(H) TYPICAL PROFILES FOR BUTT WELDS BETWEEN UNEQUAL THICKNESSES

Figure 7.4 (Continued)—Requirements for Weld Profiles (see Tables 7.8 and 7.9)

8. Inspection

Part A
General Requirements

8.1 Scope

This clause contains requirements for inspection and nondestructive testing. It is divided into seven parts as follows:

Part A – General Requirements

Part B – Contractor Responsibilities

Part C – Acceptance Criteria

Part D – NDT Procedures

Part E – Radiographic Testing (RT)

Part F – Ultrasonic Testing (UT) of Groove Welds

Part G – Other Examination Methods

8.1.1 Information Furnished to Bidders. When NDT other than visual is to be required, it shall be so stated in the information furnished to the bidders. This information shall designate the categories of welds to be examined, the extent of examination of each category, and the method or methods of testing.

8.1.2 Inspection and Contract Stipulations. For the purpose of this code, fabrication/erection inspection and testing, and verification inspection and testing shall be separate functions.

8.1.2.1 Contractor's Inspection. This type of inspection and testing shall be performed as necessary prior to assembly, during assembly, during welding, and after welding to ensure that materials and workmanship meet the requirements of the contract documents. Fabrication/erection inspection and testing shall be the responsibilities of the Contractor unless otherwise provided in the contract documents.

8.1.2.2 Verification Inspection. This type of inspection and testing shall be performed and their results reported to the Owner and Contractor in a timely manner to avoid delays in the work. Verification inspection and testing are the prerogatives of the Owner who may perform this function or, when provided in the contract, waive independent verification, or stipulate that both inspection and verification shall be performed by the Contractor.

8.1.3 Definition of Inspector Categories

8.1.3.1 Contractor's Inspector. This inspector is the duly designated person who acts for, and in behalf of, the Contractor on all inspection and quality matters within the scope of the contract documents.

8.1.3.2 Verification Inspector. This inspector is the duly designated person who acts for, and in behalf of, the Owner or Engineer on all inspection and quality matters within the scope of the contract documents.

8.1.3.3 Inspector(s). When the term inspector is used without further qualification as to the specific inspector category described above, it applies equally to inspection and verification within the limits of responsibility described in 8.1.2.

8.1.4 Qualification of Inspection Personnel

8.1.4.1 Engineer's Responsibilities. If the Engineer requires a specific basis of inspection personnel qualification other than those listed in 8.1.4.2, the basis shall be designated in the contract documents.

8.1.4.2 Basis for Qualification of Welding Inspectors. Inspectors responsible for acceptance or rejection of material and workmanship on the basis of visual inspection shall be qualified.

The acceptable qualification basis shall be one of the following:

(1) Current or previous certification as an AWS Certified Welding Inspector (CWI) or Senior Certified Welding Inspector (SCWI) in conformance with the requirements of AWS QC1, *Standard for AWS Certification of Welding Inspectors*,

(2) Current or previous certification as a Level 2 or Level 3 Welding Inspector in conformance with the requirements of Canadian Standards Association (CSA) Standard W178.2, *Certification of Welding Inspectors*,

(3) Current or previous qualification as a Welding Inspector (WI) or Senior Welding Inspector (SWI) in conformance with the requirements of AWS B5.1, *Specification for the Qualification of Welding Inspectors*,

(4) Current or previous qualification as an ASNT SNT-TC–1A-VT Level II in conformance with the requirements of ASNT Recommended Practice No. *SNT-TC–1A, Personnel Qualification and Certification in Nondestructive Testing*, or ANSI/ASNT CP–189 *ASNT Standard for Qualification and Certification of Nondestructive Personnel* or

(5) An individual who, by training or experience, or both, in metals fabrication, inspection and testing, is competent to perform inspection of the work.

8.1.4.3 Alternative Inspector Qualifications.

The basis of alternative qualification for inspection personnel shall be specified in contract documents if different than the requirements in 8.1.4.2. When requested by the Engineer, or an authorized representative of the owner, documentation of the specified alternative qualification of inspection personnel shall be submitted for verification and approval.

8.1.4.4 Assistant Inspector. The Inspector may be supported by Assistant Inspectors who may perform specific inspection functions under the supervision of the Inspector. The work of Assistant Inspectors shall be regularly monitored by the Inspector.

8.1.4.5 Basis for Qualification of Assistant Inspectors. Assistant Inspectors shall be qualified to perform the specific functions to which they are assigned.

The acceptable qualification basis shall be one of the following:

(1) Current or previous certification as an AWS Certified Associate Welding Inspector (CAWI) or higher in conformance with the requirements of AWS QC1, *Standard for AWS Certification of Welding Inspectors*,

(2) Current or previous certification as a Level 1 Welding Inspector or higher in conformance with the requirements of Canadian Standards Association (CSA) W178.2, *Certification of Welding Inspectors*,

(3) Current or previous qualification as an Associate Welding Inspector (AWI) or higher in conformance with the requirements of AWS B5.1, *Specification for the Qualification of Welding Inspectors*,

(4) Current or previous qualification as an ASNT SNT-TC–1A-VT Level I in conformance with the requirements of ASNT Recommended Practice No. *SNT-TC–1A, Personnel Qualification and Certification in Nondestructive Testing*, or ANSI/ASNT CP–189, *ASNT Standard for Qualification and Certification of Nondestructive Personnel* or

(5) An individual who is qualified by training and experience to perform the specific functions they are assigned.

8.1.4.6 Eye Examination. Inspectors and Assistant Inspectors, and personnel performing NDT shall have passed an eye examination to prove natural or corrected near vision acuity, in at least one eye, of Jaeger J–2 at a minimum distance of 12 in [300 mm]. Alternatively, an equivalent test as determined by ophthalmic medical personnel is acceptable. Vision tests are required every three years, or less if necessary, to demonstrate adequacy.

8.1.4.7 Term of Effectiveness. The qualification of an Inspector shall remain in effect indefinitely, provided the Inspector remains active in inspection of welded steel fabrication and their eye examinations are current, unless there is specific reason to question the Inspector's ability.

8.1.5 Inspector Responsibility. The Inspector shall ascertain that all fabrication and erection by welding is performed in conformance with the requirements of the contract documents.

8.1.6 Items to be Furnished to the Inspector. The Inspector shall be furnished complete detailed drawings showing the size, length, type, and location of all welds to be made. The Inspector shall also be furnished the portion of the contract documents that describes material and quality requirements for the products to be fabricated or erected, or both.

8.1.7 Inspector Notification. The Inspector shall be notified in advance of the start of operations subject to inspection and verification.

8.2 Inspection of Materials and Equipment

The Contractor's Inspector shall ensure that only materials and equipment conforming to the requirements of this code shall be used.

8.3 Inspection of WPSs

8.3.1 Prequalified WPS. The Contractor's Inspector shall ensure that all prequalified WPSs to be used for the work conform with the requirements of Clauses 5, 7, 10 (if tubular), and the contract documents.

8.3.2 WPSs Qualified by Test. The Contractor's Inspector shall ensure that all WPSs qualified by test conform with the requirements of Clauses 6, 7, 10 (if tubular), and the contract documents.

8.3.3 WPSs in Production. The Contractor's Inspector shall ensure that all welding operations are performed in conformance with WPSs that meet the requirements of this code and the contract documents.

8.4 Inspection of Welder, Welding Operator, and Tack Welder Qualifications

8.4.1 Determination of Qualification. The Inspector shall allow welding to be performed only by welders, welding operators, and tack welders who are qualified in conformance with the requirements of Clause 6, or Clause 10 for tubulars, or shall ensure that each welder, welding operator, or tack welder has previously demonstrated such qualification under other acceptable supervision and approved by the Engineer in conformance with 6.2.2.1.

8.4.2 Retesting Based on Quality of Work. When the quality of a qualified welder's, welding operator's, or tack welder's work appears to be below the requirements of this code, the Inspector may require that the welder, welding operator, or tack welder demonstrate an ability to produce sound welds of the type that has not met requirements by means of a simple test, such as the fillet weld break test, or by requiring complete requalification in conformance with Clause 6, or Clause 10 for tubulars.

8.4.3 Retesting Based on Qualification Expiration. The Inspector shall require requalification of any welder, welding operator, or tack welder who has not used the process (for which they are qualified) for a period exceeding six months (see 6.2.3.1).

8.5 Inspection of Work and Records

8.5.1 Size, Length, and Location of Welds. The Inspector shall ensure that the size, length, and location of all welds conform to the requirements of this code and to the detail drawings and that no unspecified welds have been added without the approval of the Engineer.

8.5.2 Scope of Examinations. The Inspector shall, at suitable intervals, observe joint preparation, assembly practice, and the welding techniques, and performance of each welder, welding operator, and tack welder to ensure that the applicable requirements of this code are met.

8.5.3 Extent of Examination. The Inspector shall examine the work to ensure that it meets the requirements of this code. Other acceptance criteria, different from those described in the code, may be used when approved by the Engineer. Size and contour of welds shall be measured with suitable gages. Visual inspection for cracks in welds and base metal and other discontinuities should be aided by a strong light, magnifiers, or such other devices as may be found helpful.

8.5.4 Inspector Identification of Inspections Performed. Inspectors shall identify with a distinguishing mark or other recording methods all parts or joints that they have inspected and accepted. Any recording method which is mutually agreeable may be used. Die stamping of cyclically loaded members without the approval of the Engineer shall be prohibited.

8.5.5 Maintenance of Records. The Inspector shall keep a record of qualifications of all welders, welding operators, and tack welders; all WPS qualifications or other tests that are made; and such other information as may be required.

Part B
Contractor Responsibilities

8.6 Obligations of the Contractor

8.6.1 Contractor Responsibilities. The Contractor shall be responsible for visual inspection and necessary correction of all deficiencies in materials and workmanship in conformance with the requirements of this code.

8.6.2 Inspector Requests. The Contractor shall comply with all requests of the Inspector(s) to correct deficiencies in materials and workmanship as provided in the contract documents.

8.6.3 Engineering Judgment. In the event that faulty welding, or its removal for rewelding, damages the base metal so that in the judgment of the Engineer its retention is not in conformance with the intent of the contract documents, the Contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the Engineer.

8.6.4 Specified NDT Other than Visual. When NDT other than visual inspection is specified in the information furnished to bidders, it shall be the Contractor's responsibility to ensure that all specified welds shall meet the quality requirements of Clause 8, Part C or Clause 10, Part F for tubulars, whichever is applicable.

8.6.5 Nonspecified NDT Other than Visual. If NDT other than visual inspection is not specified in the original contract agreement but is subsequently requested by the Owner, the Contractor shall perform any requested testing or shall allow any testing to be performed in conformance with 8.14. The Owner shall be responsible for all associated costs including handling, surface preparation, NDT, and repair of discontinuities other than those described in 8.9, whichever is applicable, at rates mutually agreeable between Owner and Contractor. However, if such testing should disclose an attempt to defraud or gross nonconformance to this code, repair work shall be done at the Contractor's expense.

Part C
Acceptance Criteria

8.7 Scope

Acceptance criteria for visual and NDT inspection of statically and cyclically loaded nontubular connections are described in Part C. The extent of examination and the acceptance criteria shall be specified in the contract documents in the information furnished to the bidder.

8.8 Engineer's Approval for Alternate Acceptance Criteria

The fundamental premise of the code is to provide general stipulations applicable to most situations. Acceptance criteria for production welds different from those described in the code may be used for a particular application, provided they are suitably documented by the proposer and approved by the Engineer. These alternate acceptance criteria may be based upon evaluation of suitability for service using past experience, experimental evidence or engineering analysis considering material type, service load effects, and environmental factors.

8.9 Visual Inspection

All welds shall be visually inspected and shall be acceptable if the criteria of Table 8.1, or Table 10.15 (if tubular) are satisfied.

8.10 Penetrant Testing (PT) and Magnetic Particle Testing (MT)

Welds that are subject to PT and MT, in addition to visual inspection, shall be evaluated on the basis of the acceptance criteria for visual inspection. The testing shall be performed in conformance with 8.14.4 or 8.14.5, whichever is applicable.

8.11 Nondestructive Testing (NDT)

Except as provided for in 10.28 for tubulars, all NDT methods including equipment requirements and qualifications, personnel qualifications, and operating methods shall be in conformance with Clause 8, Inspection. Acceptance criteria shall be as described in this section. Welds subject to NDT shall have been found acceptable by visual inspection in conformance with 8.9.

For welds subject to NDT in conformance with 8.10, 8.11, 10.25.2, and 10.26.1, the testing may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A514, A517, and A709 Grade HPS 100W [690W] steels shall be based on NDT performed not less than 48 hours after completion of the welds.

8.12 Radiographic Testing (RT)

Welds shown by RT that do not meet the requirements of Part C, or alternate acceptance criteria per 8.8, shall be repaired in conformance with 7.25. Discontinuities other than cracks shall be evaluated on the basis of being either elongated or rounded. Regardless of the type of discontinuity, an elongated discontinuity shall be defined as one in which its length exceeds three times its width. A rounded discontinuity shall be defined as one in which its length is three times its width or less and may be round or irregular and may have tails.

8.12.1 Discontinuity Acceptance Criteria for Statically Loaded Nontubular Connections. Welds that are subject to RT in addition to visual inspection shall have no cracks and shall be unacceptable if the RT shows any discontinuities exceeding the following limitations. The limitations given by Figure 8.1 for 1–1/8 in [30 mm] weld size (S) shall apply to all weld sizes greater than 1-1/8 in [30 mm].

(1) Elongated discontinuities exceeding the maximum size of Figure 8.1.

(2) Discontinuities closer than the minimum clearance allowance of Figure 8.1.

(3) Rounded discontinuities greater than a maximum size of S/3, not to exceed 1/4 in [6 mm]. However, when S is greater than 2 in [50 mm], the maximum rounded indication may be 3/8 in [10 mm]. The minimum clearance of rounded discontinuities greater than or equal to 3/32 in [2.5 mm] to an acceptable elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(4) At the intersection of a weld with another weld or a free edge (i.e., an edge beyond which no material extension exists), acceptable discontinuities shall conform to the limitations of Figure 8.1, Cases I–IV.

(5) Isolated discontinuities such as a cluster of rounded indications, having a sum of their greatest dimensions exceeding the maximum size single discontinuity allowed in Figure 8.1. The minimum clearance to another cluster or an elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(6) The sum of individual discontinuities each having a greater dimension of less than 3/32 in [2.5 mm] shall not exceed 2S/3 or 3/8 in [10 mm], whichever is less, in any linear 1 in [25 mm] of weld. This requirement is independent of (1), (2), and (3) above.

(7) In-line discontinuities, where the sum of the greatest dimensions exceeds S in any length of 6S. When the length of the weld being examined is less than 6S, the allowable sum of the greatest dimensions shall be proportionally less.

8.12.2 Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections. Welds that are subject to RT in addition to visual inspection shall have no cracks and shall be unacceptable if the RT shows any of the types of discontinuities described in 8.12.2.1, 8.12.2.2, or 8.12.2.3. The limitations given by Figures 8.2 and 8.3 for 1–1/2 in [38 mm] weld size (S) shall apply to all weld sizes greater than 1–1/2 in [38 mm].

8.12.2.1 Cyclically Loaded Nontubular Connections in Tension

(1) Discontinuities exceeding the maximum size of Figure 8.2.

(2) Discontinuities closer than the minimum clearance allowance of Figure 8.2.

(3) At the intersection of a weld with another weld or a free edge (i.e., an edge beyond which no material extension exists), acceptable discontinuities shall conform to the limitations of Figure 8.2, Cases I–IV.

(4) Isolated discontinuities such as a cluster of rounded indications, having a sum of their greatest dimensions exceeding the maximum size single discontinuity allowed in Figure 8.2. The minimum clearance to another cluster or an elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(5) The sum of individual discontinuities each having a greater dimension of less than 3/32 in [2.5 mm] shall not exceed 2S/3 or 3/8 in [10 mm], whichever is less, in any linear 1 in [25 mm] of weld. This requirement is independent of (1), (2), and (3) above.

(6) In-line discontinuities, where the sum of the greatest dimensions exceeds S in any length of 6S. When the length of the weld being examined is less than 6S, the allowable sum of the greatest dimensions shall be proportionally less.

8.12.2.2 Cyclically Loaded Nontubular Connections in Compression

(1) Discontinuities exceeding the maximum size of Figure 8.3.

(2) Discontinuities closer than the minimum clearance allowance of Figure 8.3.

(3) At the intersection of a weld with another weld or a free edge (i.e., an edge beyond which no material extension exists), acceptable discontinuities shall conform to the limitations of Figure 8.3, Cases I–V.

(4) Isolated discontinuities such as a cluster of rounded indications, having a sum of their greatest dimensions exceeding the maximum size single discontinuity allowed in Figure 8.3. The minimum clearance to another cluster or an elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(5) The sum of individual discontinuities each having a greater dimension of less than 3/32 in [2.5 mm] shall not exceed 2S/3 or 3/8 in [10 mm], whichever is less, in any linear 1 in [25 mm] of weld. This requirement is independent of (1), (2), and (3) above.

(6) In-line discontinuities, where the sum of the greatest dimensions exceeds S in any length of 6S. When the length of the weld being examined is less than 6S, the allowable sum of the greatest dimensions shall be proportionally less.

8.12.2.3 Discontinuities Less than 1/16 in [2 mm]. In addition to the requirements of 8.12.2.1 and 8.12.2.2, discontinuities having a greatest dimension of less than 1/16 in [2 mm] shall be unacceptable if the sum of their greatest dimensions exceeds 3/8 in [10 mm] in any linear inch of weld.

8.13 Ultrasonic Testing (UT)

8.13.1 Acceptance Criteria for Statically Loaded Nontubular Connections. The acceptance criteria for welds subject to UT in addition to visual inspection shall meet the requirements of Table 8.2. For CJP web-to-flange welds, acceptance of discontinuities detected by scanning movements other than scanning pattern 'E' (see 8.30.2.2) may be based on weld thickness equal to the actual web thickness plus 1 in [25 mm].

Discontinuities detected by scanning pattern 'E' shall be evaluated to the criteria of Table 8.2 for the actual web thickness. When CJP web-to-flange welds are subject to calculated tensile stress normal to the weld, they should be so designated on the design drawing and shall conform to the requirements of Table 8.2. Ultrasonically tested welds are evaluated on the basis of a discontinuity reflecting ultrasound in proportion to its effect on the integrity of the weld. Indications of discontinuities that remain on the display as the search unit is moved towards and away from the discontinuity (scanning movement "B") may be indicative of planar discontinuities with significant through-throat dimension.

Since the major reflecting surface of the most critical discontinuities is oriented a minimum of 20° (for a 70° search unit) to 45° (for a 45° search unit) from perpendicular to the sound beam, amplitude evaluation (dB rating) does not allow reliable disposition. When indications exhibiting these planar characteristics are present at scanning sensitivity, a more detailed evaluation of the discontinuity by other means shall be required (e.g., alternate UT techniques, RT, grinding or gouging for visual inspection, etc.).

8.13.2 Acceptance Criteria for Cyclically Loaded Nontubular Connections. The acceptance criteria for welds subject to UT in addition to visual inspection shall meet the following requirements:

(1) Welds subject to tensile stress under any condition of loading shall conform to the requirements of Table 8.3.

(2) Welds subject to compressive stress shall conform to the requirements of Table 8.2.

8.13.2.1 Indications. Ultrasonically tested welds are evaluated on the basis of a discontinuity reflecting ultrasound in proportion to its effect on the integrity of the weld. Indications of discontinuities that remain on the display as the search unit is moved towards and away from the discontinuity (scanning movement "B") may be indicative of planar discontinuities with significant through throat dimension. As the orientation of such discontinuities, relative to the sound beam, deviates from the perpendicular, dB ratings which do not allow direct, reliable evaluation of the welded joint integrity may result. When indications that exhibit these planar characteristics are present at scanning sensitivity, a more detailed evaluation of the discontinuity by other means may be required (e.g., alternate UT techniques, RT, grinding, or gouging for visual inspection, etc.).

8.13.2.2 Scanning. CJP web-to-flange welds shall conform to the requirements of Table 8.2, and acceptance for discontinuities detected by scanning movements other than scanning pattern 'E' (see 8.30.2.2) may be based on a weld thickness equal to the actual web thickness plus 1 in [25 mm]. Discontinuities detected by scanning pattern 'S' shall be evaluated to the criteria of 8.13.2 for the actual web thickness. When such web-to-flange welds are subject to calculated tensile stress normal to the weld, they shall be so designated on design drawings and shall conform to the requirements of Table 8.3.

Part D
NDT Procedures

8.14 Procedures

The NDT procedures as described in this code have been in use for many years and provide reasonable assurance of weld integrity; however, it appears that some users of the code incorrectly consider each method capable of detecting all unacceptable discontinuities. Users of the code should become familiar with all the limitations of NDT methods to be used, particularly the inability to detect and characterize planar discontinuities with specific orientations. (The limitations and complementary use of each method are explained in the latest edition of AWS B1.10, *Guide for Nondestructive Examination of Welds*.)

8.14.1 RT. When RT is used, the procedure and technique shall be in conformance with Part E of this clause or Clause 10, Part F and 10.27 for tubulars.

8.14.2 Radiation Imaging Systems. When examination is performed using radiation imaging systems, the procedures and techniques shall be in conformance with Part G of this clause.

8.14.3 UT. When UT is used, the procedure and technique shall be in conformance with Part F of this clause.

8.14.4 MT. When MT is used, the procedure and technique shall be in conformance with ASTM E709, and the standard of acceptance shall be in conformance with Clause 8, Part C, of this code.

8.14.5 PT. For detecting discontinuities that are open to the surface, PT may be used. The standard methods set forth in ASTM E165 shall be used for PT inspection, and the standards of acceptance shall be in conformance with Clause 8, Part C, of this code.

8.14.6 Personnel Qualification

8.14.6.1 ASNT Requirements. Personnel performing NDT other than visual shall be qualified in conformance with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A. Individuals who perform NDT shall be qualified for:

(1) NDT Level II, or

(2) NDT Level I working under the NDT Level II

8.14.6.2 Certification. Certification of Level I and Level II individuals shall be performed by a Level III individual who has:

(1) been certified by the American Society for Nondestructive Testing, or

(2) the education, training, experience, and has successfully passed the written examination described in SNT-TC–1A.

8.14.6.3 Exemption of QC1 Requirements. Personnel performing NDT under the provisions of 8.14.6 need not be qualified and certified under the provisions of AWS QC1.

8.15 Extent of Testing

Information furnished to the bidders shall clearly identify the extent of NDT (types, categories, or location) of welds to be tested.

8.15.1 Full Testing. Weld joints requiring testing by contract specification shall be tested for their full length, unless partial or spot testing is specified.

8.15.2 Partial Testing. When partial testing is specified, the location and lengths of welds or categories of weld to be tested shall be clearly designated in the contract documents.

8.15.3 Spot Testing. When spot testing is specified, the number of spots in each designated category of welded joint to be tested in a stated length of weld or a designated segment of weld shall be included in the information furnished to the bidders. Each spot test shall cover at least 4 in [100 mm] of the weld length. When spot testing reveals indications of unacceptable discontinuities that require repair, the extent of those discontinuities shall be explored. Two additional spots in the same segment of weld joint shall be taken at locations away from the original spot. The location of the additional spots shall be agreed upon between the Contractor and the Verification Inspector.

When either of the two additional spots shows defects that require repair, the entire segment of weld represented by the original spot shall be completely tested. If the weld involves more than one segment, two additional spots in each segment shall be tested at locations agreed upon by the Contractor and the Verification Inspector, subject to the foregoing interpretation.

8.15.4 Relevant Information. NDT personnel shall, prior to testing, be furnished or have access to relevant information regarding weld joint geometries, material thicknesses, and welding processes used in making the weldment. NDT personnel shall be apprised of any subsequent repairs to the weld.

Part E
Radiographic Testing (RT)

8.16 RT of Groove Welds in Butt Joints

8.16.1 Procedures and Standards. The procedures and standards set forth in Part E shall govern radiographic testing (RT) when such inspection is required by the contract documents as provided in 8.15. The requirements described herein are specifically for testing groove welds in butt joints in plate, shapes, and bars by X-ray or gamma-ray sources. The methods shall conform to ASTM E94, *Standard Guide for Radiographic Examination using Industrial Radiographic Film*; and ASTM E1032, *Radiographic Examination of Weldments using Industrial X-Ray Film.*

Digital Image archival shall be in accordance with ASTM E2339, *Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE).*

8.16.1.1 Digital Radiography. The digital radiography method shall be either computed radiography (CR) using a photostimulable phosphor plate, more commonly known as a storage phosphor imaging plate (SPIP), or direct radiography (DR) using a Digital Detector Array (DDA).

(1) CR shall comply with ASTM E2033, *Standard Practice for Radiographic Examination using Computed Radiology (Photostimulable Luminescence Method)* and ASTM E2445, *Standard Practice for Performance Evaluation and Long-Term Stability of Computed Radiology Systems.*

(2) DR shall comply with ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays* and ASTM E2737, *Standard Practice for Digital Detector Array Performance Evaluation and Long-Term Stability.*

8.16.2 Variations. Variations in testing procedures, equipment, and acceptance standards may be used upon agreement between the Contractor and the Owner. Such variations include, but are not limited to, the following:

(1) RT of fillet welds and all welds in T and corner joints;

(2) changes in source-to-film distance;

(3) unusual application of film;

(4) use of SPIPS and DDAs;

(5) unusual hole-type or wire-type image quality indicators (IQI) applications (including film side IQI);

(6) and for RT of thicknesses greater than 6 in [150 mm];

(7) film types;

(8) density or brightness requirements;

(9) variations in exposure, film development or image processing; and

(10) viewing techniques.

8.17 RT Procedures

8.17.1 Procedure. Radiographic film and digital images shall be made using a single source of either X-ray or gamma-ray radiation. The radiographic film or digital image sensitivity shall be judged based on hole-type or wire IQI. Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required hole-type IQIs and the essential holes or wires as described in 8.17.7 and 10.27.1; Tables 8.4, 8.5, 10.16, and 10.17; and Figures 8.4 and 8.5. Identifying letters and numbers shall show clearly in the radiographic film or digital image.

8.17.2 Safety Requirements. RT shall be performed in conformance with all applicable safety requirements.

8.17.3 Removal of Reinforcement. When the contract documents require the removal of weld reinforcement, the welds shall be prepared as described in 7.23.3.1. Other weld surfaces need not be ground or otherwise smoothed unless surface irregularities or the junction between weld and base metal may cause objectionable weld discontinuities to be obscured in the radiographic film or digital image.

8.17.3.1 Tabs. Weld tabs shall be removed prior to RT unless otherwise approved by the Engineer.

8.17.3.2 Steel Backing. When required by 7.9.1.4 or other provisions of the contract documents, steel backing shall be removed, and the surface shall be finished flush by grinding prior to RT. Grinding shall be as described in 7.23.3.1.

8.17.3.3 Reinforcement. When weld reinforcement or backing, or both, is not removed, or wire IQI alternate placement is not used, steel shims which extend at least 1/8 in [3 mm] beyond three sides of the required hole-type IQI or wire IQI shall be placed under the hole-type IQI or wire IQI, so that the total thickness of steel between the hole-type IQI and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

8.17.4 Radiographic Film. Radiographic film shall be as described in ASTM E94. Lead foil screens shall be used as described in ASTM E94. Fluorescent screens shall be prohibited.

8.17.5 Technique. Radiographs shall be made with a single source of radiation centered as near as practicable with respect to the length and width of that portion of the weld being examined.

8.17.5.1 Geometric Unsharpness. Gamma ray or X-ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation as defined in 8.17.5.1.1. The calculation of geometric unsharpness below shall determine the minimum source-to-film distance:

$U_g = Fd/D$

where:

U_g = geometric unsharpness

F = source size – the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance D from the source side of the subject being radiographed.

D = distance from source of radiation to subject being radiographed.

d = distance from source side of subject to the film.

8.17.5.1.1 Geometric Unsharpness Limitation. (D) and (d) shall be determined at the approximate center of the area of interest. Material thickness for determining allowable geometric unsharpness shall be the thickness upon which the IQI selection is based. The maximum values for geometric unsharpness are as follows:

Material Thickness, in [mm]	Ug Maximum, in [mm]
Under 2 [50]	0.020 [0.5]
2 through 3 [50 – 75]	0.030 [0.75]
Over 3 through 4 [75 – 100]	0.040 [1]
Greater than 4 [100]	0.070 [1.75]

8.17.5.2 Source-to-Subject Distance. The source to-subject distance shall not be less than the total length of film being exposed in a single plane. This provision shall not apply to panoramic exposures.

8.17.5.3 Source-to-Subject Distance Limitations. The source-to-subject distance shall not be less than seven times the thickness of weld plus reinforcement and backing, if any, nor such that the inspecting radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than 26–1/2° from a line normal to the weld surface.

8.17.6 Sources. X-ray units, 600 kVp maximum, and iridium 192 may be used as a source for all RT provided they have adequate penetrating ability. Cobalt 60 shall only be used as a radiographic source when the steel being radiographed exceeds 2–1/2 in [65 mm] in thickness. Other radiographic sources may be used with the approval of the Engineer.

8.17.7 IQI Selection and Placement. IQIs shall be selected and placed on the weldment in the area of interest being radiographed as shown in Table 8.6. Steel backing shall not be considered part of the weld or weld reinforcement in IQI selection.

8.17.8 Technique. Welded joints shall be radiographed and the film indexed by methods that will provide complete and continuous inspection of the joint within the limits specified to be examined. Joint limits shall show clearly in the radiographs. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable.

8.17.8.1 Film or Plate Length. Film, SPIPs, and DDAs shall have sufficient length and shall be placed to provide at least 1/2 in [12 mm] of imaging data beyond the projected edge of the weld.

8.17.8.2 Overlapping Film. Welds longer than 14 in [350 mm] may be radiographed by overlapping film cassettes and making a single exposure, or by using single film cassettes with either SPIPs or conventional film, or DDAs, and making separate exposures. The provisions of 8.17.5 shall apply.

8.17.8.3 Backscatter. To check for backscatter radiation, a lead symbol "B", 1/2 in [12 mm] high, 1/16 in [2 mm] thick shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be considered unacceptable.

8.17.9 Film, SPIP, and DDA Width. Film, SPIP, and DDA widths shall be sufficient to depict all portions of the weld joint, including the HAZs, and shall provide sufficient additional space for the required hole-type IQIs or wire IQI and film identification without infringing upon the area of interest.

8.17.10 Quality of Radiographic Film and Digital Images. All radiographic film and digital images shall be free from imperfections and artifacts to the extent that they cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph.

8.17.10.1 Radiographic Film and Digital Image Artifacts.

Imperfections include, but are not limited to the following as applicable:

(1) fogging

(2) processing defects such as streaks, water marks, or chemical stains

(3) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears

(4) loss of detail due to poor screen-to-film contact

(5) false indications due to defective screens, SPIP, DDA, or internal faults

(6) artifacts due to non-functional pixels

8.17.11 Density Limitations.

8.17.11.1 Radiographic Film. The transmitted film density through the radiographic image of the body of the required hole-type IQI(s) and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma-ray source. For composite viewing of double film exposures, the minimum density shall be 2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

8.17.11.1.1 H & D Density. The density measured shall be H & D density (radiographic density), which is a measure of film blackening, expressed as:

$$D = \log I_o/I$$

where:

D = H & D (radiographic) density
I_o = light intensity on the film, and
I = light transmitted through the film.

8.17.11.1.2 Transitions. When weld transitions in thickness are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements of 8.17.11.1 shall be waived unless otherwise provided in the contract documents.

8.17.11.2 Digital Image Sensitivity Range. The contrast and brightness range that demonstrates the required sensitivity shall be considered valid contrast and brightness values for interpretation. When multiple IQIs are used to cover different thickness ranges, the contrast and brightness range that demonstrates the required IQI image of each IQI shall be determined. Intervening thicknesses may be interpreted using the overlapping portions of the determined contrast and brightness ranges. When there is no overlap, additional IQI(s) shall be used.

8.17.12 Identification Marks. A radiograph identification mark and two location identification marks shall be placed on the steel at each radiograph location. A corresponding radiograph identification mark and two location identification marks, all of which shall show in the image, shall be provided by placing lead numbers or letters, or both, over each of the identical identification and location marks made on the steel to provide a means for matching the image to the weld or base metal. Additional identification information may be pre-printed no less than 3/4 in [20 mm] from the edge of the weld or shall be produced on the radiograph by placing lead figures on the steel. Information required to show on the radiograph shall include the Owner's contract identification, initials of the RT company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, the date, and the weld repair number, if applicable. For digital images, the additional information may be added as text on the processed image. When such text information is added, the software locking tool shall be enabled to prevent subsequent editing of the information.

8.17.13 Edge Blocks. Edge blocks shall be used when radiographing butt joints greater than 1/2 in [12 mm] thickness. The edge blocks shall have a length sufficient to extend beyond each side of the weld centerline for a minimum distance equal to the weld thickness, but no less than 2 in [50 mm], and shall have a thickness equal to or greater than the thickness of the weld. The minimum width of the edge blocks shall be equal to half the weld thickness, but not less than 1 in [25 mm]. The edge blocks shall be centered on the weld against the plate being radiographed, allowing no more than 1/16 in [2 mm] gap for the minimum specified length of the edge blocks. Edge blocks shall be made of radiographically clean steel and the surface shall have a finish of ANSI 125 μin [3 μm] or smoother (see Figure 8.10).

8.17.14 Linear Reference Comparators. When using SPIPs or DDAs, a measuring scale or an object of known dimension shall be used to serve as a linear reference comparator. The comparator shall be attached to the SPIP holder or DDA prior to exposure. As an alternative, when using SPIPs a transparent scale with opaque gradations may be placed on the SPIP prior to processing. In any case the reference comparator shall not interfere with interpretation of the image.

8.18 Examination, Report, and Disposition of Radiographs

8.18.1 Equipment Provided by Contractor.

8.18.1.1 Film Radiography. The Contractor shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H & D density of 4.0. Film review shall be done in an area of subdued light.

8.18.1.2 Digital Radiography. The work station monitor, for evaluating images, shall have a display resolution with a pixel count which is equal to or greater than the pixel count of the direct imaging plate.

8.18.2 Reports. Before a weld subject to RT by the Contractor for the Owner is accepted, all of its radiographic film and digital images, including any that show unacceptable quality prior to repair, and a report interpreting them shall be submitted to the Verification Inspector.

8.18.3 Radiographic Film or Digital Image Retention. A full set of radiographic film or digital images, including any that show unacceptable quality prior to repair, shall be delivered to the Owner upon completion of the work. The Contractor's obligation to retain radiographic film or digital images shall cease:

(1) upon delivery of this full set to the Owner, or

(2) one full year after the completion of the Contractor's work, provided the Owner is given prior written notice.

8.18.4 Radiographic Film or Digital Image Archival

8.18.4.1 Radiographic Film. Radiographic film shall be stored in accordance with ASTM E1254, *Standard Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films*.

8.18.4.2 Radiographic Digital Images. Radiographic digital images shall be archived using a reproducible electronic medium. Data file format shall comply with ASTM E2699, *Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Digital Radiographic (DR) Test Methods*. The image archival method shall be documented and proven at system installation. This shall include the image file nomenclature to enable the retrieval of images at a later date. Archived image files shall maintain the bit depth and spatial resolution of the original image. Image data compression is not allowed. The initial image presented by the SPIP or DDA system shall be preserved (stored) without altering the original spatial resolution and pixel intensity. The final image used for disposition shall also be archived when additional image processing is applied (excluding window/level and digital image zoom) to achieve the required image quality level. Annotations made to the image shall be stored in a manner which will not mask or hide diagnostic areas of the image.

Part F
Ultrasonic Testing (UT) of Groove Welds

8.19 General

8.19.1 Procedures and Standards. The procedures and standards set forth in Part F shall govern the UT of groove welds and HAZs between the thicknesses of 5/16 in and 8 in [8 mm and 200 mm] inclusive, when such testing is required by 8.14 of this code. For thicknesses less than 5/16 in [8 mm] or greater than 8 in [200 mm], testing shall be performed in conformance with Annex O. These procedures and standards shall be prohibited for testing tube-to-tube T-, Y-, or K-connections.

8.19.2 Variations. Annex O and Annex H specify alternative ultrasonic techniques for performing conventional UT and phased array UT examination of groove welds. Other variations in testing procedures, equipment, and acceptance standards not included in Part F of Clause 8 may be used with the approval of the Engineer. Such variations include other thicknesses, weld geometries, transducer sizes, frequencies, couplant, painted surfaces, testing techniques, etc. Such approved variations shall be recorded in the inspection records.

8.19.3 Piping Porosity. To detect possible piping porosity, RT is recommended to supplement UT of ESW or EGW welds.

8.19.4 Base Metal. These procedures are not intended to be employed for the procurement testing of base metals. However, welding related discontinuities (cracking, lamellar tearing, delaminations, etc.) in the adjacent base metal which would not be acceptable under the provisions of this code shall be reported to the Engineer for disposition.

8.20 Qualification Requirements

In satisfying the requirements of 8.14.6, the qualification of the UT operator shall include a specific and practical examination which shall be based on the requirements of this code. This examination shall require the UT operator to demonstrate the ability to apply the rules of this code in the accurate detection and disposition of discontinuities.

8.21 UT Equipment

8.21.1 Equipment Requirements. The UT instrument shall be the pulse echo type suitable for use with transducers oscillating at frequencies between 1 and 6 megahertz. The display shall be an "A" scan rectified video trace. The requirements shall be as shown in Table 8.8.

8.21.2 Horizontal Linearity. The horizontal linearity of the test instrument shall be qualified over the full soundpath distance to be used in testing in conformance with 8.28.1.

8.21.3 Requirements for Test Instruments. Test instruments shall include internal stabilization so that after warm-up, no variation in response greater than ± 1 dB occurs with a supply voltage change of 15% nominal or, in the case of a battery, throughout the charge operating life. There shall be an alarm or meter to signal a drop in battery voltage prior to instrument shutoff due to battery exhaustion.

8.21.4 Calibration of Test Instruments. The test instrument shall have a calibrated gain control (attenuator) adjustable in discrete 1 or 2 dB steps over a range of at least 60 dB. The accuracy of the attenuator settings shall be within plus or minus 1 dB. The procedure for qualification shall be as described in 8.23.2 and 8.28.2.

8.21.5 Display Range. The dynamic range of the instrument's display shall be such that a difference of 1 dB of amplitude can be easily detected on the display.

8.21.6 Straight-Beam (Longitudinal Wave) Search Units. Straight-beam (longitudinal wave) search unit transducers shall have an active area of not less than 1/2 in^2 [323 mm^2] nor more than 1 in^2 [645 mm^2]. The transducer shall be round or square. Transducers shall be capable of resolving the three reflections as described in 8.27.1.3.

8.21.7 Angle-Beam Search Units. Angle-beam search units shall consist of a transducer and an angle wedge. The unit may be comprised of the two separate elements or may be an integral unit.

8.21.7.1 Frequency. The transducer frequency shall be between 2 and 2.5 MHz, inclusive.

8.21.7.2 Transducer Dimensions. The transducer crystal shall be square or rectangular in shape and may vary from 5/8 in to 1 in [15 mm to 25 mm] in width and from 5/8 in to 13/16 in [15 mm to 20 mm] in height (see Figure 8.11). The maximum width to height ratio shall be 1.2 to 1.0, and the minimum width-to-height ratio shall be 1.0 to 1.0.

8.21.7.3 Angles. The search unit shall produce a sound beam in the material being tested within plus or minus 2° of one of the following proper angles: 70°, 60°, or 45°, as described in 8.27.2.2.

8.21.7.4 Marking. Each search unit shall be marked to clearly indicate the frequency of the transducer, nominal angle of refraction, and index point. The index point location procedure is described in 8.27.2.1.

8.21.7.5 Internal Reflections. Maximum allowable internal reflections from the search unit shall be as described in 8.23.3 and 8.28.3.

8.21.7.6 Edge Distance. The dimensions of the search unit shall be such that the distance from the leading edge of the search unit to the index point shall not exceed 1 in [25 mm].

8.21.7.7 IIW Type Block. The qualification procedure using the IIW reference block or other IIW type block shall be in conformance with 8.27.2.6 and as shown in Figure 8.12.

8.22 Reference Standards

8.22.1 IIW Standard. Any of the International Institute of Welding (IIW) type UT reference blocks may be used as the standard for both distance and sensitivity calibration, provided the block includes the 0.060 in [1.5 mm] diameter hole as shown in Figure 8.13 and distance, resolution, and angle verification features of Figure 8.16 (positions A through G). IIW type blocks shall conform to ASTM E164. Other portable blocks may be used, provided the reference level sensitivity for instrument/ search unit combination is adjusted to be the equivalent of that achieved with the IIW type block (see Annex G, for examples).

8.22.2 Prohibited Reflectors. The use of a "corner" reflector for calibration purposes shall be prohibited.

8.22.3 Resolution Requirements. The combination of search unit and instrument shall resolve three holes in the RC resolution reference test block shown in Figure 8.14. The search unit position is described in 8.27.2.5. The resolution shall be evaluated with the instrument controls set at normal test settings and with indications from the holes brought to midscreen height. Resolution shall be sufficient to distinguish at least the peaks of indications from the three holes. Use of the RC resolution reference block for calibration shall be prohibited. Each combination of instrument search unit (shoe and transducer) shall be checked prior to its initial use. This equipment verification shall be done initially with each search unit and UT unit combination. The verification need not be done again provided documentation is maintained that records the following items:

(1) UT machine's make, model and serial number

(2) Search unit's manufacturer, type, size, angle, and serial number

(3) Date of verification and technician's name

8.23 Equipment Qualification

8.23.1 Horizontal Linearity. The horizontal linearity of the test instrument shall be requalified at two-month intervals in each of the distance ranges that the instrument will be used. The qualification procedure shall be in conformance with 8.28.1 (see Annex G, for alternative method).

8.23.2 Gain Control. The instrument's gain control (attenuator) shall meet the requirements of 8.21.4 and shall be checked for correct calibration at two month intervals in conformance with 8.28.2. Alternative methods may be used for calibrated gain control (attenuator) qualification if proven at least equivalent with 8.28.2.

8.23.3 Internal Reflections. Maximum internal reflections from each search unit shall be verified at a maximum time interval of 40 hours of instrument use in conformance with 8.28.3.

8.23.4 Calibration of Angle-Beam Search Units. With the use of an approved calibration block, each angle beam search unit shall be checked after each eight hours of use to determine that the contact face is flat, that the sound entry point is correct, and that the beam angle is within the allowed plus or minus 2° tolerance in conformance with 8.27.2.1 and 8.27.2.2. Search units which do not meet these requirements shall be corrected or replaced.

8.24 Calibration for Testing

8.24.1 Position of Reject Control. All calibrations and tests shall be made with the reject (clipping or suppression) control turned off. Use of the reject (clipping or suppression) control may alter the amplitude linearity of the instrument and invalidate test results.

8.24.2 Technique. Calibration for sensitivity and horizontal sweep (distance) shall be made by the UT operator just prior to and at the location of the first weld tested. After that, requirements of 8.24.3 recalibration shall apply.

8.24.3 Recalibration. Recalibration shall be made after a change of operators, each two-hour maximum time interval, or when the electrical circuitry is disturbed in any way which includes the following:

(1) Transducer change

(2) Battery change

(3) Electrical outlet change

(4) Coaxial cable change

(5) Power outage (failure)

8.24.4 Straight-Beam Testing of Base Metal. Calibration for straight-beam testing of base metal shall be made with the search unit applied to Face A of the base metal and performed as follows:

8.24.4.1 Sweep. The horizontal sweep shall be adjusted for distance calibration to present the equivalent of at least two plate thicknesses on the display.

8.24.4.2 Sensitivity. The sensitivity shall be adjusted at a location free of indications so that the first back reflection from the far side of the plate will be 50% to 75% of full screen height.

8.24.5 Calibration for Angle-Beam Testing. Calibration for angle-beam testing shall be performed as follows (see Annex G, G2.4 for alternative method).

8.24.5.1 Horizontal Sweep. The horizontal sweep shall be adjusted to represent the actual sound-path distance by using the IIW type block or alternative blocks as described in 8.22.1. The distance calibration shall be made using either the 5 in [125 mm] scale or 10 in [250 mm] scale on the display, whichever is appropriate. If, however, the joint configuration or thickness prevents full examination of the weld at either of these settings, the distance calibration shall be made using 15 in or 20 in [400 mm or 500 mm] scale as required. The search unit position is described in 8.27.2.3.

NOTE: The horizontal location of all screen indications is based on the location at which the left side of the trace deflection breaks the horizontal base line.

8.24.5.2 Zero Reference Level. The zero reference level sensitivity used for discontinuity evaluation ("b" on the ultrasonic test report, Annex P, Form P–11) shall be attained by adjusting the calibrated gain control (attenuator) of the discontinuity detector, meeting the requirements of 8.21, so that a maximized horizontal trace deflection (adjusted to horizontal reference line height with calibrated gain control [attenuator]) results on the display between 40% and 60% screen height, in conformance with 8.27.2.4.

8.25 Testing Procedures

8.25.1 "X" Line. An "X" line for discontinuity location shall be marked on the test face of the weldment in a direction parallel to the weld axis. The location distance perpendicular to the weld axis shall be based on the dimensional figures on the detail drawing and usually falls on the centerline of the butt joint welds, and always falls on the near face of the connecting member of T and corner joint welds (the face opposite Face C).

8.25.2 "Y" Line. A "Y" accompanied with a weld identification number shall be clearly marked on the base metal adjacent to the weld that is subject to UT. This marking is used for the following purposes:

(1) Weld identification

(2) Identification of Face A

(3) Distance measurements and direction (+ or –) from the "X" line

(4) Location measurement from weld ends or edges

8.25.3 Cleanliness. All surfaces to which a search unit is applied shall be free of weld spatter, dirt, grease, oil (other than that used as a couplant), paint, and loose scale and shall have a contour allowing intimate coupling.

8.25.4 Couplants. A couplant material shall be used between the search unit and the test material. The couplant shall be either glycerin or cellulose gum and water mixture of a suitable consistency. A wetting agent may be added if needed. Light machine oil may be used for couplant on calibration blocks.

8.25.5 Extent of Testing. The entire base metal through which ultrasound must travel to test the weld shall be tested for laminar reflectors using a straight-beam search unit conforming to the requirements of 8.21.6 and calibrated in conformance with 8.24.4. If any area of base metal exhibits total loss of back reflection or an indication equal to or greater than the original back reflection height is located in a position that will interfere with the normal weld scanning procedure, its size, location, and depth from the Face A shall be determined and reported on the UT report, and an alternate weld scanning procedure shall be used.

8.25.5.1 Reflector Size. The reflector size evaluation procedure shall be in conformance with 8.29.1.

8.25.5.2 Inaccessibility. If part of a weld is inaccessible to testing in conformance with the requirements of Table 8.7, due to laminar content recorded in conformance with 8.25.5, the testing shall be conducted using one or more of the following alternative procedures as necessary to attain full weld coverage:

(1) Weld surface(s) shall be ground flush in conformance with 7.23.3.1.

(2) Testing from Faces A and B shall be performed.

(3) Other search unit angles shall be used.

8.25.6 Testing of Welds. Welds shall be tested using an angle beam search unit conforming to the requirements of 8.21.7 with the instrument calibrated in conformance with 8.24.5 using the angle as shown in Table 8.7. Following calibration and during testing, the only instrument adjustment allowed is the sensitivity level adjustment with the calibrated gain control (attenuator). The reject (clipping or suppression) control shall be turned off. Sensitivity shall be increased from the reference level for weld scanning in conformance with Table 8.2 or Table 8.3, as applicable.

8.25.6.1 Scanning. The testing angle and scanning procedure shall be in conformance with those shown in Table 8.7.

8.25.6.2 Butt Joints. All butt joint welds shall be tested from each side of the weld axis. Corner and T-joint welds shall be primarily tested from one side of the weld axis only. All welds shall be tested using the applicable scanning pattern or patterns shown in Figure 8.15 as necessary to detect both longitudinal and transverse discontinuities. It is intended that, as a minimum, all welds be tested by passing sound through the entire volume of the weld and the HAZ in two crossing directions, wherever practical.

8.25.6.3 Maximum Indication. When a discontinuity indication appears on the screen, the maximum attainable indication from the discontinuity shall be adjusted to produce a horizontal reference level trace deflection on the display. This adjustment shall be made with the calibrated gain control (attenuator), and the instrument reading in decibels shall be used as the "Indication Level, a," for calculating the "Indication Rating, d," as shown on the test report (Annex P, Form P–11).

8.25.6.4 Attenuation Factor. The "Attenuation Factor, (c)," on the test report shall be attained by subtracting 1 in [25 mm] from the sound-path distance and multiplying the remainder by 2 for U.S. Customary Units or by 0.08 for SI Units.

The factor (c) shall be rounded to the closest significant decimal place (0.1). Values less than 0.05 shall be reduced to the lower 0.1 and those of 0.05 or greater increased to the higher 0.1.

8.25.6.5 Indication Rating. The "Indication Rating, (d)," in the UT Report, Annex P, Form P–11, represents the algebraic difference in decibels between the indication level and the reference level with correction for attenuation as indicated in the following expressions:

Instruments with gain in dB: $a - b - c = d$

Instruments with attenuation in dB: $b - a - c = d$

The indication rating shall be rounded to the nearest whole number (1 dB) value. Resulting decimal values less than 0.5 dB shall be rounded down and those of 0.5 dB or greater shall be rounded up.

8.25.7 Length of Discontinuities. The length of discontinuities shall be determined in conformance with the procedure described in 8.29.2.

8.25.8 Basis for Acceptance or Rejection. Each weld discontinuity shall be accepted or rejected on the basis of its indication rating and its length, in conformance with Table 8.2 for statically loaded structures or Table 8.3 for cyclically loaded structures, whichever is applicable. Only those discontinuities which are unacceptable need be recorded on the test report, except that for welds designated in the contract documents as being "Fracture Critical," acceptable ratings that are within 6 dB, inclusive, of the minimum unacceptable rating shall be recorded on the test report.

8.25.9 Identification of Rejected Area. Each unacceptable discontinuity shall be indicated on the weld by a mark directly over the discontinuity for its entire length. The depth from the surface and indication rating shall be noted on nearby base metal.

8.25.10 Repair. Welds found unacceptable by UT shall be repaired by methods allowed by 7.25 of this code. Repaired areas shall be retested ultrasonically with results tabulated on the original form (if available) or additional report forms.

8.25.11 Retest Reports. Evaluation of retested repaired weld areas shall be tabulated on a new line on the report form. If the original report form is used, an R1, R2, . . . Rn shall prefix the indication number. If additional report forms are used, the R number shall prefix the report number.

8.25.12 Steel Backing. UT of CJP groove welds with steel backing shall be performed with a UT procedure that recognizes potential reflectors created by the base metal-backing interface (see Commentary C–8.25.12 for additional guidance scanning groove welds containing steel backing).

8.26 Preparation and Disposition of Reports

8.26.1 Content of Reports. A report form which clearly identifies the work and the area of inspection shall be completed by the UT operator at the time of inspection. The report form for welds that are acceptable need only contain sufficient information to identify the weld, the operator (signature), and the acceptability of the weld. An example of such a form is shown in Annex P, Form P–11.

8.26.2 Prior Inspection Reports. Before a weld subject to UT by the Contractor for the Owner is accepted, all report forms pertaining to the weld, including any that show unacceptable quality prior to repair, shall be submitted to the Inspector.

8.26.3 Completed Reports. A full set of completed report forms of welds subject to UT by the Contractor for the Owner, including any that show unacceptable quality prior to repair, shall be delivered to the Owner upon completion of the work. The Contractor's obligation to retain UT reports shall cease:

(1) upon delivery of this full set to the Owner, or

(2) one full year after completion of the Contractor's work, provided that the Owner is given prior written notice.

8.27 Calibration of the UT Unit with IIW Type or Other Approved Reference Blocks (Annex G)

See 8.22 and Figures 8.13, 8.14, and 8.16.

8.27.1 Longitudinal Mode

8.27.1.1 Distance Calibration. See Annex G, G1 for alternative method.

(1) The transducer shall be set in position G on the IIW type block.

(2) The instrument shall be adjusted to produce indications at 1 in [25 mm on a metric block], 2 in [50 mm on a metric block], 3 in [75 mm on a metric block], 4 in [100 mm on a metric block], etc., on the display.

8.27.1.2 Amplitude. See Annex G, G1.2 for alternative method.

(1) The transducer shall be set in position G on the IIW type block.

(2) The gain shall be adjusted until the maximized indication from first back reflection attains 50% to 75% screen height.

8.27.1.3 Resolution

(1) The transducer shall be set in position F on the IIW type block.

(2) Transducer and instrument shall resolve all three distances.

8.27.1.4 Horizontal Linearity Qualification. Qualification procedure shall be per 8.23.1.

8.27.1.5 Gain Control (Attenuation) Qualification. The qualification procedure shall be in conformance with 8.23.2 or an alternative method, in conformance with 8.23.2, shall be used.

8.27.2 Shear Wave Mode (Transverse)

8.27.2.1 Index Point. The transducer sound entry point (index point) shall be located or checked by the following procedure:

(1) The transducer shall be set in position D on the IIW type block.

(2) The transducer shall be moved until the signal from the radius is maximized. The point on the transducer which aligns with the radius line on the calibration block is the point of sound entry (see Annex G, G2.1 for alternative method).

8.27.2.2 Angle. The transducer sound-path angle shall be checked or determined by one of the following procedures:

(1) The transducer shall be set in position B on IIW type block for angles 40° through 60°, or in position C on IIW type block for angles 60° through 70° (see Figure 8.16).

(2) For the selected angle, the transducer shall be moved back and forth over the line indicative of the transducer angle until the signal from the radius is maximized. The sound entry point on the transducer shall be compared with the angle mark on the calibration block (tolerance ± 2°) (see Annex G, G2.2 for alternative methods).

8.27.2.3 Distance Calibration Procedure. The transducer shall be set in position D on an IIW type block (any angle). The instrument shall then be adjusted to attain one indication at 4 in [100 mm on a metric block] and a second indication at 8 in [200 mm on a metric block] or 9 in [225 mm on a metric block] (see Annex G, G2.3 for alternative methods).

8.27.2.4 Amplitude or Sensitivity Calibration Procedure. The transducer shall be set in position A on the IIW type block (any angle). The maximized signal shall then be adjusted from the 0.060 in [1.59 mm] hole to attain a horizontal reference-line height indication (see Annex G, G2.4 for alternative method). The maximum decibel reading obtained shall be used as the "Reference Level, b" reading on the Test Report sheet (Annex P, Form P–11) in conformance with 8.22.1.

8.27.2.5 Resolution

(1) The transducer shall be set on resolution block RC position Q for 70° angle, position R for 60° angle, or position S for 45° angle.

(2) Transducer and instrument shall resolve the three test holes, at least to the extent of distinguishing the peaks of the indications from the three holes.

8.27.2.6 Approach Distance of Search Unit. The minimum allowable distance between the toe of the search unit and the edge of IIW type block shall be as follows (see Figure 8.12):

for 70° transducer	X = 2 in [50 mm]
for 60° transducer	X = 1–7/16 in [37 mm]
for 45° transducer	X = 1 in [25 mm]

8.28 Equipment Qualification Procedures

8.28.1 Horizontal Linearity Procedure. *NOTE: Since this qualification procedure is performed with a straight-beam search unit which produces longitudinal waves with a sound velocity of almost double that of shear waves, it is necessary to double the shear wave distance ranges to be used in applying this procedure.* Example: The use of a 10 in [250 mm] screen calibration in shear wave would require a 20 in [500 mm] screen calibration for this qualification procedure.

The following procedure shall be used for instrument qualification (see Annex G, G3, for alternative method):

(1) A straight-beam search unit shall be coupled meeting the requirements of 8.21.6 to the IIW type block or DS block in Position G, T, or U (see Figure 8.16) as necessary to attain five back reflections in the qualification range being certified (see Figure 8.16).

(2) The first and fifth back reflections shall be adjusted to their proper locations with use of the distance calibration and zero delay adjustments.

(3) Each indication shall be adjusted to reference level with the gain or attenuation control for horizontal location examination.

(4) Each intermediate trace deflection location shall be correct within 2% of the screen width 8.28.2.

8.28.2 dB Accuracy

8.28.2.1 Procedure. *NOTE: In order to attain the required accuracy (± 1%) in reading the indication height, the display shall be graduated vertically at 2% intervals, or 2.5% for instruments with digital amplitude readout, at horizontal mid-screen height. These graduations shall be placed on the display between 60% and 100% of screen height. This may be accomplished with use of a graduated transparent screen overlay. If this overlay is applied as a permanent part of the UT unit, care should be taken that the overlay does not obscure normal testing displays.*

(1) A straight-beam search unit shall be coupled, meeting the requirements of 8.21.6 to the DS block shown in Figure 8.14 and position "T," Figure 8.16.

(2) The distance calibration shall be adjusted so that the first 2 in [50 mm] back reflection indication (hereafter called *the indication*) is at horizontal mid-screen.

(3) The calibrated gain or attenuation control shall be adjusted so that the indication is exactly at or slightly above 40% screen height.

(4) The search unit shall be moved toward position U, see Figure 8.16, until the indication is at exactly 40% screen height.

(5) The sound amplitude shall be increased 6 dB with the calibrated gain or attenuation control. The indication level theoretically should be exactly at 80% screen height.

(6) The dB reading shall be recorded under "a" and actual % screen height under "b" from step 5 on the certification report (Annex P, Form P–8), Line 1.

(7) The search unit shall be moved further toward position U, Figure 8.16, until the indication is at exactly 40% screen height.

(8) Step 5 shall be repeated.

(9) Step 6 shall be repeated; except, information should be applied to the next consecutive line on Annex P, Form P–8.

(10) Steps 7, 8, and 9 shall be repeated consecutively until the full range of the gain control (attenuator) is reached (60 dB minimum).

(11) The information from Rows "a" and "b" shall be applied to equation 8.28.2.2 or the nomograph described in 8.28.2.3 to calculate the corrected dB.

(12) Corrected dB from step 11 to Row "c" shall be applied.

(13) Row "c" value shall be subtracted from Row "a" value and the difference in Row "d," dB error shall be applied.

NOTE: These values may be either positive or negative and so noted. Examples of Application of Forms P–8, P–9, and P –10 are found in Annex P.

(14) Information shall be tabulated on a form, including minimum equivalent information as displayed on Form P–8, and the unit evaluated in conformance with instructions shown on that form.

(15) Form P–9 provides a relatively simple means of evaluating data from item (14). Instructions for this evaluation are given in items (16) through (18).

(16) The dB information from Row "e" (Form P–8) shall be applied vertically and dB reading from Row "a" (Form P–8) horizontally as X and Y coordinates for plotting a dB curve on Form P–9.

(17) The longest horizontal length, as represented by the dB reading difference, which can be inscribed in a rectangle representing 2 dB in height, denotes the dB range in which the equipment meets the code requirements. The minimum allowable range is 60 dB.

(18) Equipment that does not meet this minimum requirement may be used, provided correction factors are developed and used for discontinuity evaluation outside the instrument acceptable linearity range, or the weld testing and discontinuity evaluation is kept within the acceptable vertical linearity range of the equipment.

NOTE: The dB error figures (Row "d") may be used as correction factor figures.

8.28.2.2 Decibel Equation. The following equation shall be used to calculate decibels:

$$dB_2 - dB_1 = 20 \times \text{Log} \frac{\%_2}{\%_1}$$

$$dB_2 = 20 \times \text{Log} \frac{\%_2}{\%_1} + dB_1$$

As related to Annex P, From P-8

dB_1 = Row "a"
dB_2 = Row "c"
$\%_1$ = Row "b"
$\%_2$ = Defined on From P-8

8.28.2.3 Annex P. The following notes apply to the use of the nomograph in Annex P Form P–10:

(1) Rows a, b, c, d, and e are on certification sheet, Annex P, Form P–8.

(2) The A, B, and C scales are on the nomograph, Annex P, Form P–10.

(3) The zero points on the C scale shall be prefixed by adding the necessary value to correspond with the instrument settings; i.e., 0, 10, 20, 30, etc.

8.28.2.4 Procedure. The following procedures shall apply to the use of the nomograph in Annex P, Form P–10:

(1) A straight line between the decibel reading from Row "a" applied to the C scale and the corresponding percentage from Row "b" applied to the A scale shall be extended.

(2) The point where the straight line from step 1 crosses the pivot line B as a pivot point for a second straight line shall be used.

(3) A second straight line from the average % point on the A scale through the pivot point developed in step 2 and on to the dB scale C shall be extended.

(4) This point on the C scale is indicative of the corrected dB for use in Row "c."

8.28.2.5 Nomograph. For an example of the use of the nomograph, see Annex P, Form P–10.

8.28.3 Internal Reflections Procedure

(1) Calibrate the equipment in conformance with 8.24.5.

(2) Remove the search unit from the calibration block without changing any other equipment adjustments.

(3) Increase the calibrated gain or attenuation 20 dB more sensitive than reference level.

(4) The screen area beyond 1/2 in [12 mm] sound path and above reference level height shall be free of any indication.

8.29 Discontinuity Size Evaluation Procedures

8.29.1 Straight-Beam (Longitudinal) Testing. The size of lamellar discontinuities is not always easily determined, especially those that are smaller than the transducer size. When the discontinuity is larger than the transducer, a full loss of back reflection will occur and a 6 dB loss of amplitude and measurement to the centerline of the transducer is usually reliable for determining discontinuity edges. However, the approximate size evaluation of those reflectors, which are smaller than the transducer, shall be made by beginning outside of the discontinuity with equipment calibrated in conformance with 8.24.4 and moving the transducer toward the area of discontinuity until an indication on the display begins to form. The leading edge of the search unit at this point is indicative of the edge of the discontinuity.

8.29.2 Angle-Beam (Shear) Testing. The following procedure shall be used to determine lengths of indications which have dB ratings more serious than for a Class D indication. The length of such indication shall be determined by measuring the distance between the transducer centerline locations where the indication rating amplitude drops 50% (6 dB) below the rating for the applicable discontinuity classification. This length shall be recorded under "discontinuity length" on the test report. Where warranted by discontinuity amplitude, this procedure shall be repeated to determine the length of Class A, B, and C discontinuities.

8.30 Scanning Patterns (See Figure 8.15)

8.30.1 Longitudinal Discontinuities

8.30.1.1 Scanning Movement A. Rotation angle a = 10°.

8.30.1.2 Scanning Movement B. Scanning distance b shall be such that the section of weld being tested is covered.

8.30.1.3 Scanning Movement C. Progression distance c shall be approximately one-half the transducer width.

NOTE: Movements A, B, and C may be combined into one scanning pattern.

8.30.2 Transverse Discontinuities

8.30.2.1 Ground Welds. Scanning pattern D shall be used when welds are ground flush.

8.30.2.2 Unground Welds. Scanning pattern E shall be used when the weld reinforcement is not ground flush. Scanning angle e = 15° max.

NOTE: The scanning pattern shall cover the full weld section.

8.30.3 ESW or EGW Welds (Additional Scanning Pattern). Scanning Pattern E Search unit rotation angle e between 45° and 60°.

NOTE: The scanning pattern shall cover the full weld section.

8.31 Examples of dB Accuracy Certification

Annex P shows examples of the use of Forms P–8, P–9, and P–10 for the solution to a typical application of 8.28.2.

Part G
Other Examination Methods

8.32 General Requirements

This part contains NDT methods not addressed in Parts D, E, or Part F of Clause 8, or Clause 10, Part F for tubulars of this code. The NDT methods set forth in part G may be used as an alternative to the methods outlined in Parts D, E, or F of Clause 8, or Clause 10, Part F for tubulars, providing procedures, qualification criteria for procedures and personnel, and acceptance criteria are documented in writing and approved by the Engineer.

8.33 Radiation Imaging Systems

Examination of welds may be performed using ionizing radiation methods other than RT, such as electronic imaging, including real-time imaging systems. Sensitivity of such examination as seen on the monitoring equipment (when used for acceptance and rejection) and the recording medium shall be no less than that required for RT.

8.33.1 Procedures. Written procedures shall contain the following essential variables:

(1) Equipment identification including manufacturer, make, model, and serial number,

(2) Radiation and imaging control setting for each combination of variables established herein,

(3) Weld thickness ranges,

(4) Weld joint types,

(5) Scanning speed,

(6) Radiation source to weld distance,

(7) Image conversion screen to weld distance,

(8) Angle of X-rays through the weld (from normal),

(9) IQI location (source side or screen side),

(10) Type of recording medium (video recording, photographic still film, photographic movie film, or other acceptable mediums),

(11) Computer enhancement (if used),

(12) Width of radiation beam,

(13) Indication characterization protocol and acceptance criteria, if different from this code.

8.33.2 IQI. The wire-type IQI, as described in Part E, shall be used. IQI placement shall be as specified in Part E of this clause, or Clause 10, Part F for tubulars for static examination. For in-motion examination, placement shall be as follows:

(1) Two IQIs positioned at each end of area of interest and tracked with the run,

(2) One IQI at each end of the run and positioned at a distance no greater than 10 ft. [3 m] between any two IQIs during the run.

8.34 Advanced Ultrasonic Systems

Advanced Ultrasonic Systems includes, but are not limited to, multiple probe, multi-channel systems, automated inspection, time-of-flight diffraction (TOFD), and phased array systems.

8.34.1 Procedures. Written procedures shall contain the following essential variables:

(1) Equipment identification including manufacturer, make, model, and serial numbers;

(2) Type of probes, including size, shape, angle, and frequency (MHz);

(3) Scanning control settings for each combination of variables established herein;

(4) Setup and calibration procedure for equipment and probes using industry standards or workmanship samples;

(5) Weld thickness ranges;

(6) Weld joint type;

(7) Scanning speeds;

(8) Number of probes;

(9) Scanning angle;

(10) Type of scan (A, B, C, other);

(11) Type of recording medium (video recording, computer assisted, or other acceptable mediums);

(12) Computer based enhancement (if used);

(13) Identification of computer software (if used); and

(14) Indication characterization protocol and acceptance criteria, if different from this code.

8.35 Additional Requirements

8.35.1 Procedure Qualification. Procedures shall be qualified by testing the NDT method (system) and recording medium to establish and record all essential variables and conditions. Qualification testing shall consist of determining that each combination of the essential variables or ranges of variables can provide the minimum required sensitivity. Test results shall be recorded on the recording medium that is to be used for production examination. Procedures shall be approved by an individual qualified as ASNT SNT-TC-1A, Level III (see 8.35.2).

8.35.2 Personnel Qualifications. In addition to the personnel qualifications of 8.14.6, the following shall apply.

(1) Level III—shall have minimum of six months experience using the same or similar equipment and procedures for examination of welds in structural or piping metallic materials.

(2) Levels I and II—shall be certified by the Level III above and have a minimum of three months experience using the same or similar equipment and procedures for examination of welds in structural or piping metallic materials. Qualification shall consist of written and practical examinations for demonstrating capability to use the equipment and procedures to be used for production examination.

8.35.3 Image Enhancement. Computer enhancement of the recording images shall be acceptable for improving the recorded image and obtaining additional information, providing required minimum sensitivity and accuracy of characterizing discontinuities are maintained. Computer enhanced images shall be clearly marked that enhancement was used and enhancement procedures identified.

8.35.4 Records—Radiation Imaging Examinations. Examinations, which are used for acceptance or rejection of welds, shall be recorded on an acceptable medium. The record shall be in-motion or static, whichever is used to accept or reject the welds. A written record shall be included with the recorded images giving the following information as a minimum:

(1) Identification and description of welds examined

(2) Procedure(s) used

(3) Equipment used

(4) Location of the welds within the recorder medium

(5) Results, including a list of unacceptable welds and repairs and their locations within the recorded medium.

Table 8.1
Visual Inspection Acceptance Criteria (see 8.9)

Discontinuity Category and Inspection Criteria	Statically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections
(1) Crack Prohibition Any crack shall be unacceptable, regardless of size or location.	X	X
(2) Weld/Base Metal Fusion Complete fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 7.23.	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A514, A517, and A709 Grade HPS 100W [HPS 690W] steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in [mm] — U, allowable decrease from L, in [mm] ≤ 3/16 [5] — ≤ 1/16 [2] 1/4 [6] — ≤ 3/32 [2.5] ≥ 5/16 [8] — ≤ 1/8 [3] In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, underrun shall be prohibited at the ends for a length equal to twice the width of the flange.	X	X
(7) Undercut (A) For material less than 1 in [25 mm] thick, undercut shall not exceed 1/32 in [1 mm], with the following exception: undercut shall not exceed 1/16 in [2 mm] for any accumulated length up to 2 in [50 mm] in any 12 in [300 mm]. For material equal to or greater than 1 in [25 mm] thick, undercut shall not exceed 1/16 in [2 mm] for any length of weld.	X	
(B) In primary members, undercut shall be no more than 0.01 in [0.25 mm] deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in [1 mm] deep for all other cases.		X
(8) Porosity (A) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in [1 mm] or greater in diameter shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.	X	
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.		X
(C) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in [100 mm] of length and the maximum diameter shall not exceed 3/32 in [2.5 mm].		X

Note: An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

Table 8.2
UT Acceptance-Rejection Criteria (Statically Loaded Nontubular Connections and Cyclically Loaded Nontubular Connections in Compression) (see 8.13.1, 8.13.2(2), and C–8.25.6)

Discontinuity Severity Class	Weld Size[a] in inches [mm] and Search Unit Angle										
	5/16 through 3/4 [8–20]	> 3/4 through 1–1/2 [20–38]	> 1–1/2 through 2–1/2 [38–65]			> 2–1/2 through 4 [65–100]			> 4 through 8 [100–200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	–2 & lower	+1 & lower	+3 & lower	–5 & lower	–2 & lower	0 & lower	–7 & lower	–4 & lower	–1 & lower
Class B	+6	+3	–1 0	+2 +3	+4 +5	–4 –3	–1 0	+1 +2	–6 –5	–3 –2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	–2 to +2	+1 +2	+3 +4	–4 to +2	–1 to +2	+2 +3
Class D	+8 & up	+5 & up	+3 & up	+6 & up	+8 & up	+3 & up	+3 & up	+5 & up	+3 & up	+3 & up	+4 & up

[a] Weld size in butt joints shall be the nominal thickness of the thinner of the two parts being joined.

Notes:
1. Class B and C discontinuities shall be separated by at least 2L, L being the length of the longer discontinuity, except that when two or more such discontinuities are not separated by at least 2L, but the combined length of discontinuities and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the discontinuity shall be considered a single acceptable discontinuity.
2. Class B and C discontinuities shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the discontinuity length.
3. Discontinuities detected at "scanning level" in the root face area of CJP double groove weld joints shall be evaluated using an indication rating 4 dB more sensitive than described in 8.25.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d"). This shall not apply if the weld joint is backgouged to sound metal to remove the root face and MT used to verify that the root face has been removed.
4. ESW or EGW: Discontinuities detected at "scanning level" that exceed 2 in [50 mm] in length shall be suspected as being piping porosity and shall be further evaluated with radiography.
5. For indications that remain on the display as the search unit is moved, refer to 8.13.1.

Class A (large discontinuities)

Any indication in this category shall be rejected (regardless of length).

Class B (medium discontinuities)

Any indication in this category having a length greater than 3/4 in [20 mm] shall be rejected.

Class C (small discontinuities)

Any indication in this category having a length greater than 2 in [50 mm] shall be rejected.

Class D (minor discontinuities)

Any indication in this category shall be accepted regardless of length or location in the weld.

Scanning Levels

Sound path[b] in inches [mm]	Above Zero Reference, dB
through 2–1/2 [65 mm]	14
> 2–1/2 through 5 [65– 125 mm]	19
> 5 through 10 [125–250 mm]	29
> 10 through 15 [250– 380 mm]	39

[b] This column refers to sound path distance; NOT material thickness.

Table 8.3
UT Acceptance-Rejection Criteria (Cyclically Loaded Nontubular Connections in Tension) (see 8.13.2 and C–8.25.6)

Discontinuity Severity Class	Weld Size[a] in inches [mm] and Search Unit Angle										
	5/16 through 3/4 [8–20]	> 3/4 through 1–1/2 [20–38]	> 1–1/2 through 2–1/2 [38–65]			> 2–1/2 through 4 [65–100]			> 4 through 8 [100–200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+10 & lower	+8 & lower	+4 & lower	+7 & lower	+9 & lower	+1 & lower	+4 & lower	+6 & lower	–2 & lower	+1 & lower	+3 & lower
Class B	+11	+9	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	–1 0	+2 +3	+4 +5
Class C	+12	+10	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7
Class D	+13 & up	+11 & up	+9 & up	+12 & up	+14 & up	+6 & up	+9 & up	+11 & up	+3 & up	+6 & up	+8 & up

[a] Weld size in butt joints shall be the nominal thickness of the thinner of the two parts being joined.

Notes:
1. Class B and C discontinuities shall be separated by at least 2L, L being the length of the longer discontinuity, except that when two or more such discontinuities are not separated by at least 2L, but the combined length of discontinuities and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the discontinuity shall be considered a single acceptable discontinuity.
2. Class B and C discontinuities shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the discontinuity length.
3. Discontinuities detected at "scanning level" in the root face area of CJP double groove weld joints shall be evaluated using an indication rating 4 dB more sensitive than described in 8.25.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d"). This shall not apply if the weld joint is backgouged to sound metal to remove the root face and MT used to verify that the root face has been removed.
4. For indications that remain on the display as the search unit is moved, refer to 8.13.2.1.

Class A (large discontinuities)
Any indication in this category shall be rejected (regardless of length).

Class B (medium discontinuities)
Any indication in this category having a length greater than 3/4 in [20 mm] shall be rejected.

Class C (small discontinuities)
Any indication in this category having a length greater than 2 in [50 mm] in the middle half or 3/4 in [20 mm] length in the top or bottom quarter of weld thickness shall be rejected.

Class D (minor discontinuities)
Any indication in this category shall be accepted regardless of length or location in the weld.

Scanning Levels

Sound path[b] in [mm]	Above Zero Reference, dB
through 2–1/2 [65 mm]	20
> 2–1/2 through 5 [65–125 mm]	25
> 5 through 10 [125–250 mm]	35
> 10 through 15 [250–380 mm]	45

[b] This column refers to sound path distance; NOT material thickness.

Table 8.4
Hole-Type IQI Requirements (see 8.17.1)

Nominal Material Thickness Range, in	Nominal Material Thickness Range, mm	Source Side	
		Designation	Essential Hole
Up to 0.25 incl.	Up to 6 incl.	10	4T
Over 0.25 to 0.375	Over 6 through 10	12	4T
Over 0.375 to 0.50	Over 10 through 12	15	4T
Over 0.50 to 0.625	Over 12 through 16	15	4T
Over 0.625 to 0.75	Over 16 through 20	17	4T
Over 0.75 to 0.875	Over 20 through 22	20	4T
Over 0.875 to 1.00	Over 22 through 25	20	4T
Over 1.00 to 1.25	Over 25 through 32	25	4T
Over 1.25 to 1.50	Over 32 through 38	30	2T
Over 1.50 to 2.00	Over 38 through 50	35	2T
Over 2.00 to 2.50	Over 50 through 65	40	2T
Over 2.50 to 3.00	Over 65 through 75	45	2T
Over 3.00 to 4.00	Over 75 through 100	50	2T
Over 4.00 to 6.00	Over 100 through 150	60	2T
Over 6.00 to 8.00	Over 150 through 200	80	2T

Table 8.5
Wire IQI Requirements (see 8.17.1)

Nominal Material Thickness Range, in	Nominal Material Thickness Range, mm	Source Side Essential Wire Identity
Up to 0.25 incl.	Up to 6 incl.	6
Over 0.25 to 0.375	Over 6 to 10	7
Over 0.375 to 0.625	Over 10 to 16	8
Over 0.625 to 0.75	Over 16 to 20	9
Over 0.75 to 1.50	Over 20 to 38	10
Over 1.50 to 2.00	Over 38 to 50	11
Over 2.00 to 2.50	Over 50 to 65	12
Over 2.50 to 4.00	Over 65 to 100	13
Over 4.00 to 6.00	Over 100 to 150	14
Over 6.00 to 8.00	Over 150 to 200	16

Table 8.6
IQI Selection and Placement (see 8.17.7)

	Equal T ≥ 10 in [250 mm] L		Equal T < 10 in [250 mm] L		Unequal T ≥ 10 in [250 mm] L		Unequal T < 10 in [250 mm] L	
IQI Types	Hole	Wire	Hole	Wire	Hole	Wire	Hole	Wire
Number of IQIs Nontubular	2	2	1	1	3	2	2	1
ASTM Standard Selection—	E1025	E747	E1025	E747	E1025	E747	E1025	E747
Table	8.4	8.5	8.4	8.5	8.4	8.5	8.4	8.5
Figures	8.6		8.7		8.8		8.9	

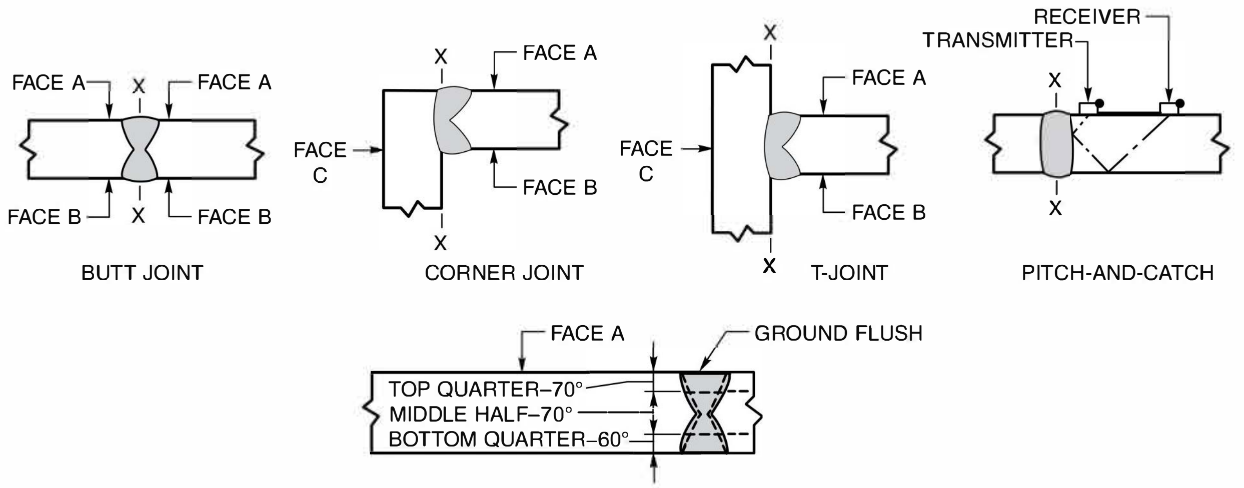
T = Nominal base metal thickness (T1 and T2 of Figures).
L = Weld Length in area of interest of each radiograph.
Note: T may be increased to provide for the thickness of allowable weld reinforcement provided shims are used under hole IQIs per 8.17.3.3.

Table 8.7
Testing Angle (see 8.25)

Procedure Chart

Material Thickness, in [mm]

Application	5/16 [8] to 1–1/2 [38]		> 1–1/2 [38] to 1–3/4 [45]		> 1–3/4 [45] to 2–1/2 [65]		> 2–1/2 [65] to 3–1/2 [90]		> 3–1/2 [90] to 4–1/2 [110]		> 4–1/2 [110] to 5 [130]		> 5 [130] to 6–1/2 [160]		> 6–1/2 [160] to 7 [180]		>7 [180] to 8 [200]	
		*		*		*		*		*		*		*		*		*
Butt Joint	1	O	1	F	1G or 4	F	1G or 5	F	6 or 7	F	8 or 10	F	9 or 11	F	12 or 13	F	12	F
T-Joint	1	O	1	F or XF	4	F or XF	5	F or XF	7	F or XF	10	F or XF	11	F or XF	13	F or XF	—	—
Corner Joint	1	O	1	F or XF	1G or 4	F or XF	1G or 5	F or XF	6 or 7	F or XF	8 or 10	F or XF	9 or 11	F or XF	13 or 14	F or XF	—	—
ESW/EGW Welds	1	O	1	O	1G or 4	1**	1G or 5	P1 or P3	6 or 7	P3	11 or 15	11 P3 15	11 or 15	P3	11 or 15	P3	11 or 15**	P3



Notes:
1. Where possible, all examinations shall be made from Face A and in Leg 1, unless otherwise specified in this table.
2. Root areas of single groove weld joints that have backing not requiring removal by contract, shall be tested in Leg 1, where possible, with Face A being that opposite the backing. (Grinding of the weld face or testing from additional weld faces may be necessary to permit complete scanning of the weld root.)
3. Examination in Leg II or III shall be made only to satisfy provisions of this table or when necessary to test weld areas made inaccessible by an unground weld surface, or interference with other portions of the weldment, or to meet the requirements of 8.25.6.2.
4. A maximum of Leg III shall be used only where thickness or geometry prevents scanning of complete weld areas and HAZs in Leg I or Leg II.
5. On tension welds in cyclically loaded structures, the top quarter of thickness shall be tested with the final leg of sound progressing from Face B toward Face A, the bottom quarter of thickness shall be tested with the final leg of sound progressing from Face A toward Face B; i.e., the top quarter of thickness shall be tested either from Face A in Leg II or from Face B in Leg I at the Contractor's option, unless otherwise specified in the contract documents.
6. The weld face indicated shall be ground flush before using procedure 1G, 6, 8, 9, 12, 14, or 15. Face A for both connected members shall be in the same plane.

(See Legend on next page)

Table 8.7 (Continued)
Testing Angle (see 8.25)

Legend:
X — Check from Face C.
G — Grind weld face flush.
O — Not required.
* — Required only where display reference height indication of discontinuity is noted at the weld metal-base metal interface while searching at scanning level with primary procedures selected from first column.
** — Use 15 in [400 mm] or 20 in [500 mm] screen distance calibration.
P — Pitch and catch shall be conducted for further discontinuity evaluation in only the middle half of the material thickness with only 45° or 70° transducers of equal specification, both facing the weld. (Transducers must be held in a fixture to control positioning—see sketch.) Amplitude calibration for pitch and catch is normally made by calibrating a single search unit. When switching to dual search units for pitch and catch inspection, there should be assurance that this calibration does not change as a result of instrument variables.
F — Weld metal-base metal interface indications shall be further evaluated with either 70°, 60°, or 45° transducer—whichever sound path is nearest to being perpendicular to the suspected fusion surface.
Face A — the face of the material from which the initial scanning is done (on T-and corner joints, follow above sketches).
Face B — opposite Face A (same plate).
Face C — the face opposite the weld on the connecting member or a T-or corner joint.

Procedure Legend			
	Area of Weld Thickness		
No.	Top Quarter	Middle Half	Bottom Quarter
1	70°	70°	70°
2	60°	60°	60°
3	45°	45°	45°
4	60°	70°	70°
5	45°	70°	70°
6	70° G Face A	70°	60°
7	60° Face B	70°	60°
8	70° G Face A	60°	60°
9	70° G Face A	60°	45°
10	60° Face B	60°	60°
11	45° Face B	70°**	45°
12	70° G Face A	45°	70° G Face B
13	45° Face B	45°	45°
14	70° G Face A	45°	45°
15	70° G Face A	70° A Face B	70° G Face B

Table 8.8
UT Equipment Qualification and Calibration Requirements (see 8.21.1)

		Type of Qualification or Calibration Activity: Description	Type of Qualification or Calibration Activity: Code Clause	Minimum Frequency: Minimum Frequency	Minimum Frequency: Code Clause
Equipment Qualification Procedures	Instruments	Horizontal Linearity	8.28.1	2 months	8.23.1
		Gain Control/dB Accuracy	8.28.2	2 months	8.23.2
	Search Units	Internal Reflections	8.28.3	40 hours of use[a]	8.23.3
		Angle Beam Search Units (Index Point, Angle)	8.27.2.1 8.27.2.2	8 hours of use[a]	8.23.4
	Instrument/Search Unit Combinations	Resolution (Angle Beam)	8.22.3 8.27.2.5	Prior to initial use[b]	8.22.3
		Resolution (Straight Beam)	8.27.1.3	Prior to initial use[b]	8.22.3
Calibration for Testing	Straight Beam (for Base Material Testing)	Range	8.24.4.1 or 8.27.1.1	Just prior to and at the location of the first weld tested[c]	8.24.2
		Sensitivity	8.24.4.2 or 8.27.1.2		
	Angle Beams	Range	8.24.5.1 8.27.2.3		
		Sensitivity	8.24.5.2 8.27.2.4		
		Index Point	8.27.2.1		
		Angle	8.27.2.2		
	Straight Beam and Angle Beam	Recalibration	8.24.3	2 hours[d]	8.24.3

[a] Must be performed for each search unit.
[b] Must be performed for each combination of search unit (transducer and shoe) and instrument prior to initial use.
[c] After the requirements of 8.24.2 are met the recalibration requirements of 8.24.3 shall apply.
[d] Or when electrical circuitry is disturbed in any way which includes the following:
(1) Transducer Change
(2) Battery Change
(3) Electrical outlet change
(4) Coaxial cable change
(5) Power outage (failure)

Legend for Figures 8.1, 8.2, and 8.3

Dimensions of Discontinuities

B = Maximum allowed dimension of a radiographed discontinuity.
L = Largest dimension of a radiographed discontinuity.
L' = Largest dimension of adjacent discontinuities.
C = Minimum clearance measured along the longitudinal axis of the weld between edges of porosity or fusion-type discontinuities (larger of adjacent discontinuities governs), or to an edge or an end of an intersecting weld.
C1= Minimum allowed distance between the nearest discontinuity to the free edge of a plate or tubular, or the intersection of a longitudinal weld with a girth weld, measured parallel to the longitudinal weld axis.
W = Smallest dimension of either of adjacent discontinuities.

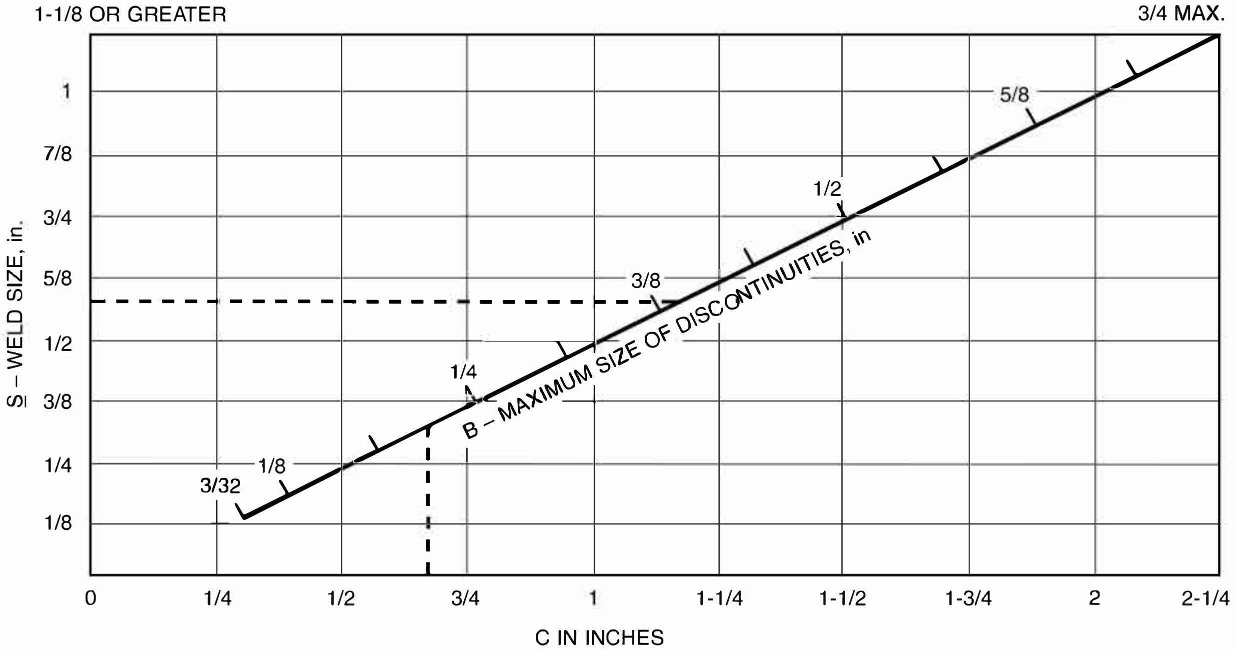
Material Dimensions

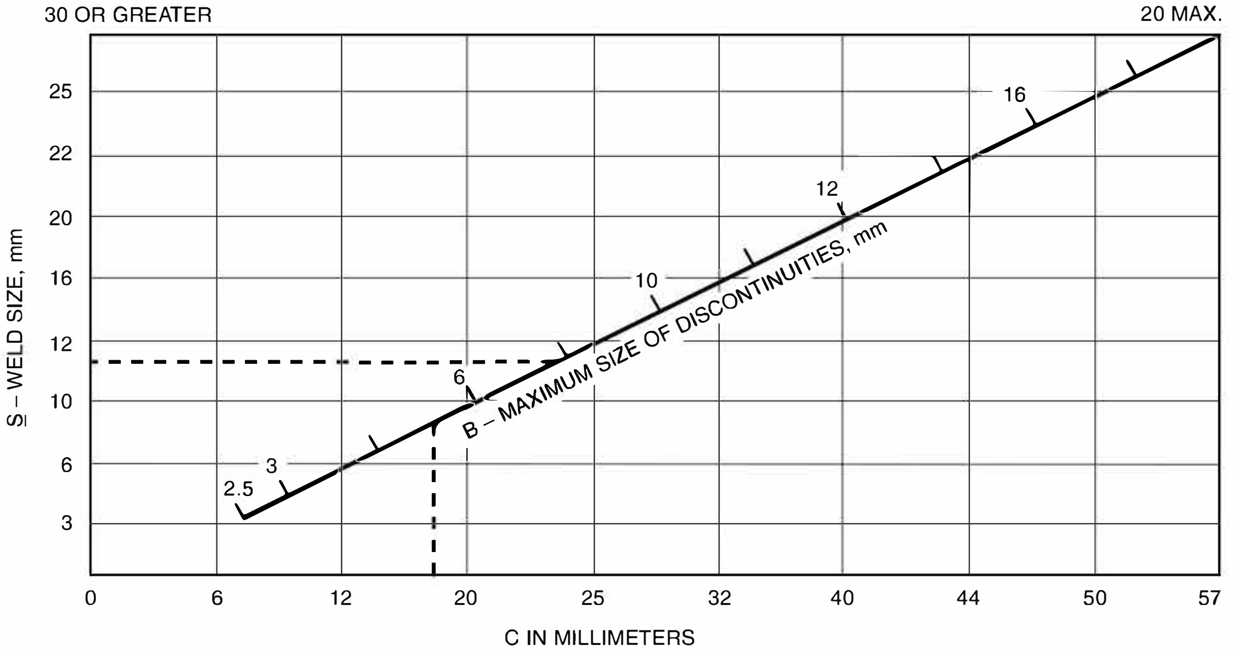
S = Weld size

T = Plate or pipe thickness for CJP groove welds

Definitions of Discontinuities

- An elongated discontinuity shall have the largest dimension (L) exceed 3 times the smallest dimension.
- A rounded discontinuity shall have the largest dimension (L) less than or equal to 3 times the smallest dimension.
- A cluster shall be defined as a group of nonaligned, acceptably-sized, individual adjacent discontinuities with spacing less than the minimum allowed (C) for the largest individual adjacent discontinuity (L'), but with the sum of the greatest dimensions (L) of all discontinuities in the cluster equal to or less than the maximum allowable individual discontinuity size (B). Such clusters shall be considered as individual discontinuities of size L for the purpose of assessing minimum spacing.
- Aligned discontinuities shall have the major axes of each discontinuity approximately aligned.



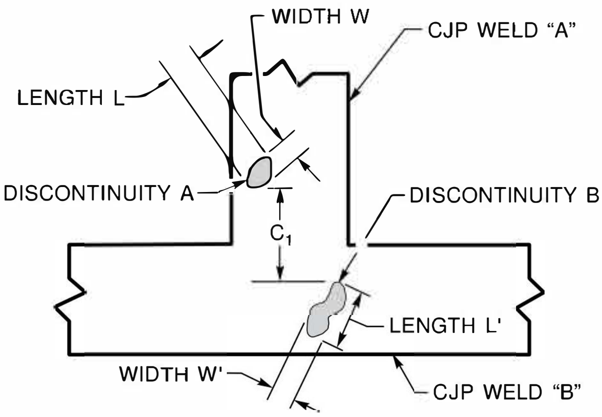


Notes:
1. To determine the maximum size of discontinuity allowed in any joint or weld size, project S horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size greater than or equal to 3/32 in [2.5 mm], project B vertically to C.
3. See Legend on page 246 for definitions.

Figure 8.1—Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections (see 8.12.1 and 10.25.2 for tubulars)

KEY FOR FIGURE 8.1, CASES I, II, III, AND IV

DISCONTINUITY A = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD A
DISCONTINUITY B = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD B
L AND W = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY A
L' AND W' = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY B
S = WELD SIZE
C_1 = SHORTEST DISTANCE PARALLEL TO THE WELD A AXIS, BETWEEN THE NEAREST DISCONTINUITY EDGES



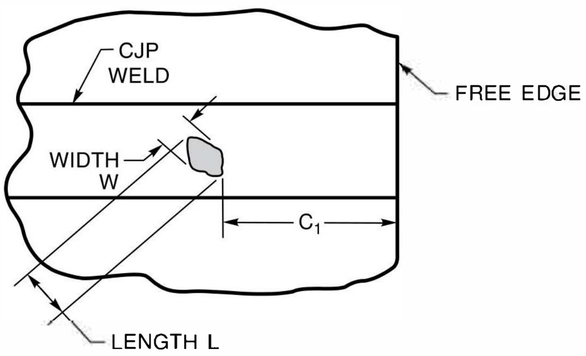
CASE I DISCONTINUITY LIMITATIONS[a]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	< S/3, ≤ 1/4 in [6 mm]	S ≤ 2 in [50 mm]
	≤ 3/8 in [10 mm]	S > 2 in [50 mm]
C_1	≥ 3L	(A) ONE DISCONTINUITY ROUNDED, THE OTHER ROUNDED OR ELONGATED[a] (B) L ≥ 3/32 in [2.5 mm]

[a] The elongated discontinuity may be located in either weld "A" or "B." For the purposes of this illustration the elongated discontinuity "B" was located in weld "B."

Case I—Discontinuity at Weld Intersection

Figure 8.1 (Continued)—Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections (see 8.12.1 and 10.25.2 for tubulars)

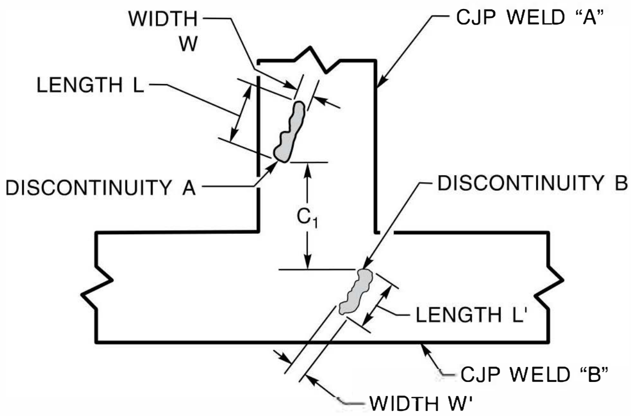


CASE II DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	< S/3, ≤ 1/4 in [6 mm]	S ≤ 2 in [50 mm]
	≤ 3/8 in [10 mm]	S > 2 in [50 mm]
C_1	≥ 3L	L ≥ 3/32 in [2.5 mm]

Case II—Discontinuity at Free Edge of CJP Groove Weld

Figure 8.1 (Continued)—Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections (see 8.12.1 and 10.25.2 for tubulars)

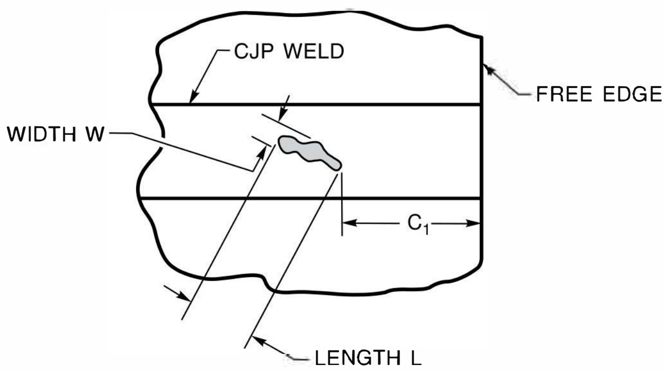


CASE III DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	≤ S/3	L/W > 3
C_1	> 3L OR 2S, WHICHEVER IS GREATER	L ≥ 3/32 in [2.5 mm]

Case III—Discontinuity at Weld Intersection

Figure 8.1 (Continued)—Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections (see 8.12.1 and 10.25.2 for tubulars)

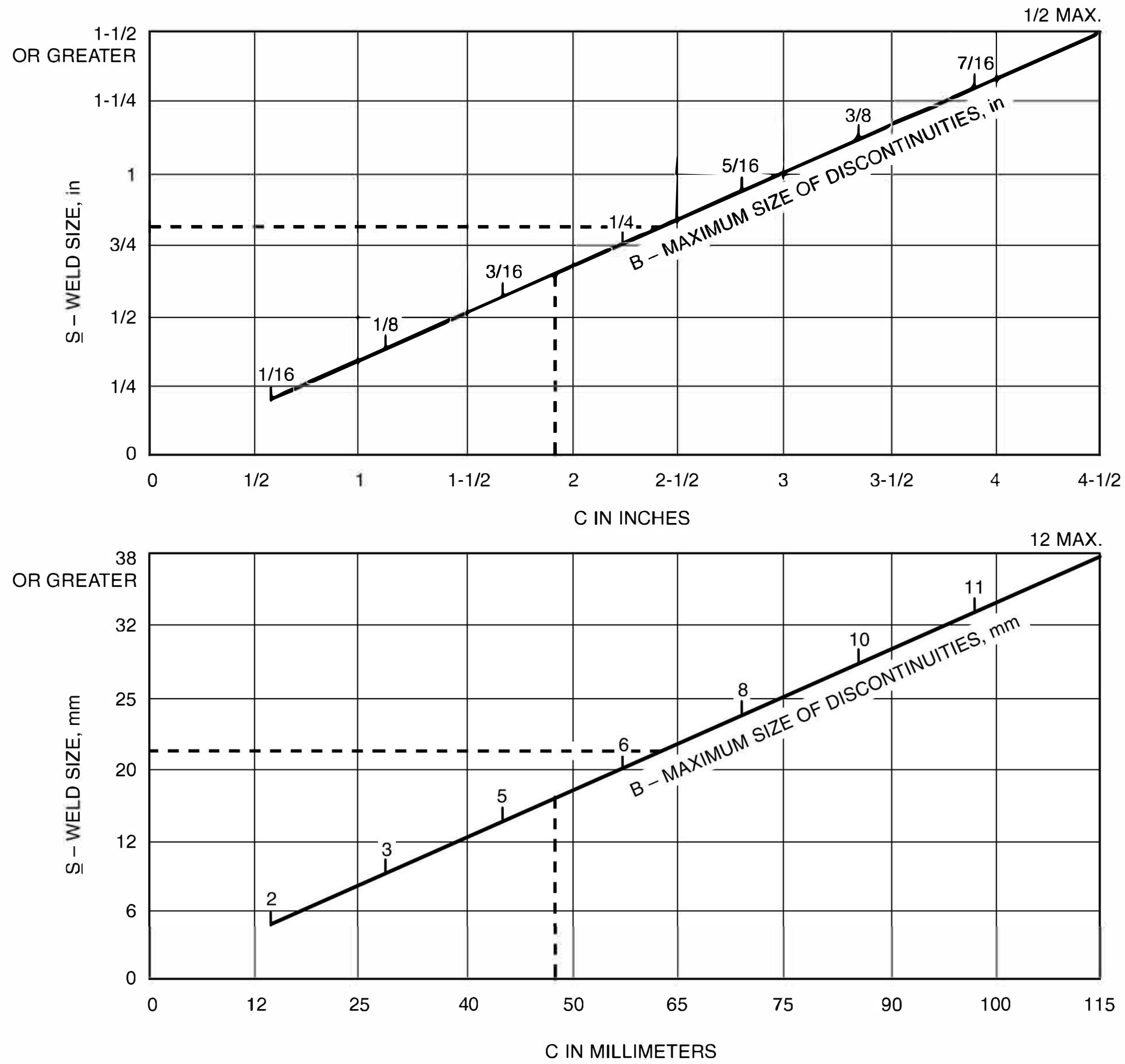


CASE IV DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	≤ S/3	L/W > 3
C_1	≥ 3L OR 2S, WHICHEVER IS GREATER	L ≥ 3/32 in [2.5 mm]

Case IV—Discontinuity at Free Edge of CJP Groove Weld

Figure 8.1 (Continued)—Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections (see 8.12.1 and 10.25.2 for tubulars)

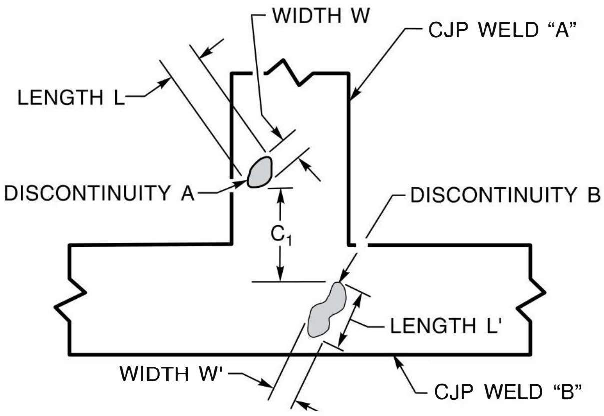


Notes:
1. To determine the maximum size of discontinuity allowed in any joint or weld size, project S horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size, project B vertically to C.
3. See Legend on page 246 for definitions.

Figure 8.2—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities) (see 8.12.2.1)

KEY FOR FIGURE 8.2, CASES I, II, III AND IV

DISCONTINUITY A = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD A
DISCONTINUITY B = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD B
L AND W = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY A
L' AND W' = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY B
S = WELD SIZE
C_1 = SHORTEST DISTANCE PARALLEL TO THE WELD A AXIS, BETWEEN THE NEAREST DISCONTINUITY EDGES



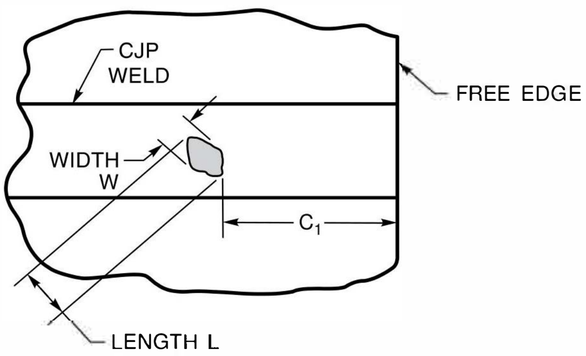
CASE I DISCONTINUITY LIMITATIONS[a]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.2 GRAPH (B DIMENSION)	L ≥ 1/16 in [2 mm]
C_1	SEE FIGURE 8.2 GRAPH (C DIMENSION)	—

[a] The elongated discontinuity may be located in either weld "A" or "B." For the purposes of this illustration the elongated discontinuity "B" was located in weld "B."

Case I—Discontinuity at Weld Intersection

Figure 8.2 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities) (see 8.12.2.1)

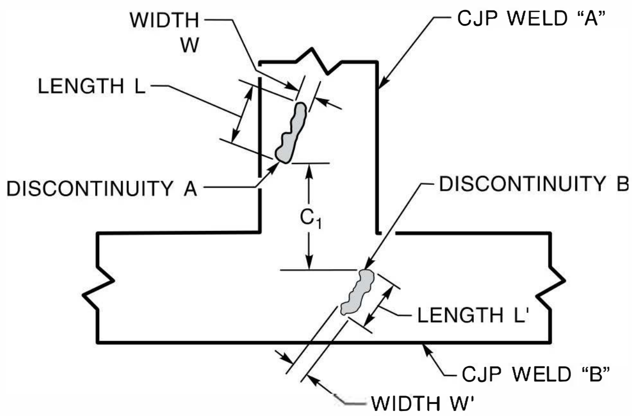


CASE II DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.2 GRAPH (B DIMENSION)	L ≥ 1/16 in [2 mm]
C_1	SEE FIGURE 8.2 GRAPH (C DIMENSION)	—

Case II—Discontinuity at Free Edge of CJP Groove Weld

Figure 8.2 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities) (see 8.12.2.1)

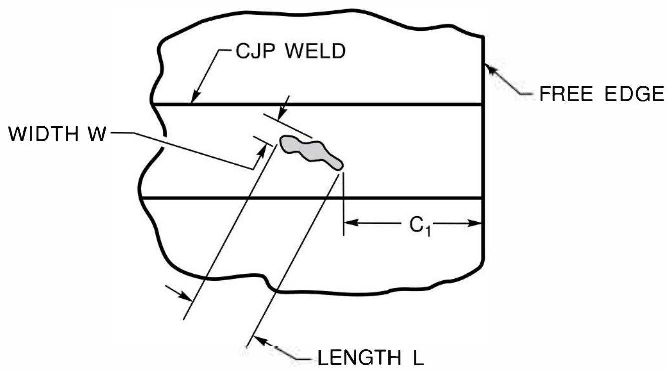


CASE III DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.2 GRAPH (B DIMENSION)	L ≥ 1/16 in [2 mm]
C_1	SEE FIGURE 8.2 GRAPH (C DIMENSION)	—

Case III—Discontinuity at Weld Intersection

Figure 8.2 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities) (see 8.12.2.1)

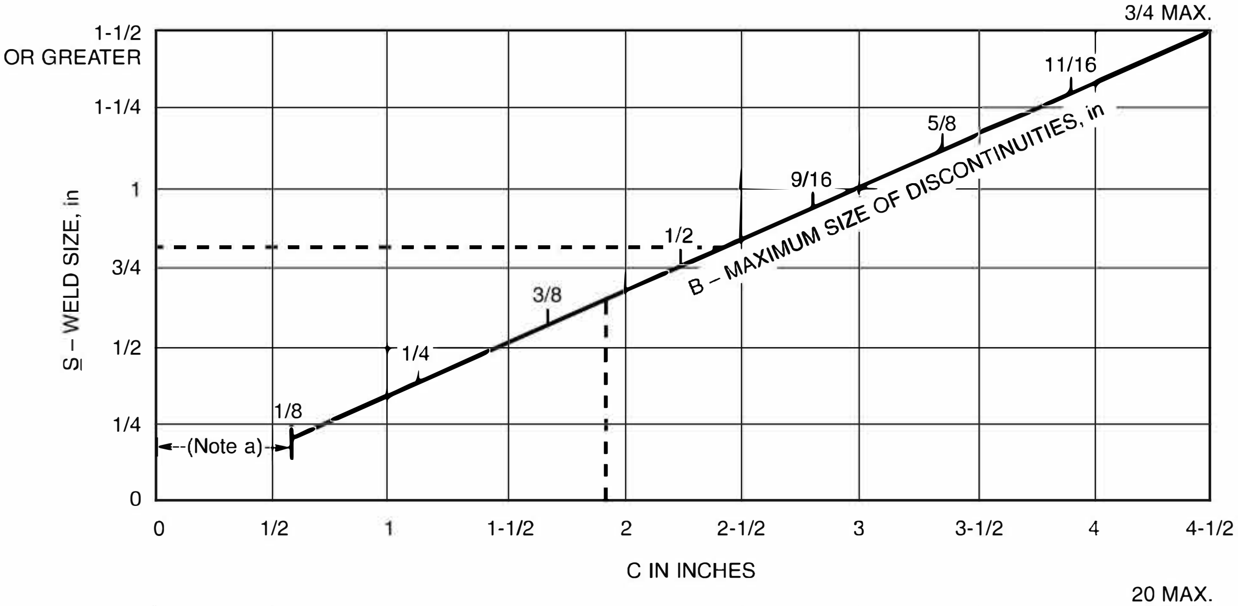


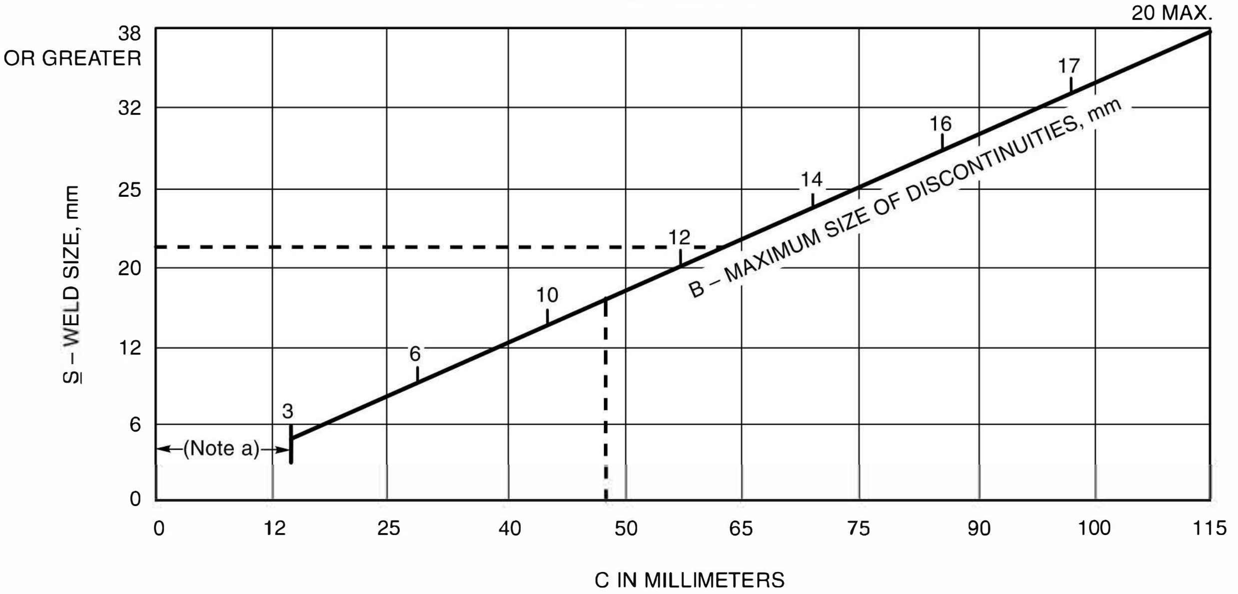
CASE IV DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.2 GRAPH (B DIMENSION)	L ≥ 1/16 in [2 mm]
C_1	SEE FIGURE 8.2 GRAPH (C DIMENSION)	—

Case IV—Discontinuity at Free Edge of CJP Groove Weld

Figure 8.2 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities) (see 8.12.2.1)





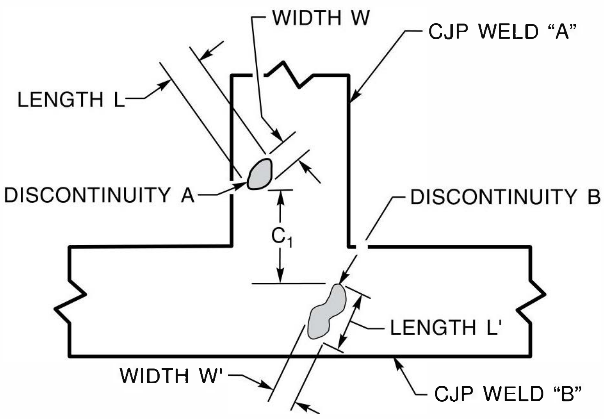
[a] The maximum size of a discontinuity located within this distance from an edge of plate shall be 1/8 in [3 mm], but a 1/8 in [3 mm] discontinuity shall be 1/4 in [6 mm] or more away from the edge. The sum of discontinuities less than 1/8 in [3 mm] in size and located within this distance from the edge shall not exceed 3/16 in [5 mm]. Discontinuities 1/16 in [2 mm] to less than 1/8 in [3 mm] shall not be restricted in other locations unless they are separated by less than 2 L (L being the length of the larger discontinuity); in which case, the discontinuities shall be measured as one length equal to the total length of the discontinuities and space and evaluated as shown in this figure.

Notes:
1. To determine the maximum size of discontinuity allowed in any joint or weld size, project S horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size, project B vertically to C.
3. See Legend on page 246 for definitions.

Figure 8.3—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities) (see 8.12.2.2)

KEY FOR FIGURE 8.3, CASES I, II, III, IV, AND V

DISCONTINUITY A = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD A
DISCONTINUITY B = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD B
L AND W = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY A
L' AND W' = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY B
S = WELD SIZE
C_1 = SHORTEST DISTANCE PARALLEL TO THE WELD A AXIS, BETWEEN THE NEAREST DISCONTINUITY EDGES



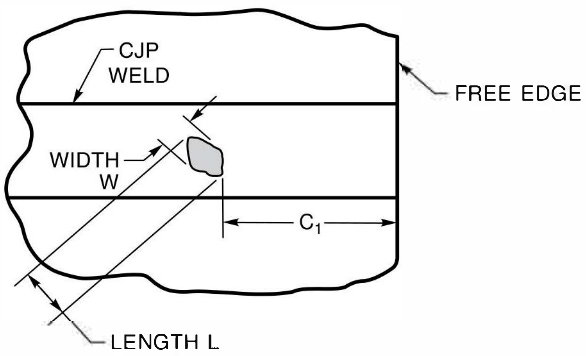
CASE I DISCONTINUITY LIMITATIONS[a]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.3 GRAPH (B DIMENSION)	L ≥ 1/8 in [3 mm]
C_1	SEE FIGURE 8.3 GRAPH (C DIMENSION)	C_1 ≥ 2L or 2L', WHICHEVER IS GREATER

[a] The elongated discontinuity may be located in either weld “A” or “B.” For the purposes of this illustration the elongated discontinuity “B” was located in weld “B.”

Case I—Discontinuity at Weld Intersection

Figure 8.3 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities) (see 8.12.2.2)

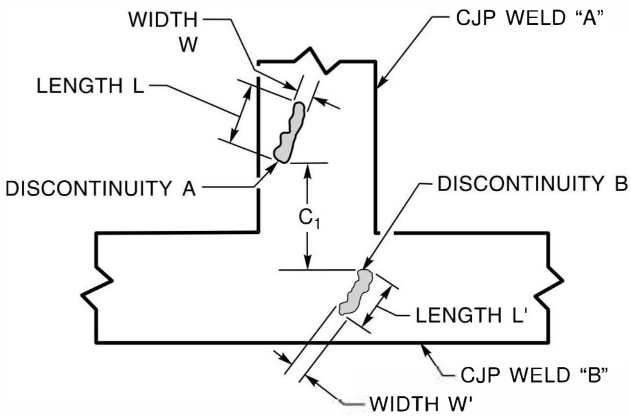


CASE II DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.3 GRAPH (B DIMENSION)	L ≥ 1/8 in [3 mm]
C_1	SEE FIGURE 8.3 GRAPH (C DIMENSION)	C_1 ≥ 5/8 in [16 mm]

Case II—Discontinuity at Free Edge of CJP Groove Weld

Figure 8.3 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities) (see 8.12.2.2)

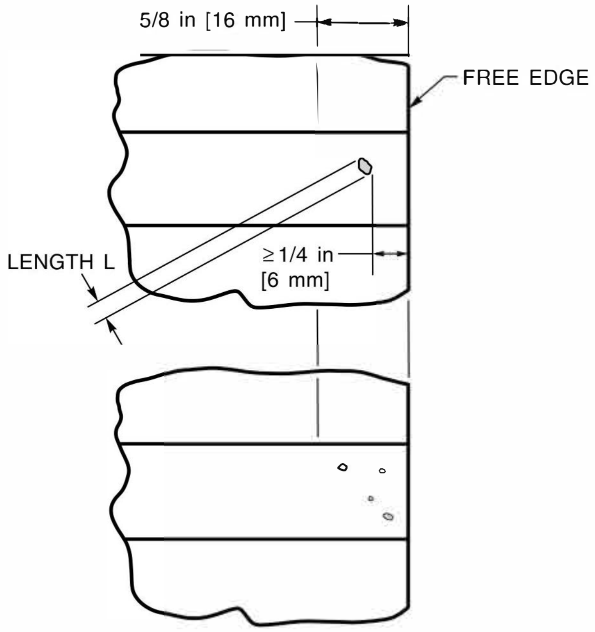


CASE III DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	SEE FIGURE 8.3 GRAPH (B DIMENSION)	L ≥ 1/8 in [3 mm]
C_1	SEE FIGURE 8.3 GRAPH (C DIMENSION)	C_1 ≥ 2L or 2L', WHICHEVER IS GREATER

Case III—Discontinuity at Weld Intersection

Figure 8.3 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities) (see 8.12.2.2)

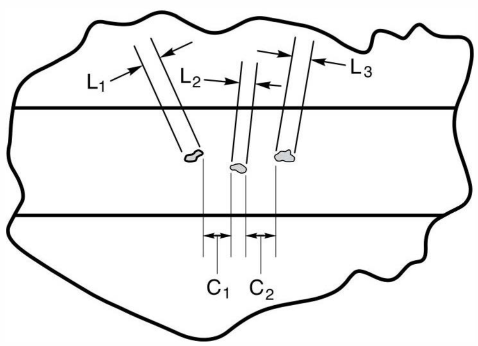


(A) MINIMUM DIMENSION FROM FREE EDGE TO 1/8 in [3 mm] DISCONTINUITY

(B) SUM OF ALL L (LARGEST) DISCONTINUITY DIMENSIONS, EACH LESS THAN 1/8 in [3 mm], SHALL BE EQUAL TO OR LESS THAN 3/16 in [5 mm].

Note: All dimensions between discontinuities ≥ 2L (L being largest of any two)

Case IV—Discontinuities Within 5/8 in [16 mm] of a Free Edge



(A) ALL L DIMENSIONS ARE GREATER THAN 1/16 in [2 mm] BUT LESS THAN 1/8 in [3 mm]

(B) IF C_1 IS LESS THAN THE LARGER OF L_1 AND L_2 AND C_2 IS LSS THAN THE LARFGER OF L_2 AND L_3, ADD $L_1 + L_2 + L_3 + C_1 + C_2$ AND TREAT AS SINGLE DISCONTINUITY

Note: The weld shown above is for illustration only. These limitations apply to all locations or intersections. The number of discontinuities is also for illustration only.

Case V—Discontinuities Separated by Less Than 2L Anywhere in Weld (Use Figure 8.3 Graph "B" Dimension for Single Flaw)

Figure 8.3 (Continued)—Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities) (see 8.12.2.2)

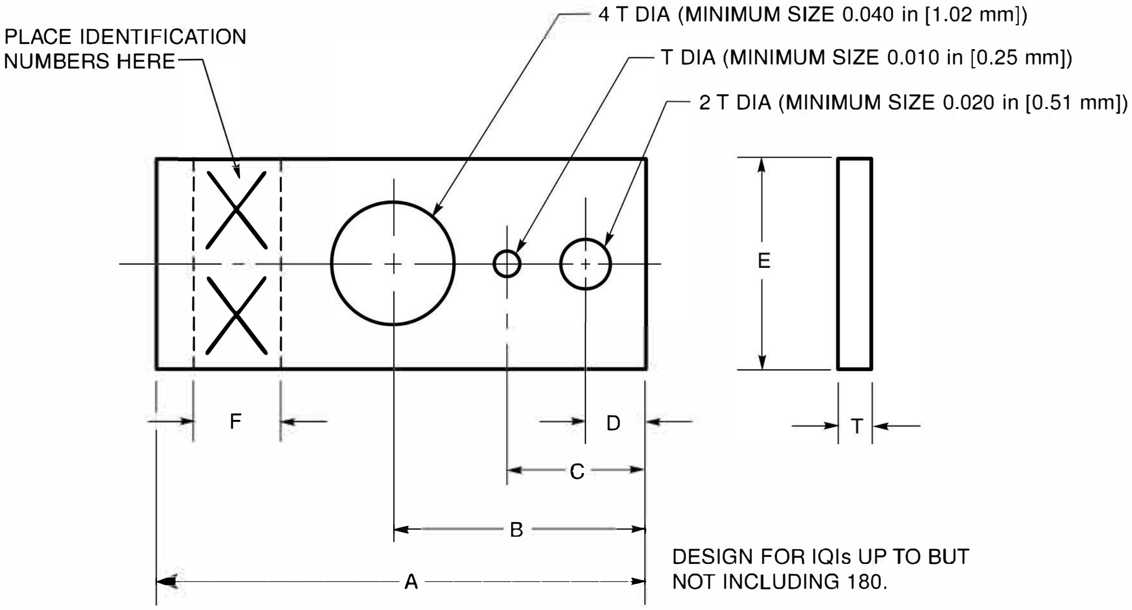


Table of Dimensions of IQI (in)

Number[a]	A	B	C	D	E	F	IQI Thickness and Hole Diameter Tolerances
5–20	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 0.0005
21–59	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 0.0025
60–179	2.250 ± 0.030	1.375 ± 0.030	0.750 ± 0.015	0.375 ± 0.030	1.000 ± 0.030	0.375 ± 0.030	± 0.005

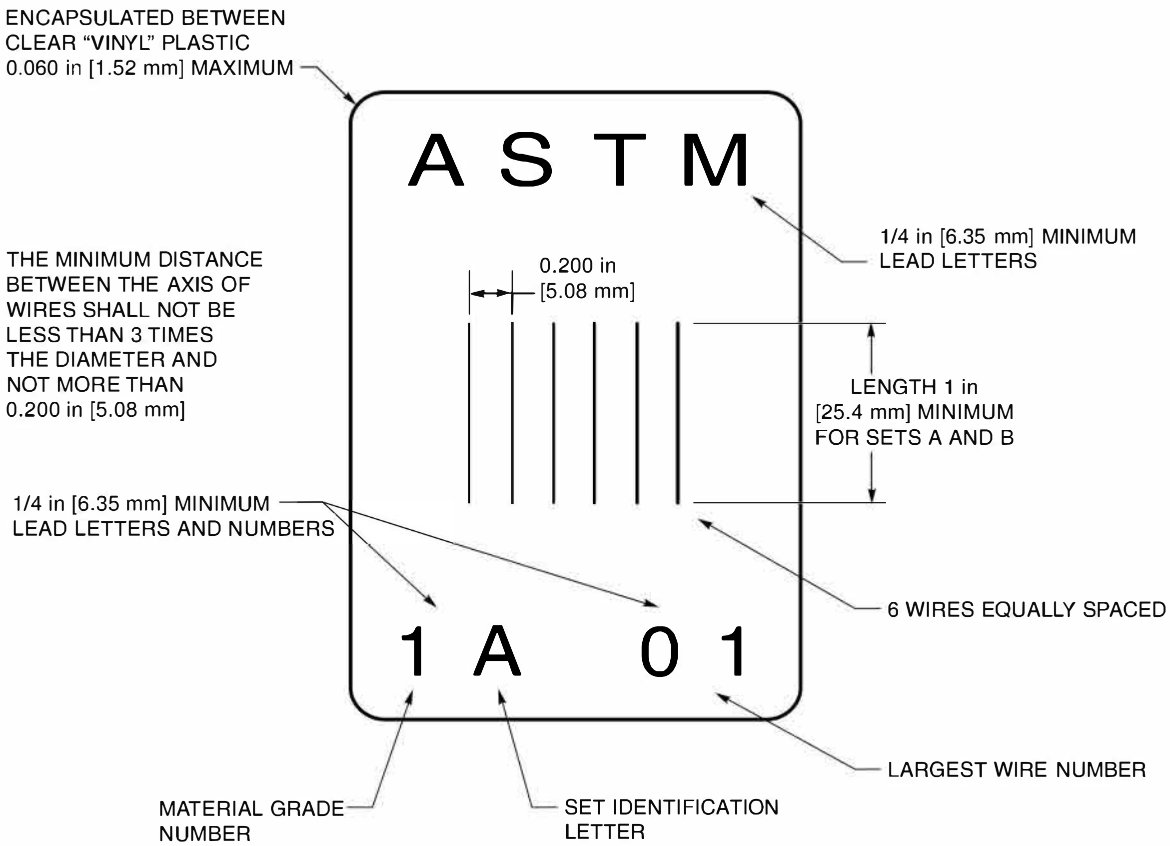
Table of Dimensions of IQI (mm)

Number[a]	A	B	C	D	E	F	IQI Thickness and Hole Diameter Tolerances
5–20	38.10 ± 0.38	19.05 ± 0.38	11.13 ± 0.38	6.35 ± 0.38	12.70 ± 0.38	6.35 ± 0.38	± 0.013
21–59	38.10 ± 0.38	19.05 ± 0.38	11.13 ± 0.38	6.35 ± 0.38	12.70 ± 0.38	6.35 ± 0.38	± 0.06
60–179	57.15 ± 0.80	34.92 ± 0.80	19.05 ± 0.80	9.52 ± 0.80	25.40 ± 0.80	9.525 ± 0.80	± 0.13

[a] IQIs No. 5 through 9 are not 1T, 2T, and 4T.

Note: Holes shall be true and normal to the IQI. Do not chamfer.

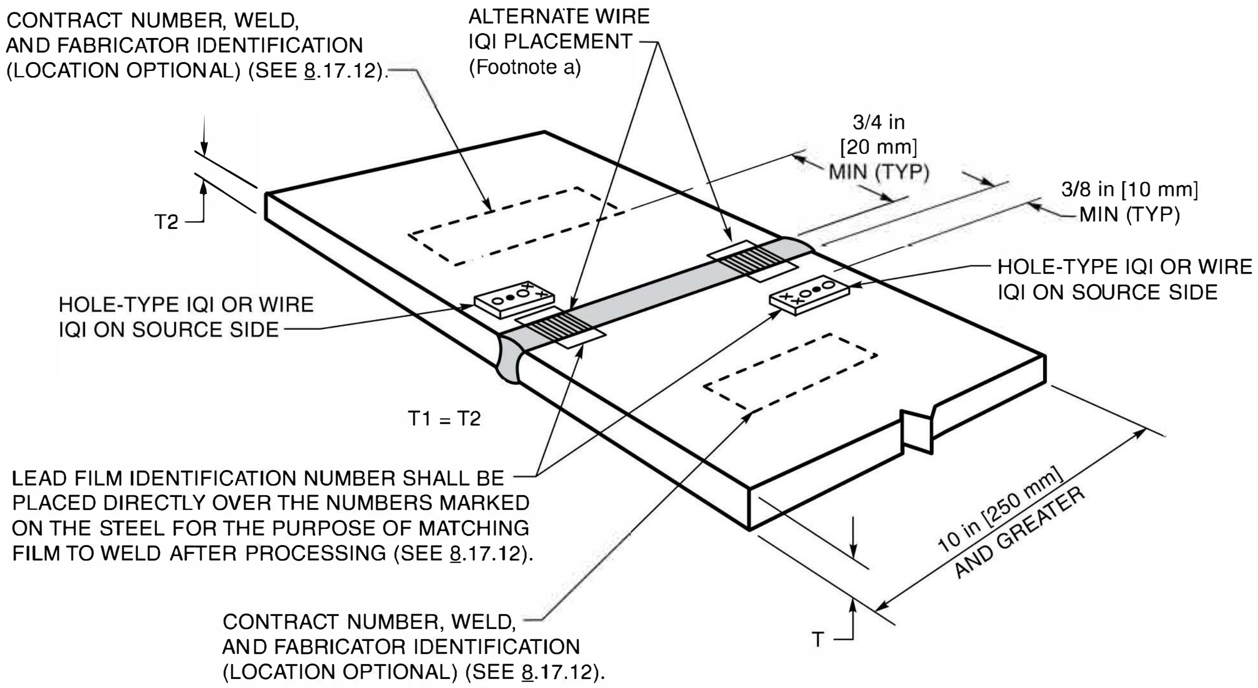
Figure 8.4—Hole-Type IQI (see 8.17.1 and 10.28.1)
(Reprinted by permission of the ASTM International, copyright.)



Wire IQI Sizes and Wire Identity Numbers

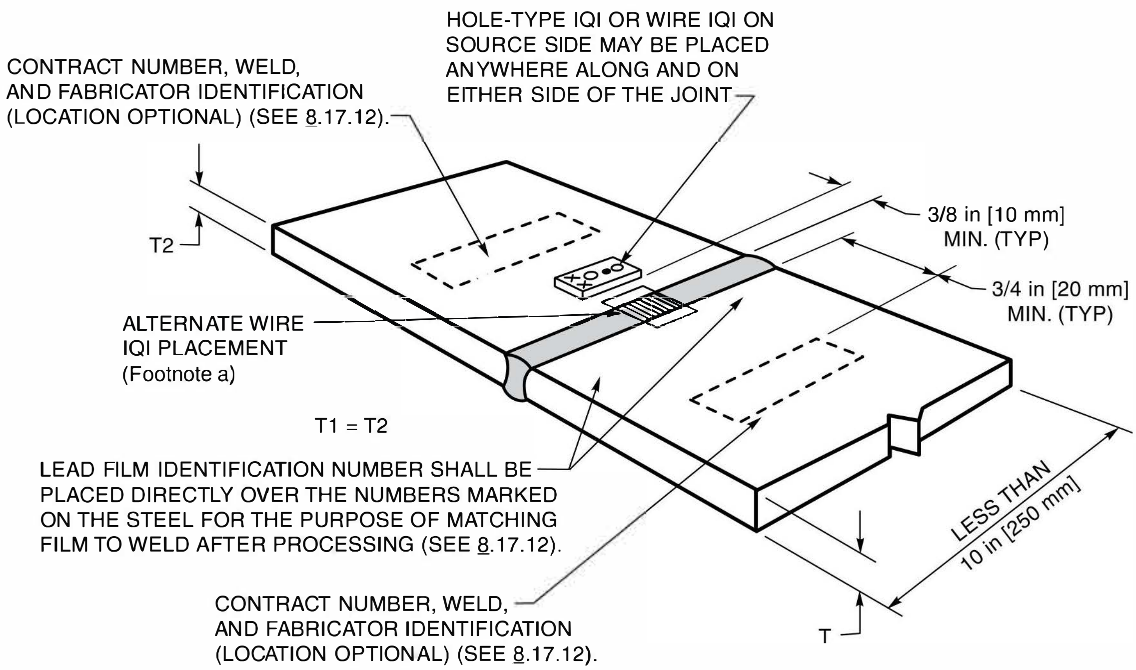
Set A		Set B		Set C		Set D	
Wire Diameter in [mm]	Wire Identity	Wire Diameter in [mm]	Wire Identity	Wire Diameter in [mm]	Wire Identity	Wire Diameter in [mm]	Wire Identity
0.0032 [0.08]	1	0.010 [0.25]	6	0.032 [0.81]	11	0.10 [2.5]	16
0.004 [0.1]	2	0.013 [0.33]	7	0.040 [1.02]	12	0.125 [3.2]	17
0.005 [0.13]	3	0.016 [0.4]	8	0.050 [1.27]	13	0.160 [4.06]	18
0.0063 [0.16]	4	0.020 [0.51]	9	0.063 [1.6]	14	0.20 [5.1]	19
0.008 [0.2]	5	0.025 [0.64]	10	0.080 [2.03]	15	0.25 [6.4]	20
0.010 [0.25]	6	0.032 [0.81]	11	0.100 [2.5]	16	0.32 [8]	21

Figure 8.5—Wire IQI (see 8.17.1 and 10.27.1)
(Reprinted by permission of the ASTM International, copyright.)



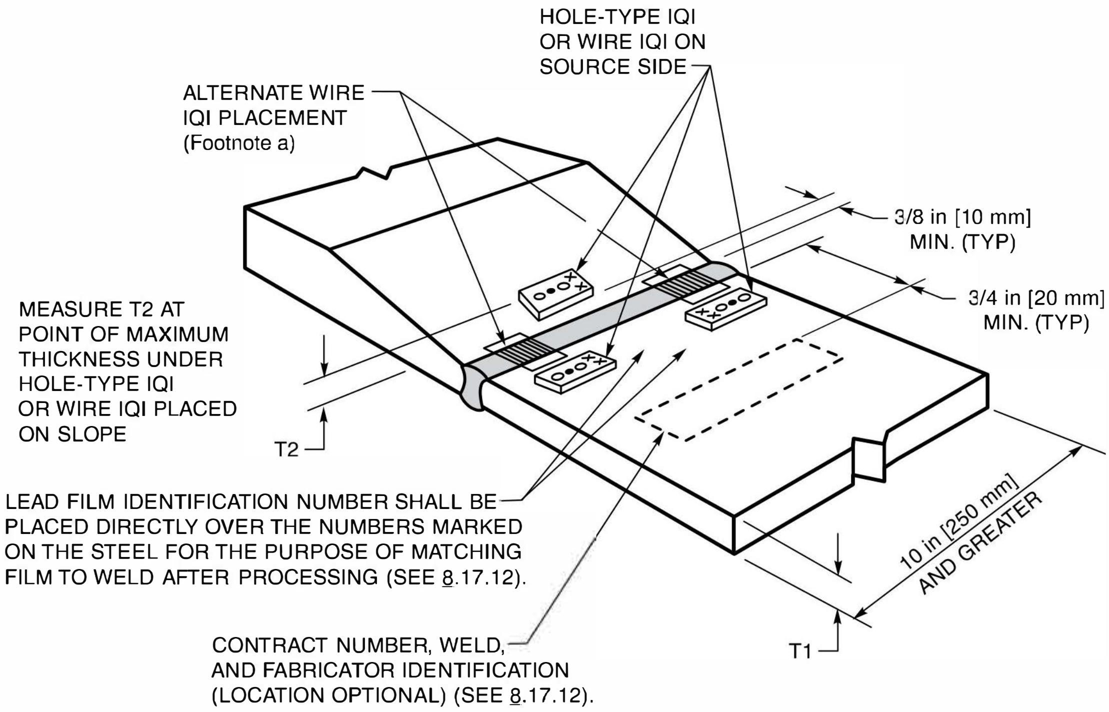
[a] Alternate source side IQI placement allowed for tubular applications and other applications when approved by the Engineer.

Figure 8.6—RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length (see 8.17.7 and 10.27.2)



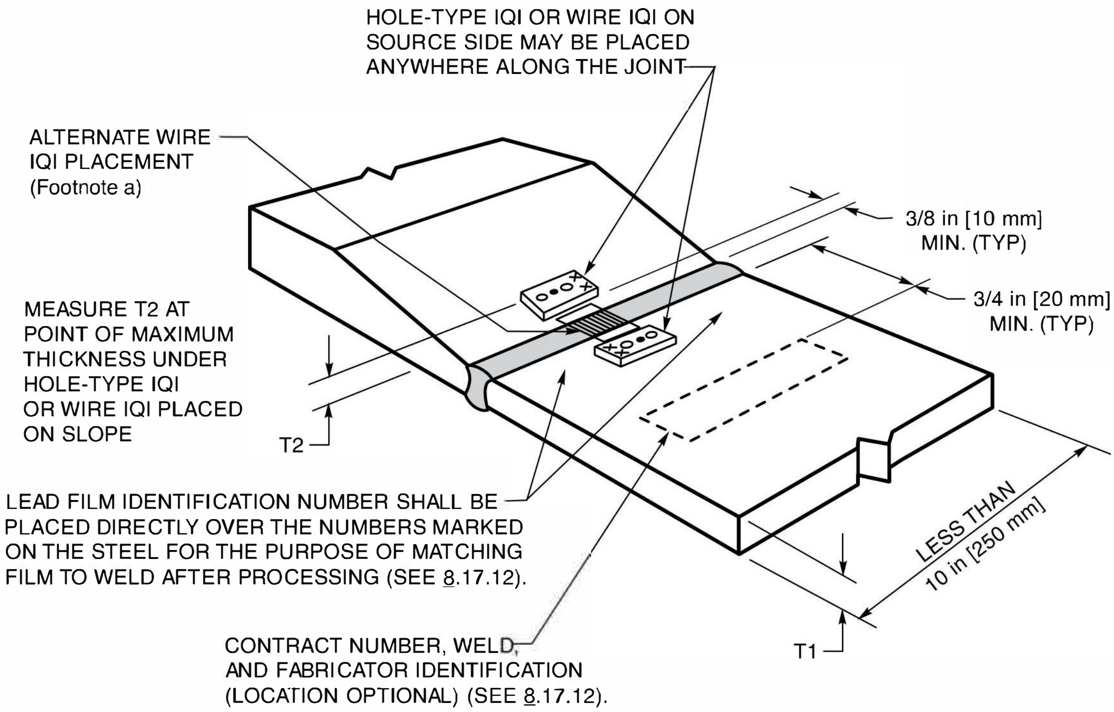
[a] Alternate source side IQI placement allowed for tubular applications and other applications when approved by the Engineer.

Figure 8.7—RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less than 10 in [250 mm] in Length (see 8.17.7 and 10.27.2)



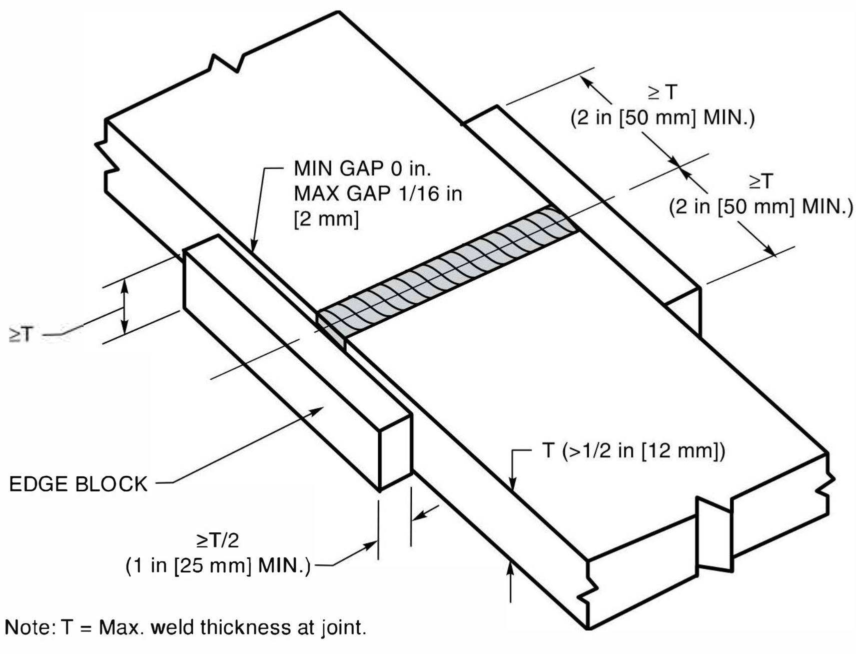
[a] Alternate source side IQI placement allowed for tubular applications and other applications when approved by the Engineer.

Figure 8.8—RT Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length (see 8.17.7 and 10.27.2)



[a] Alternate source side IQI placement allowed for tubular applications and other applications when approved by the Engineer.

Figure 8.9—RT Identification and Hole-Type or Wire IQI Locations on Transition Joints Less than 10 in [250 mm] in Length (see 8.17.7 and 10.27.2)



Note: T = Max. weld thickness at joint.

Figure 8.10—RT Edge Blocks (see 8.17.13)

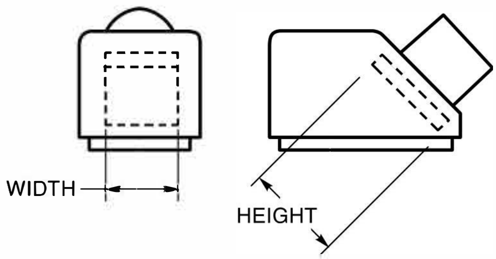


Figure 8.11—Transducer Crystal (see 8.21.7.2)

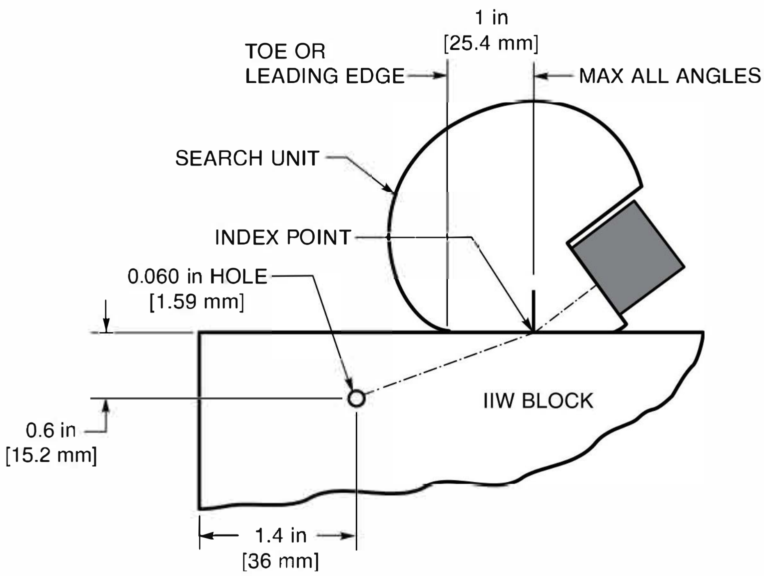
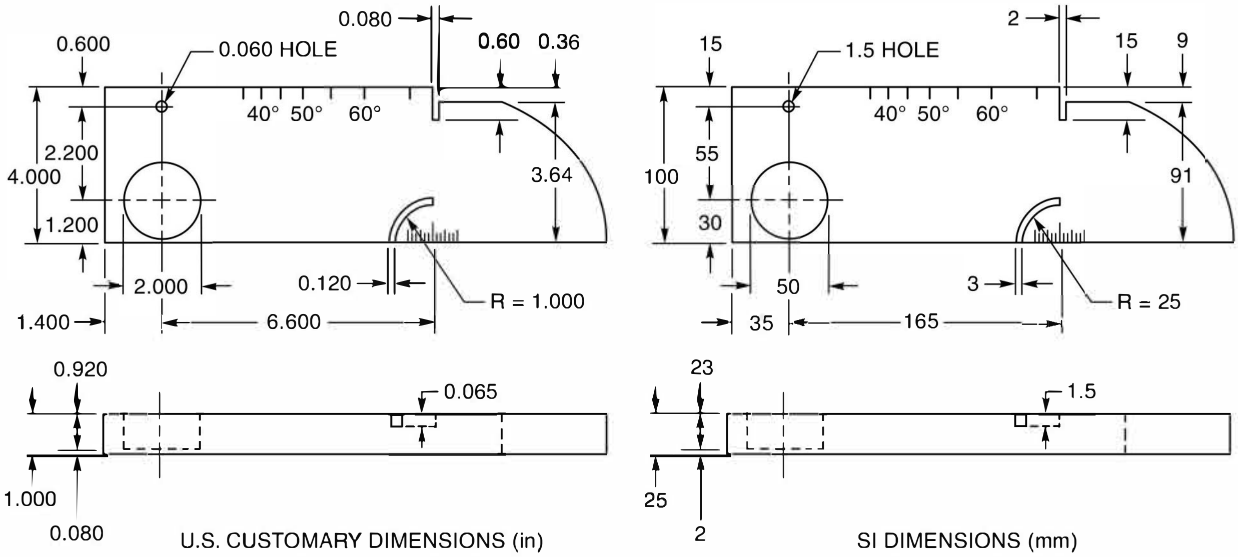
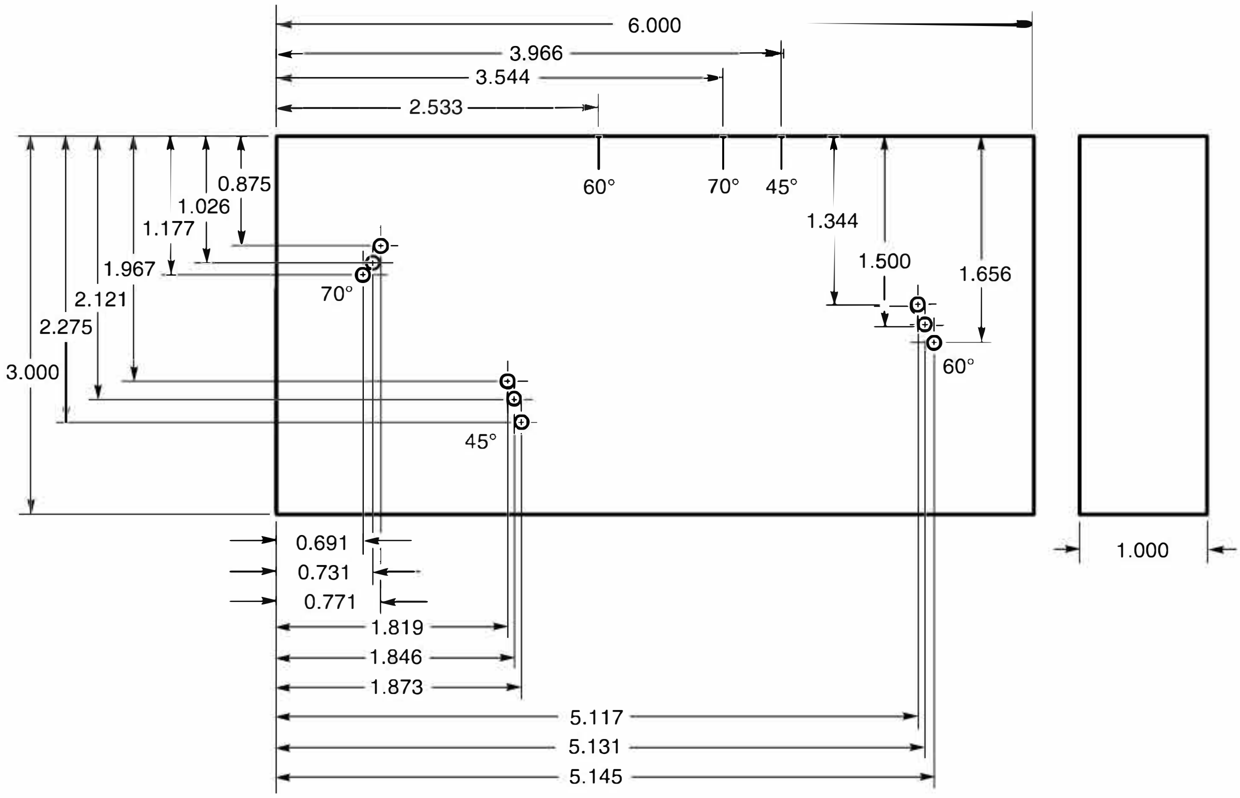


Figure 8.12—Qualification Procedure of Search Unit Using IIW Reference Block (see 8.21.7.7)



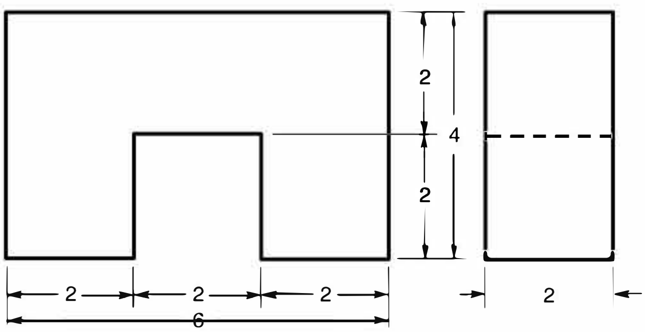
Notes:
1. The dimensional tolerance between all surfaces involved in referencing or calibrating shall be within ±0.005 in [0.13 mm] of detailed dimension.
2. The surface finish of all surfaces to which sound is applied or reflected from shall have a maximum of 125 μin [3.17 μm] r.m.s.
3. All material shall be ASTM A36 or acoustically equivalent.
4. All holes shall have a smooth internal finish and shall be drilled 90° to the material surface.
5. Degree lines and identification markings shall be indented into the material surface so that permanent orientation can be maintained.
6. These notes shall apply to all sketches in Figures 8.13 and 8.14.

Figure 8.13—Typical IIW Type Block (see 8.22.1)



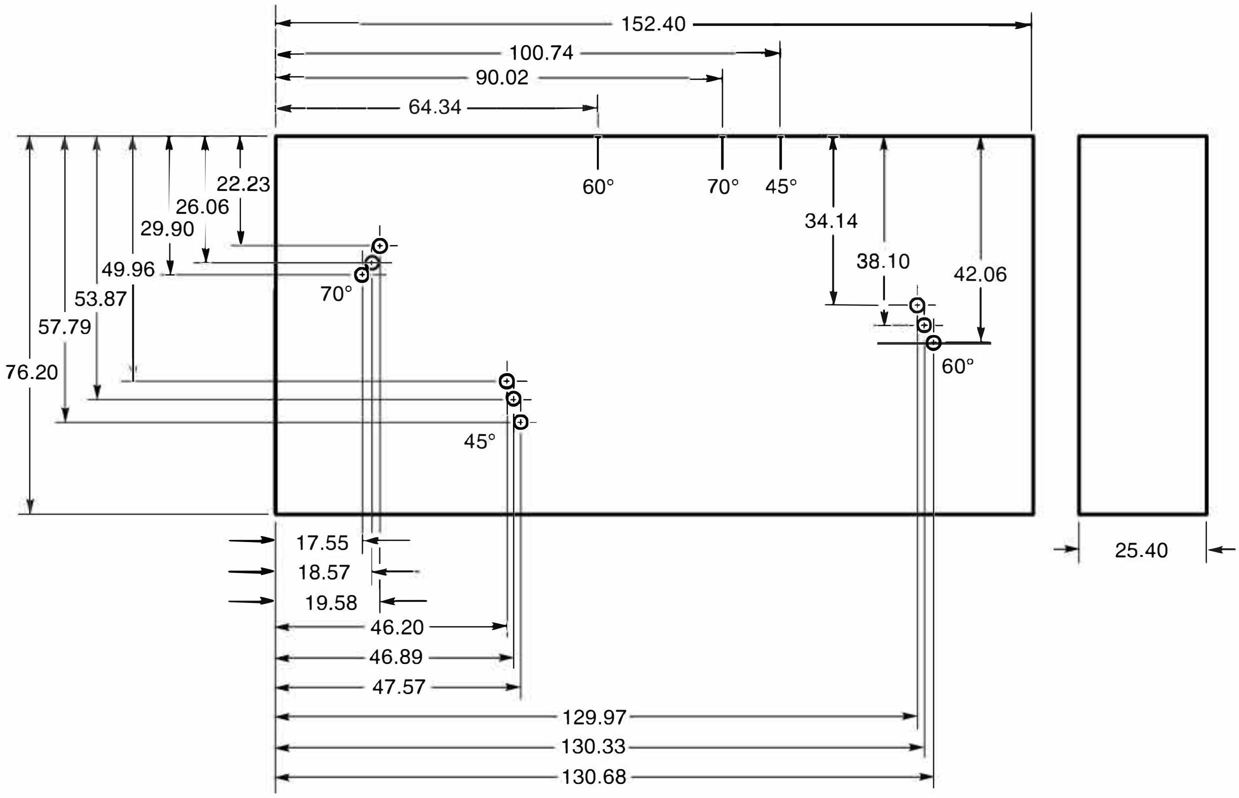
Note: All holes are 1/16 inch in diameter.

RC – RESOLUTION REFERENCE BLOCK



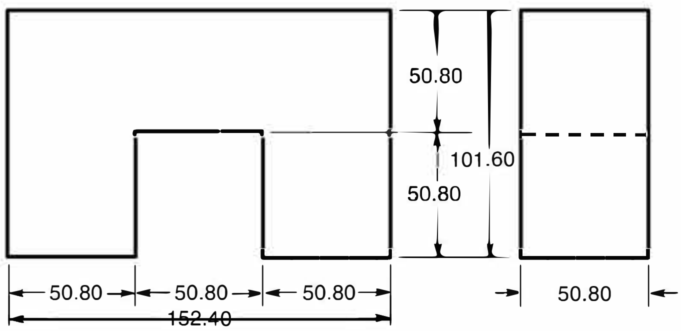
TYPE – DISTANCE AND SENSITIVITY REFERENCE BLOCK

Figure 8.14—Qualification Blocks (see 8.22.3 and 8.27) (Dimensions in Inches)



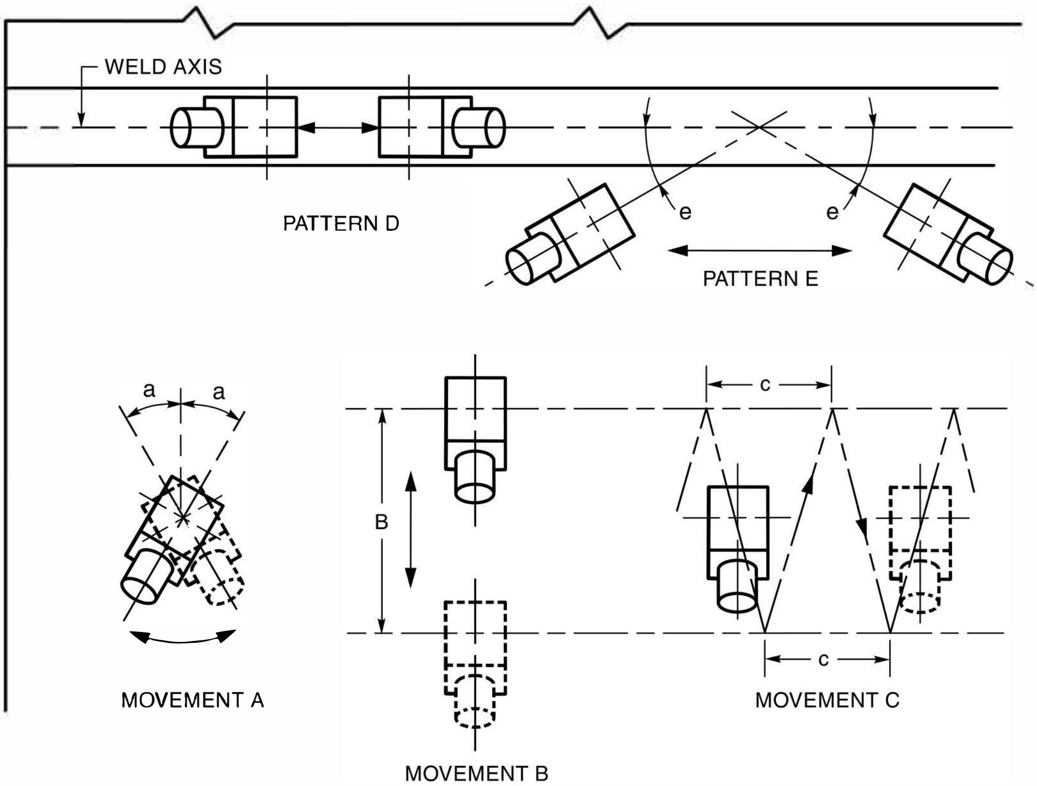
Note: All holes are 1.59 mm in diameter.

RC – RESOLUTION REFERENCE BLOCK



TYPE – DISTANCE AND SENSITIVITY REFERENCE BLOCK

Figure 8.14 (Continued)—Qualification Blocks (see 8.22.3 and 8.27) (Dimensions in Millimeters)



Notes:
1. Testing patterns are all symmetrical around the weld axis with the exception of pattern D, which shall be conducted directly over the weld axis.
2. Testing from both sides of the weld axis shall be made wherever mechanically possible.

Figure 8.15—Plan View of UT Scanning Patterns (see 8.30)

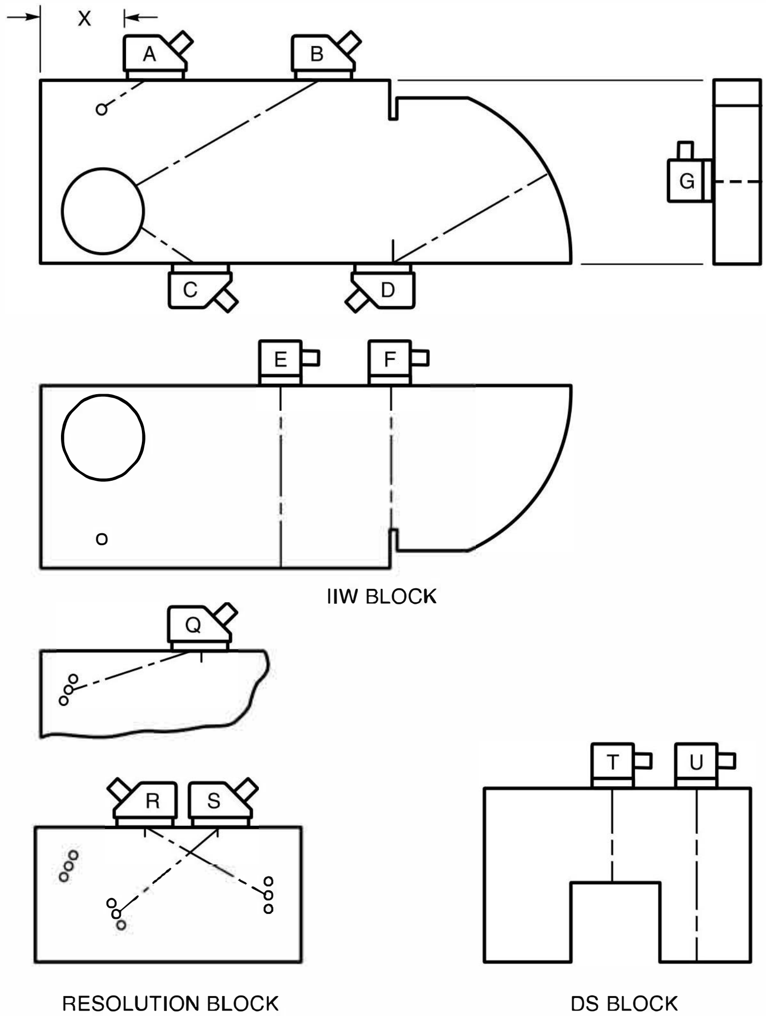


Figure 8.16—Transducer Positions (Typical) (see 8.22, 8.27, and 8.28)

9. Stud Welding

9.1 Scope

Clause 9 contains general requirements (9.2) for welding of steel studs to steel, and stipulates specific requirements for:

(1) Mechanical properties and material of steel studs, and requirements for qualification of stud bases – Clauses 9.3 and 9.9.

(2) Application qualification testing, operator qualification, preproduction testing, and workmanship – Clause 9.6.

(3) Stud welding during production, fabrication/ erection, and inspection – Clauses 9.4, 9.5, and 9.7.

(4) The stud manufacturer's certification of stud base weldability – Clause 9.9.

NOTE: Approved steels; for studs, see 9.2.6; for base metals, see Table 5.3 (Groups I and II). For guidance, see C-9.6.2.

9.2 General Requirements

9.2.1 Stud Design. Studs shall be of suitable design for arc welding to steel members with the use of automatically timed stud welding equipment. The type and size of the stud shall be as specified by the drawings, specifications, or special provisions. For headed-type studs, see Figure 9.1. Alternative head configurations may be used with proof of mechanical and embedment tests confirming full-strength development of the design, and with the approval of the Engineer.

9.2.1.1 Manufacturer's ID. All headed anchor studs and deformed anchor bars shall have a manufacturer's permanent identification.

9.2.2 Arc Shields. An arc shield (ferrule) of heat-resistant ceramic or other suitable material shall be furnished with each stud.

9.2.3 Flux. A suitable deoxidizing and arc stabilizing flux for welding shall be furnished with each stud of 5/16 in [8 mm] diameter or larger. Studs less than 5/16 in [8 mm] in diameter may be furnished with or without flux.

9.2.4 Stud Bases. A stud base, to be qualified, shall have passed the test described in 9.9. Only studs with qualified stud bases shall be used. Qualification of stud bases in conformance with 9.9 shall be at the manufacturer's expense. The arc shield used in production shall be the same as used in qualification tests or as recommended by the manufacturer. When requested by the Engineer, the Contractor shall provide the following information:

(1) A description of the stud and arc shield

(2) Certification from the manufacturer that the stud base is qualified in conformance with 9.9.

(3) Qualification test data

9.2.5 Stud Finish

9.2.5.1 Stud finish shall be produced by heading, rolling, or machining. Finished studs shall be of uniform quality and condition, free of defects that may affect the welding quality, suitability for intended application, or fit of the studs in the specified ceramic arc shields (ferrules). Such defects include laps, fins, seams, cracks, twists, bends, thread defects, discontinuities, or foreign materials (see 9.4.1 and 9.4.2).

9.2.5.2 Headed studs are subject to cracks or bursts in the stud head which are abrupt interruptions of the periphery caused by radial separation of the metal extending from the head inward to the stud shank. These cracks or bursts shall not be the cause for rejection, provided that they do not exceed one half of the distance from the stud head to the stud shank as determined by visual inspection (see Figure C-9.1.) Studs shall be rejected if the cracks or bursts are of a number or width that does not permit the head to fit into the welding tool chuck or cause arcing between the stud head and the chuck affecting chuck life or weld quality.

9.2.6 Stud Material. Studs shall be made from cold drawn bar conforming to the requirements of ASTM A29/A29M-12e1, *Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought, Grades 1010 through* 1020, inclusive, either semi-killed or killed aluminum or silicon deoxidation.

9.2.7 Base Metal Thickness. When welding directly to base metal, the base metal shall be no thinner than 1/3 the stud diameter. When welding through deck, the stud diameter shall be no greater than 2.5 times the base material thickness. In no case shall studs be welded through more than two plies of metal decking.

9.3 Mechanical Requirements

9.3.1 Standard Mechanical Requirements. At the manufacturer's option, mechanical properties of studs shall be determined by testing either the steel after cold finishing or the full diameter finished studs. In either case, the studs shall conform to the standard properties shown in Table 9.1.

9.3.2 Testing. Mechanical properties shall be determined in conformance with the applicable sections of ASTM A370, *Mechanical Testing of Steel Products*. A typical test fixture is used, similar to that shown in Figure 9.2.

9.3.3 Engineer's Request. Upon request by the Engineer, the Contractor shall furnish:

(1) The stud manufacturer's certification that the studs, as delivered, conform to the applicable requirements of 9.2 and 9.3.

(2) Certified copies of the stud manufacturer's test reports covering the last completed set of in-plant quality control mechanical tests, required by 9.3 for each diameter delivered.

(3) Certified material test reports (CMTR) from the steel supplier indicating diameter, chemical properties, and grade on each heat number delivered.

9.3.4 Absence of Quality Control Tests. When quality control tests are not available, the Contractor shall furnish a chemical test report conforming to 9.2.6 and a mechanical test report conforming to the requirements of 9.3 for each lot number. Unidentified and untraceable studs shall not be used.

9.3.5 Additional Studs. The Contractor is responsible for furnishing additional studs of each type and size, at the request of the Engineer, for checking the requirements of 9.2 and 9.3. Testing shall be at the Owner's expense.

9.4 Workmanship/Fabrication

9.4.1 Cleanliness. At the time of welding, the studs shall be free from rust, rust pits, scale, oil, moisture, or other deleterious matter that would adversely affect the welding operation.

9.4.2 Coating Restrictions. The stud base shall not be painted, galvanized, or cadmium-plated prior to welding.

9.4.3 Base Metal Preparation. The areas to which the studs are to be welded shall be free of scale, rust, moisture, paint, or other injurious material to the extent necessary to obtain satisfactory welds and prevent objectionable fumes. These areas may be cleaned by wire brushing, scaling, prick-punching, or grinding.

9.4.4 Moisture. The arc shields or ferrules shall be kept dry. Any arc shields which show signs of surface moisture from dew or rain shall be oven dried at 250°F [120°C] for two hours before use.

9.4.5 Spacing Requirements. Longitudinal and lateral spacings of stud shear connectors (Type B) may vary a maximum of 1 in [25 mm] from the location shown in the drawings. The minimum distance from the edge of a stud base to the edge of a flange shall be the diameter of the stud plus 1/8 in [3 mm], but preferably not less than 1-1/2 in [40 mm].

9.4.6 Arc Shield Removal. After welding, arc shields shall be broken free from studs to be embedded in concrete, and, where practical, from all other studs.

9.4.7 Acceptance Criteria. The studs, after welding, shall be free of any discontinuities or substances that would interfere with their intended function and have a full 360° flash. However, nonfusion on the legs of the flash and small shrink fissures shall be acceptable. The fillet weld profiles shown in Figure 7.4 shall not apply to the flash of automatically timed stud welds.

9.5 Technique

9.5.1 Automatic Mechanized Welding. Studs shall be welded with automatically timed stud welding equipment connected to a suitable source of direct current electrode negative power. Welding voltage, current, time, and gun settings for lift and plunge should be set at optimum settings, based on past practice, recommendations of stud and equipment manufacturer, or both. AWS C5.4, *Recommended Practices for Stud Welding*, should also be used for technique guidance.

9.5.2 Multiple Welding Guns. If two or more stud welding guns shall be operated from the same power source, they shall be interlocked so that only one gun can operate at a time, and so that the power source has fully recovered from making one weld before another weld is started.

9.5.3 Movement of Welding Gun. While in operation, the welding gun shall be held in position nominally perpendicular to the base material, and without movement until the weld metal has solidified.

9.5.4 Ambient and Base Metal Temperature Requirements. Welding shall not be done when the base metal temperature is below 0°F [–18°C] or when the surface is wet or exposed to falling rain or snow. When the temperature of the base metal is below 32°F [0°C], one additional stud in each 100 studs welded shall be tested by methods described in 9.7.1.3 and 9.7.1.4, except that the angle of testing shall be approximately 15°. This is in addition to the first two studs tested for each start of a new production period or change in set-up. Set-up includes stud gun, power source, stud diameter, gun lift and plunge, total welding lead length, and changes greater than ± 5% in current (amperage) and time.

9.5.5 Fillet Weld Option. At the option of the Contractor, studs may be attached with fillet welds using a WPS qualified in accordance with Clause 5 or 6.

9.5.5.1 Production Control. Conformance to 9.7 shall not be required for studs attached by fillet welding.

9.5.5.2 Stud Materials. Stud materials shall meet the following requirements:

(1) Studs meeting the requirements of 9.2.6 shall be acceptable for use in a prequalified WPS;

(2) Stud materials shall be considered Group II material for the selection of matching filler metal strengths.

9.5.5.3 Surfaces. Base metal shall be sufficiently clean to permit making welds that meet Clauses 7, 8, and 9.4.3. The cleanliness of the stud shall be in accordance with 9.4.1. Base metal shall be prepared to meet the requirements of 9.4.3 and 7.14.1.

9.5.5.4 Stud Fit. The base of the stud shall be prepared so that the base is in contact with the base metal. When a contact over the entire stud base with the base metal cannot be made, the following apply:

(1) The gap between the base material and the stud shall not exceed 1/16 in [2 mm] at any point, except as permitted below.

(2) If the separation is greater than 1/16 in [2 mm], the legs of the fillet weld shall be increased by the amount of the root opening, or the contractor shall demonstrate that the required effective throat has been obtained.

9.5.5.5 Tack Welds. Tack welds are permitted when required to facilitate the installation. Tack welds shall comply with 7.17.

9.5.5.6 Minimum Weld Size. When fillet welds are used, the minimum size shall be the larger of those required in Table 7.7 or Table 9.2.

9.5.5.7 Preheat. The base metal to which studs are welded shall be preheated in conformance with the requirements of the WPS.

9.5.5.8 Welders. Welders shall be qualified to perform fillet welding per Clause 6 or Clause 10.

9.5.5.9 Repairs of Fillet Welded Studs. Fillet welds that require repair shall be repaired in accordance with 7.25.

9.5.5.10 Visual Inspection. All fillet welded studs and welded repairs shall be visually inspected in conformance with 8.9.

9.6 Stud Application Qualification Requirements

All Welding Procedure Specifications (WPSs) shall be written by the Contractor.

9.6.1 Prequalified WPSs. Studs conforming to 9.2.6 which are shop or field applied in the flat (down-hand) position to a planar and horizontal surface to steel base metals in Groups I or II per Table 5.3 are deemed prequalified by virtue of the manufacturer's stud base qualification when welding is performed within the ranges of the amperage and time of the manufacturer's welding recommendations. The limit of flat position is defined as 0° – 15° slope on the surface to which the stud is applied. For curved surfaces the 15 degree flat position tolerance is measured at the tangent point where the stud is to be applied.

9.6.2 WPSs Qualified by Testing. Examples of stud applications using mechanized welding that require tests of this section are the following:

(1) Studs which are applied on nonplanar surfaces or to a planar surface in the vertical or overhead positions.

(2) Studs which are welded through decking. The tests shall be conducted using the thinnest base material thickness used in construction but no thinner than 1/2 inch, a Group I or II base material, the same base material coating, the thickest decking gauge and coating material used in construction.

(3) Studs welded to other than Groups I or II steels listed in Table 5.3.

9.6.3 Responsibilities for Tests. The Contractor shall be responsible for the performance of these tests. Tests may be performed by the Contractor, the stud manufacturer, or by another testing agency satisfactory to all parties involved.

9.6.4 Preparation of Specimens

9.6.4.1 Test Specimens. To qualify applications involving materials listed in Table 5.3, Groups I and II: specimens may be prepared using ASTM A36 steel base materials or base materials listed in Table 5.3, Groups I and II.

9.6.4.2 Recorded Information. To qualify applications involving materials other than those listed in Table 5.3, Groups I and II, the test specimen base material shall be of the chemical, physical and grade specifications to be used in production.

9.6.5 Number of Specimens. Ten specimens shall be welded consecutively using recommended procedures and settings for each diameter, position, and surface geometry.

9.6.6 Test Required. The ten specimens shall be tested using one or more of the following methods: bending, torquing, or tensioning.

9.6.7 Test Methods

9.6.7.1 Bend Test. Studs shall be tested by alternately bending 30° in opposite directions in a typical test fixture as shown in Figure 9.4 until failure occurs. Alternatively, studs may be bent 90° from their original axis. Type C studs, when bent 90°, shall be bent over a pin with a diameter of 4 times the diameter of the stud. In either case, a stud application shall be considered qualified if the studs are bent 90° and fracture occurs in the plate or shape material or in the shank of the stud and not in the weld.

9.6.7.2 Torque Test. Studs shall be torque tested using a torque test arrangement that is substantially in conformance with Figure 9.3. A stud application shall be considered qualified if all test specimens are torqued to destruction without failure in the weld.

9.6.7.3 Tension Test. Studs shall be tension tested to destruction using any machine capable of supplying the required force. A stud application shall be considered qualified if the test specimens do not fail in the weld.

9.6.8 Application Qualification Test Data. Application Qualification Test Data shall include the following:

(1) Drawings that show shapes and dimensions of studs and arc shields.

(2) A complete description of stud and base materials, and a description (part number) of the arc shield.

(3) Welding position and settings (current, time).

(4) A record, which shall be made for each qualification and shall be available for each contract. A suggested WPS/PQR form for nonprequalified application may be found in Annex J, Form J-8.

9.7 Production Control

9.7.1 Pre-Production Testing

9.7.1.1 Start of Shift. Before production welding with a particular set-up and with a given size and type of stud, and at the beginning of each day's or shift's production, testing shall be performed on the first two studs that are welded. The stud technique may be developed on a piece of material similar to the production member in thickness and properties. If actual production thickness is not available, the thickness may vary ± 25%. All test studs shall be welded in the same general position as required on the production member (flat, vertical, or overhead).

9.7.1.2 Production Member Option. Instead of being welded to separate material, the test studs may be welded on the production member, except when separate plates are required by 9.7.1.5.

9.7.1.3 Flash Requirement. Studs shall exhibit full 360° flash with no evidence of undercut into the stud base.

9.7.1.4 Bend and Torque Test. In addition to visual examination, the test shall consist of bending the studs after they are allowed to cool, to an angle of approximately 30° from their original axes by either striking the studs with a hammer on the unwelded end or placing a pipe or other suitable device over the stud and manually or mechanically bending the stud. Alternatively for threaded studs, the torque test of Figure 9.3 may be used instead of bending.

Testing performed at temperatures below 50°F [10°C], shall be done by continuous slow application of load.

9.7.1.5 Event of Failure. If on visual examination the test studs do not exhibit 360° flash, or if on testing, failure occurs in the weld zone of either stud, the procedure shall be corrected, and two more studs shall be welded to separate material or on the production member and tested in conformance with the provisions of 9.7.1.3 and 9.7.1.4. If either of the second two studs fails, additional welding shall be continued on separate plates until two consecutive studs are tested and found to be satisfactory before any more production studs are welded to the member.

9.7.2 Production Welding. Once production welding has begun, any changes made to the welding setup, as determined in 9.7.1, shall require that the testing in 9.7.1.3 and 9.7.1.4 be performed prior to resuming production welding.

9.7.3 Repair of Studs. In production, studs on which a full 360° flash is not obtained may, at the option of the Contractor, be repaired by adding the minimum fillet weld as required by 9.5.5 in place of the missing flash. The repair weld shall extend at least 3/8 in [10 mm] beyond each end of the discontinuity being repaired.

9.7.4 Operator Qualification. The pre-production test required by 9.7.1, if successful, shall also serve to qualify the stud welding operator. Before any production studs are welded by an operator not involved in the preproduction set-up of 9.7.1, the first two studs welded by the operator shall have been tested in conformance with the provisions of 9.7.1.3 and 9.7.1.4. When the two welded studs have been tested and found satisfactory, the operator may then weld production studs.

9.7.5 Removal Area Repair. If an unacceptable stud has been removed from a component subjected to tensile stresses, the area from which the stud was removed shall be made smooth and flush. Where in such areas the base metal has been pulled out in the course of stud removal, SMAW with low-hydrogen electrodes in conformance with the requirements of this code shall be used to fill the pockets, and the weld surface shall be flush.

In compression areas of members, if stud failures are confined to shanks or fusion zones of studs, a new stud may be welded adjacent to each unacceptable area in lieu of repair and replacement on the existing weld area (see 9.4.5). If base metal is pulled out during stud removal, the repair provisions shall be the same as for tension areas except that when the depth of discontinuity is the lesser of 1/8 in [3 mm] or 7% of the base metal thickness, the discontinuity may be faired by grinding in lieu of filling with weld metal. Where a replacement stud is to be provided, the base metal repair shall be made prior to welding the replacement stud. Replacement studs (other than threaded type which should be torque tested) shall be tested by bending to an angle of approximately 15° from their original axes. The areas of components exposed to view in completed structures shall be made smooth and flush where a stud has been removed.

9.8 Fabrication and Verification Inspection Requirements

9.8.1 Visual Inspection. If a visual inspection reveals any stud that does not show a full 360° flash or any stud that has been repaired by welding, such stud shall be bent to an angle of approximately 15° from its original axis. Threaded studs shall be torque tested. The method of bending shall be in conformance with 9.7.1.4. The direction of bending for studs with less than a 360° flash shall be opposite to the missing portion of the flash. Torque testing shall be in conformance with Figure 9.3.

9.8.2 Additional Tests. The Verification Inspector, where conditions warrant, may select a reasonable number of additional studs to be subjected to the tests described in 9.8.1.

9.8.3 Bent Stud Acceptance Criteria. The bent stud shear connectors (Type B) and deformed anchors (Type C) and other studs to be embedded in concrete (Type A) that show no sign of failure shall be acceptable for use and left in the bent position. When bent studs are required by the contract documents to be straightened, the straightening operation shall be done without heating, and before completion of the production stud welding operation.

9.8.4 Torque Test Acceptance Criteria. Threaded studs (Type A) torque tested to the proof load torque level in Figure 9.3 that show no sign of failure shall be acceptable for use.

9.8.5 Corrective Action. Welded studs not conforming to the requirements of the code shall be repaired or replaced by the Contractor. The Contractor shall revise the welding procedure as necessary to ensure that subsequent stud welding will meet code requirements.

9.8.6 Owner's Option. At the option and the expense of the Owner, the Contractor may be required, at any time, to submit studs of the types used under the contract for a qualification check in conformance with the procedures of 9.9.

9.9 Manufacturers' Stud Base Qualification Requirements

9.9.1 Purpose. The purpose of these requirements is to prescribe tests for the stud manufacturers' certification of stud base weldability.

9.9.2 Responsibility for Tests. The stud manufacturer shall be responsible for the performance of the qualification test. These tests may be performed by a testing agency satisfactory to the Engineer. The agency performing the tests shall submit a certified report to the manufacturer of the studs giving procedures and results for all tests including the information described in 9.9.10.

9.9.3 Extent of Qualification. Qualification of a stud base shall constitute qualification of stud bases with the same geometry, flux, and arc shield, having the same diameter and diameters that are smaller by less than 1/8 in [3 mm]. A stud base qualified with an approved grade of ASTM A29 steel and meets the standard mechanical properties (see 9.3.1) shall constitute qualification for all other approved grades of ASTM A29 steel (see 9.2.6), provided that conformance with all other provisions stated herein shall be achieved.

9.9.4 Duration of Qualification. A size of stud base with arc shield, once qualified, shall be considered qualified until the stud manufacturer makes any change in the stud base geometry, material, flux, or arc shield which affects the welding characteristics.

9.9.5 Preparation of Specimens

9.9.5.1 Materials. Test specimens shall be prepared by welding representative studs to suitable specimen plates of ASTM A36 steel or any of the other materials listed in Table 5.3 or Table 6.9. Studs to be welded through metal decking shall have the weld base qualification testing done by welding through metal decking representative of that used in construction, galvanized per ASTM A653 coating designation G90 for one thickness of deck or G60 for two deck plies. When studs are to be welded through decking, the stud base qualification test shall include decking representative of that to be used in construction. Welding shall be done in the flat position (plate surface horizontal). Tests for threaded studs shall be on blanks (studs without threads).

9.9.5.2 Welding Equipment. Studs shall be welded with power source, welding gun, and automatically controlled equipment as recommended by the stud manufacturer. Welding voltage, current, and time (see 9.9.6) shall be measured and recorded for each specimen. Lift and plunge shall be at the optimum setting as recommended by the manufacturer.

9.9.6 Number of Test Specimens

9.9.6.1 High Current. For studs 7/8 in [22 mm] or less in diameter, 30 test specimens shall be welded consecutively with constant optimum time, but with current 10% above optimum. For studs over 7/8 in [22 mm] diameter, 10 test specimens shall be welded consecutively with constant optimum time. Optimum current and time shall be the midpoint of the range normally recommended by the manufacturer for production welding.

9.9.6.2 Low Current. For studs 7/8 in [22 mm] or less in diameter, 30 test specimens shall be welded consecutively with constant optimum time, but with current 10% below optimum. For studs over 7/8 in [22 mm] diameter, 10 test specimens shall be welded consecutively with constant optimum time, but with current 5% below optimum.

9.9.6.3 Metal Deck. For studs to be welded through metal deck, the range of weld base diameters shall be qualified by welding 10 studs at the optimum current and time as recommended by the manufacturer conforming to the following:

(1) Maximum and minimum diameters welded through one thickness of 16 gage deck, coating designation G90.

(2) Maximum and minimum diameters welded through two plies of 16 gage deck coating designation G60.

(3) Maximum and minimum diameters welded through one thickness of 18 gage G60 deck over one thickness of 16 gage G60 deck.

(4) Maximum and minimum diameters welded through two plies of 18 gage deck, both with G60 coating designation.

The range of diameters from maximum to minimum welded through two plies of 18 gage metal deck with G60 galvanizing shall be qualified for welding through one or two plies of metal deck 18 gage or less in thickness.

9.9.7 Tests

9.9.7.1 Tension Tests. Ten of the specimens welded in conformance with 9.9.6.1 and ten in conformance with 9.9.6.2 shall be subjected to a tension test in a fixture similar to that shown in Figure 9.2, except that studs without heads may be gripped on the unwelded end in the jaws of the tension testing machine. A stud base shall be considered as qualified if all test specimens have a tensile strength equal to or above the minimum described in 9.3.1.

9.9.7.2 Bend Tests (Studs 7/8 in [22 mm] or less in diameter). Twenty of the specimens welded in conformance with 9.9.6.1 and twenty in conformance with 9.9.6.2 shall be bend tested by being bent alternately 30° from their original axes in opposite directions until failure occurs. Studs shall be bent in a bend testing device as shown in Figure 9.4, except that studs less than 1/2 in [12 mm] diameter may be bent using a device as shown in Figure 9.5. A stud base shall be considered as qualified if, on all test specimens, fracture occurs in the plate material or shank of the stud and not in the weld or HAZ. All test specimens for studs over 7/8 in [22 mm] shall only be subjected to tensile tests.

9.9.7.3 Weld through Deck Tests. All welds-through-deck stud specimens shall be tested by bending 30° in opposite directions in a bend testing device as shown in Figure 9.4, or by bend testing 90° from their original axis or tension testing to destruction in a machine capable of supplying the required force. With any test method used, the range of stud diameters from maximum to minimum shall be considered as qualified weld bases for through deck welding if, on all test specimens, fracture occurs in the plate material or shank of the stud and not in the weld or HAZ.

9.9.8 Retests. If failure occurs in a weld or the HAZ in any of the bend test groups of 9.9.7.2 or at less than specified minimum tensile strength of the stud in any of the tension groups in 9.9.7.1, a new test group (described in 9.9.6.1 or 9.9.6.2, as applicable) shall be prepared and tested. If such failures are repeated, the stud base shall fail to qualify.

9.9.9 Acceptance. For a manufacturer's stud base and arc shield combination to be qualified, each stud of each group of 30 studs shall, by test or retest, meet the requirements described in 9.9.7. Qualification of a given diameter of stud base shall be considered qualification for stud bases of the same nominal diameter (see 9.9.3, stud base geometry, material, flux, and arc shield).

9.9.10 Manufacturer's Qualification Test Data. The test data shall include the following:

(1) Drawings showing shapes and dimensions with tolerances of stud, arc shields, and flux;

(2) A complete description of materials used in the studs, including the quantity and type of flux, and a description of the arc shields; and

(3) Certified results of tests.

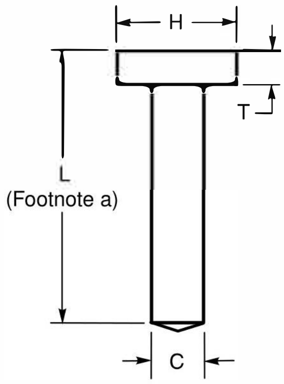
Table 9.1
Mechanical Property Requirements for Studs (see 9.3.1)

		Type A[a]	Type B[b]	Type C[c]
Tensile Strength	Psi min.	61 000	65 000	80 000
	MPa min.	420	420	552
Yield Strength (0.2% offset)	Psi min.	49 000	51 000	—
	MPa min.	340	350	
(0.5% offset)	Psi min.	—	—	70 000
	MPa min.			485
Elongation	% in 2 in. min.	17%	20%	—
	% in 5x dia. min.	14%	15%	
Reduction of area	% min.	50%	50%	—

[a] Type A studs shall be general purpose of any type and size used for purposes other than shear transfer in composite beam design and construction.
[b] Type B studs shall be studs that are headed, bent, or of other configuration in 3/8 in [10 mm], 1/2 in [12 mm], 5/8 in [16 mm], 3/4 in [20 mm], 7/8 in [22 mm], and 1 in [25 mm] diameter that are used as an essential component in composite beam design and concrete anchorage design.
[c] Type C studs shall be cold-worked deformed steel bars manufactured in conformance with specification ASTM A496 having a nominal diameter equivalent to the diameter of a plain wire having the same weight per foot as the deformed wire. ASTM A496 specifies a maximum diameter of 0.628 in [16 mm] maximum. Any bar supplied above that diameter shall have the same physical characteristics regarding deformations as required by ASTM A496.

Table 9.2
Minimum Fillet Weld Size for Studs (see 9.5.5.6)

(Dimensions in Inches)				
Stud Diameter	1/4 thru 7/16	1/2	5/8, 3/4, 7/8	1
Min. Size Fillet	3/16	1/4	5/16	3/8
(Dimensions in Millimeters)				
Stud Diameter	6 thru 11	12	16, 20, 22	25
Min. Size Fillet	5	6	8	10



[a] Manufactured length before welding.

Standard Dimensions, in				
Shank Diameter (C)	Length Tolerances (L)	Head Diameter (H)	Minimum Head Height (T)	
3/8	+0.010 −0.010	±1/16	3/4 ± 1/64	9/32
1/2	+0.010 −0.010	± 1/16	1 ± 1/64	9/32
5/8	+0.010 −0.010	± 1/16	1-1/4 ± 1/64	9/32
3/4	+0.015 −0.015	± 1/16	1-1/4 ± 1/64	3/8
7/8	+0.015 −0.015	± 1/16	1-3/8 ± 1/64	3/8
1	+0.020 −0.020	± 1/16	1-5/8 ± 1/64	1/2
Standard Dimensions, mm				
Shank Diameter (C)	Length Tolerances (L)	Head Diameter (H)	Minimum Head Height (T)	
10	+0.25 −0.25	± 1.6	19 ± 0.40	7.1
13	+0.25 −0.25	± 1.6	25 ± 0.40	7.1
16	+0.25 −0.25	± 1.6	32 ± 0.40	7.1
19	+0.40 −0.40	± 1.6	32 ± 0.40	9.5
22	+0.40 −0.40	± 1.6	35 ± 0.40	9.5
25	+0.40 −0.40	± 1.6	41 ± 0.40	12.7

Figure 9.1—Dimension and Tolerances of Standard-Type Headed Studs (see 9.2.1)

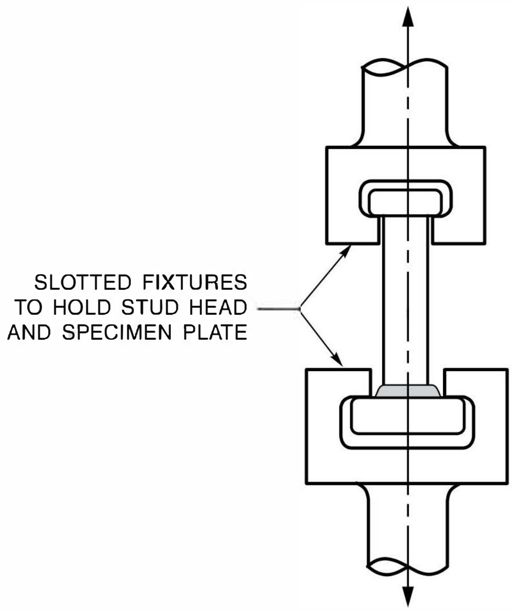
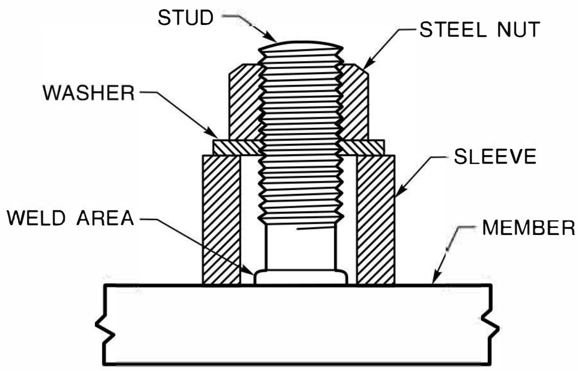


Figure 9.2—Typical Tension Test Fixture (see 9.3.2)



Note: Dimensions of test fixture details should be appropriate to the size of the stud. The threads of the stud shall be clean and free of lubricant other than the residue of cutting/cold forming lubricants in the "as received" condition from the manufacturer.

Required Proof Torque for Testing Threaded Studs[a]

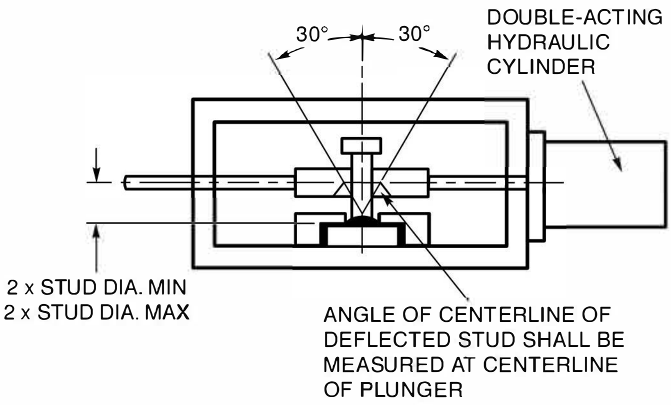
Nominal Diameter		M.E.T.A.[b]		Thread			Proof Testing Torque[c]	
in	mm	in^2	mm^2	no./in	pitch-mm	Series	lb-ft	Joule
0.236	M6	0.031	20.1		1.0	ISO-724	5.4	7.4
1/4	6.4	0.036	23.2	28		UNF	6.6	9.0
		0.032	20.6	20		UNC	5.9	7.8
5/16	7.9	0.058	37.4	24		UNF	13.3	18.1
		0.052	33.5	18		UNC	11.9	16.1
0.315	M8	0.057	36.6		1.25	ISO-724	13.2	17.9
3/8	9.5	0.088	56.8	24		UNF	24.3	32.9
		0.078	50.3	16		UNC	21.5	29.2
0.394	M10	0.090	58.0		1.5	ISO-724	26.2	35.5
7/16	11.1	0.118	76.1	20		UNF	37.9	51.4
		0.106	68.4	14		UNC	34.8	47.2
0.472	M12	0.131	84.3		1.75	ISO-724	45.7	61.9
1/2	12.7	0.160	103.2	20		UNF	58.8	79.7
		0.142	91.6	13		UNC	52.2	70.8
0.551	M14	0.178	115.0		2.0	ISO-724	72.7	98.5
9/16	14.3	0.203	131.0	18		UNF	83.9	113.8
		0.182	117.4	12		UNC	75.2	102.0
5/8	15.9	0.255	164.5	18		UNF	117.1	158.8
		0.226	145.8	11		UNC	103.8	140.8
0.630	M16	0.243	157.0		2.0	ISO-724	113.4	153.7
3/4	19.1	0.372	240.0	16		UNF	205.0	278.0
		0.334	215.5	10		UNC	184.1	249.7
0.787	M20	0.380	245.0		2.5	ISO-724	221.2	299.9
0.866	M22	0.470	303.0		2.5	ISO-724	300.9	408.0
7/8	22.2	0.509	328.4	14		UNF	327.3	443.9
		0.462	298.1	9		UNC	297.1	402.9
0.945	M24	0.547	353.0		3.0	ISO-724	382.4	518.5
1	25.4	0.678	437.4	12		UNF	498.3	675.7
		0.606	391.0	8		UNC	445.4	604.0

[a] Torque figures are based on Type A threaded studs with a minimum yield stress of 49 000 psi [340 MPa].

[b] Mean Effective Thread Area (M.E.T.A) shall be defined as the effective stress area based on a mean diameter taken approximately midway between the minor and the pitch diameters.

[c] Values are calculated on a proof testing torque of 0.9 times Nominal Stud Diameter times 0.2 Friction Coefficient Factor times Mean Effective Thread Area times Minimum Yield Stress for unplated studs in the as-received condition. Plating, coatings, or oil/grease deposits will change the Friction Coefficient Factor.

Figure 9.3—Torque Testing Arrangement and Table of Testing Torques (see 9.7.1.4)



Notes:
1. Fixture holds specimen and stud is bent 30° alternately in opposite directions.
2. Load can be applied with hydraulic cylinder (shown) or fixture adapted for use with tension test machine.

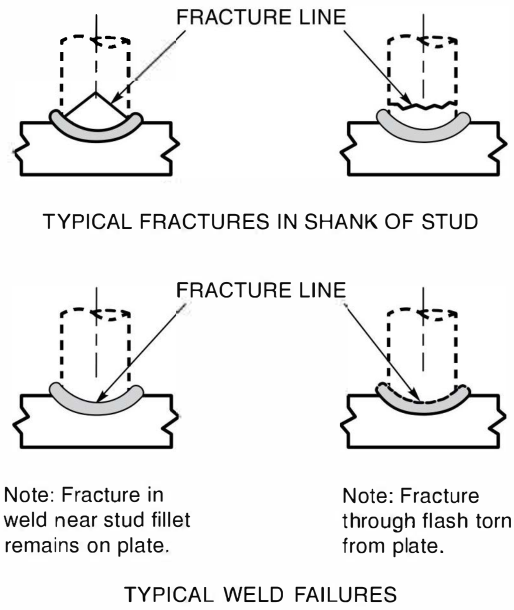


Figure 9.4—Bend Testing Device (see 9.9.7.2)

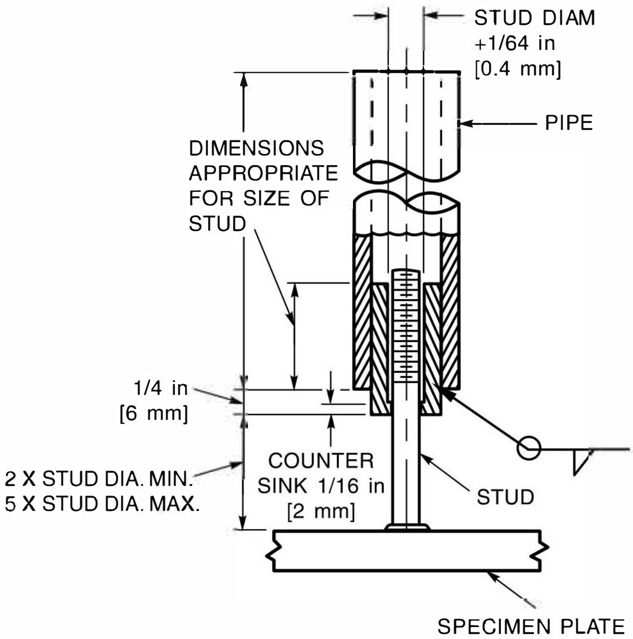


Figure 9.5—Suggested Type of Device for Qualification Testing of Small Studs (see 9.9.7.2)

10. Tubular Structures

10.1 Scope

This Clause supplements Clauses 1–9. The specific requirements of Clause 10 apply only to tubular connections as defined in 10.3 and Clause 3. Such connections may be butt joints between tubulars, T-, Y-, K- connections of tubulars to tubulars, or tubulars welded to flat plates or flat elements of other members. Where this clause refers to rectangular tubulars, square tubulars are included unless noted.

10.1.1 The scope of the term "tubular members" includes:

(1) Circular hollow structural sections (HSS);

(2) Rectangular HSS;

(3) Square HSS;

(4) Fabricated members built from flat plates and or shapes joined together with CJP longitudinal seams acting as chord members designed using the provisions of Clause 10. For design purposes, this clause shall be used with the applicable requirements of Clause 4, Part A. All provisions of Clause 10 apply to both static and cyclic applications, with the exception that the fatigue provisions of 10.2.3, only apply to cyclic applications.

10.1.2 Clause 10 is divided into six parts, as follows:

Part A — **Design of Tubular Connections**

Part B — **Prequalification of Welding Procedure Specifications (WPSs)**

Part C — **Welding Procedure Specification (WPS) Qualification**

Part D — **Performance Qualification**

Part E — **Fabrication**

Part F — **Inspection**

Part A
Design of Tubular Connections

10.2 Design Criteria

10.2.1 Statically Loaded Tubular Connections. Provisions for the design of statically loaded tubular members and connections are given in ANSI/AISC 360, *Specification for Structural Steel Buildings*, with further guidance, in the AISC *Steel Construction Manual*, and AISC Design Guide No. 24, *Hollow Structural Section Connections*. AISC permits member and connection design using either allowable strength design (ASD) or load and resistance factor design (LRFD) formats.

For the preliminary static design of circular tube connections a simple punching shear check for connection efficiency is provided in Annex R.

10.2.2 Welds Stresses. The available stresses in welds shall not exceed those given in Table 10.2, except as modified by 10.5 and ANSI/AISC 360 as it applies to rectangular and square HSS.

10.2.3 Cyclically Loaded Tubular Connections. Tubular connections subjected to repeated applications of stress shall be designed for fatigue in accordance with this Clause in addition to the general provisions of Clause 4, Part C—*Specific Requirements for Design on Nontubular Connections (Cyclically Loaded)*. For stress range and corresponding cycle count below the values of the K2 curve in Figure 10.1 fatigue analysis is not necessary. Other fatigue analysis exceptions shall be approved by the Engineer.

The applicable stress range is the nominal stress range calculated by ordinary beam theory or similar consideration of the total load and moment on a gross section and the resulting axial, shear and bending stress ranges. Fatigue Stress Design Parameters and S-N curves (i.e. Stress vs. Number of Cycles Curves) for various stress categories are included in 10.2.3.3.

10.2.3.1 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.

10.2.3.2 Fatigue Stress Categories. The type and location of material shall be categorized as shown in Tables 10.1 and 10.3.

10.2.3.3 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 10.1.

10.2.3.4 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 10.1

10.2.3.5 Critical Members. For critical members whose sole failure mode would be catastrophic, D (see 10.2.3.4) shall be limited to a fractional value of 1/3 maximum.

10.2.3.6 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 10.11. 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 10.11. 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 MT as described below. Consideration should be given to the possibility of locally degraded notch toughness due to peening.

In order to qualify fatigue categories X_1 and K_1, representative welds (all welds where peening has been applied) shall receive MT for surface and near-surface discontinuities. Any indications which cannot be resolved by light grinding shall be repaired in conformance with 7.25.1.4.

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

C_1 2 in [50 mm] thinner member at transition
C_2 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 10.4. 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.

10.3 Identification and Parts of Tubular Connections

Members in tubular structures shall be identified as shown in Figure 10.2.

10.4 Symbols

Symbols used in this clause are as shown in Annex I.

10.5 Weld Design

10.5.1 Weld Effective Lengths. For branch elements (including plates) transverse to the direction of the chord member or transverse to the overlapped branch member axis in an overlapped connection, the design of welds shall involve a consideration of the weld effective length (a proportion of the weld total length), in conformance with 10.5.5 or 10.5.6 for circular, square, and rectangular tubulars, respectively.

10.5.2 Fillet Welds

10.5.2.1 Effective Area. The effective area shall be in conformance with 4.4.2.10. The total length is calculated as the perimeter of the branch member at its intersection with the chord member. For rectangular tubulars, the total weld length shall be calculated as the perimeter of the branch member at its intersection with the chord member or by treating the rectangular branch as a box shape (and ignoring the corners). Weld effective length considerations may be waived if the fillet weld is designed to develop the yield strength of the adjoining branch member wall.

10.5.2.2 Beta Limitation for Prequalified Details. Details for prequalified fillet welds in tubular T-, Y-, and K-connections are described in Figure 10.5. These details shall be limited to $\beta \leq 1/3$ for circular tubular connections with circular chords, and $\beta \leq 0.8$ for tubular connections with rectangular chords. These details are subject to the limitations of 10.8.1. For a rectangular tubular chord member with large corner radii, a smaller limit on β may be required to keep the branch member and the weld on the flat face.

10.5.2.3 Lap Joints. Lap joints of telescoping tubulars may be single pass or multi-pass fillet welded in conformance with Figure 10.3.

10.5.3 Groove Welds. The effective area shall be in conformance with 4.4.1.5. The total weld length is calculated as the perimeter of the branch member at its intersection with the chord member.

10.5.3.1 Prequalified PJP Groove Weld Details. Prequalified PJP groove welds in tubular T-, Y-, or K-connections shall conform to Figure 10.6. The Engineer shall use the figure in conjunction with Table 10.5 to calculate the minimum required weld size. To determine the minimum weld size, the Z loss dimension shall be deducted from the distance between the joint root and the weld surface.

10.5.3.2 Prequalified CJP Groove Weld Details Welded from One Side without Backing in T-, Y-, and K-Connections. See 10.10.2 for the detail options. If fatigue behavior improvement is required, the details selected shall be based on the profile requirements of 10.2.3.6 and Table 10.4. Weld stress calculations shall not be required for CJP welds if all of the following conditions apply:

(1) the base metal configuration satisfies code requirements,

(2) matching or one strength level higher filler metal is used in accordance with the code, and

(3) the attached members are adequately designed to the relevant design standard.

10.5.4 Stresses in PJP and Fillet Welds. The maximum stress at any point in the weld shall not exceed the allowable stress in Table 10.2 or the corresponding local branch stress computed by:

$$f_{weld} = Q_z\,(t_b/t_w)\,[(f_a/K_a) + (f_b/K_b)]$$

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

Q_z, K_a and K_b are factors given in 10.5.5.

10.5.5 Weld Effective Lengths in Circular-to-Circular Tubular Connections. When using fillet welds or PJP welds sized only to resist required load or forces, the minimum required effective throat shall be determined as follows:

$$t_w = (t_b/ f_{weld})\,[(f_a/K_a) + (f_b/K_b)]\,Q_z$$

t_w = effective throat of weld

t_b = thickness of branch member

f_{weld} = available weld stress as applicable, for ASD from Table 4.3, or for both LRFD and ASD from AISC 360 Table J2.5

f_a and f_b = required axial and bending stresses in the branch, ASD or LRFD as applicable

$K_a = (1 + 1/\sin \Theta_1)/2$ for branch axial loading

$$K_b = \sqrt{K_{bip}^2 + K_{bop}^2}$$

$K_{bip} = (3 + 1/\sin \Theta_1)/4 \sin \Theta_1$ for branch in-plane bending

$K_{bop} = (1 + 3/\sin \Theta_2)/4 \sin \Theta_2$ for branch out-of-plane bending

where Θ_1 is the in-plane acute angle between the branch and chord member axes and Q_2 is the out-of-plane acute angle between the branch and chord member axes.

Q_z = load amplification factor to account for non-uniform distribution of load (or alternatively a weld effective length factor), as follows:

Electrode minimum specified tensile strength = 60 – 70 ksi

	ASD	LRFD
E60XX and E70XX—	1.35	1.5
Higher strengths—	1.60	1.8

10.5.6 Weld Effective Lengths in Rectangular T-, Y-, and K- Connections. Weld effective lengths and effective section properties, for rectangular T-,Y-, and K-connections shall comply with AISC 360 *Specification for Structural Steel Buildings*, Chapter K5.

10.6 Thickness Transition

Tension butt joints in cyclically loaded 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 10.4).

10.7 Material Limitations

10.7.1 Material Limitations for Tubular T-, Y-, K-Connections. Tubular connection materials shall be selected understanding that local stress concentrations typically exist which may lead to local yielding and plastic strains at the design load. Likewise, cyclically loaded tubular connection materials shall be selected considering the additional demands on ductility brought forth by weld discontinuities and potential fatigue cracks.

10.7.2 Tubular Base Metal Notch Toughness

10.7.2.1 CVN Test Requirements. Welded tubular members in tension shall be required to demonstrate CVN test absorbed energy of 20 ft·lbf at 70°F [27 J at 21°C] for base metal thickness of 2 in [50 mm] or greater with a specified minimum yield strength of 40 ksi [280 MPa] or greater.

CVN testing shall be in conformance with ASTM A673 (Frequency H, heat lot). For the purposes of this subclause, a tension member is defined as one having more than 10 ksi [70 MPa] tensile stress due to unfactored design loads.

10.7.2.2 LAST Requirements. Fatigue-controlled tubulars used as the main member or heavy wall joint-can in T-, Y-, and K-connections, shall be required to demonstrate CVN test absorbed energy of 20 ft·lbf [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]. CVN testing shall normally represent the as-furnished tubulars, and be tested in conformance with ASTM A673 Frequency H (heat lot).

Part B
Prequalification of Welding Procedure Specifications (WPSs)

10.8 Fillet Weld Requirements

10.8.1 Details. For prequalified status, fillet welded tubular connections shall conform to the following provisions:

(1) **Prequalified WPSs.** Fillet welded tubular connections made by SMAW, GMAW, or FCAW processes that may be used without performing WPS qualification tests are detailed in Figure 10.5 (see 10.5.2.2 for limitations). These details may also be used for GMAW-S qualified in conformance with 10.14.4.3.

(2) Details for lap joints are shown in Figure 10.3.

10.9 PJP Requirements

10.9.1 Details. Details for PJP tubular groove welds that are accorded prequalified status shall conform to the following provisions:

(1) PJP tubular groove welds, other than T-, Y-, and K-connections, may be used without performing the WPS qualification tests, when these may be applied and shall meet all of the joint dimension limitations as described in Figure 5.1.

(2) PJP T-, Y-, and K-tubular connections, welded only by the SMAW, GMAW, or FCAW process, may be used without performing the WPS qualification tests, when they may be applied and shall meet all of the joint dimension limitations as described in Figure 10.6. These details may also be used for GMAW-S qualified in conformance with 10.14.4.3.

10.9.1.1 Matched Box Connections. Details for PJP groove welds in these connections, the corner dimensions and the radii of the main tube are shown in Figure 10.6. Fillet welds may be used in toe and heel zones (see Figure 10.5). If the corner dimension or the radius of the main tube, or both, are less than as shown in Figure 10.6, a sample joint of the side detail shall be made and sectioned to verify the weld size. The test weld shall be made in the horizontal position. This requirement may be waived if the branch tube is beveled as shown for CJP groove welds in Figure 10.7.

10.10 CJP Groove Weld Requirements

10.10.1 Butt Joints. For tubular groove welds to be given prequalified status, the following conditions shall apply:

(1) **Prequalified WPSs.** Where welding from both sides or welding from one side with backing is possible, any WPS and groove detail that is appropriately prequalified in conformance with Clause 5 may be used, except that SAW is only prequalified for diameters greater than or equal to 24 in [600 mm]. Welded joint details shall be in conformance with Clause 5.

(2) **Nonprequalified Joint Detail.** There are no prequalified joint details for CJP groove welds in butt joints made from one side without backing (see 10.14.2).

10.10.2 Tubular T-, Y-, and K-Connections. Details for CJP groove welds welded from one side without backing in tubular T-, Y-, and K-connections used in circular tubes are described in this section. The applicable range of Details A, B, C, and D are described in Figures 10.7 and 10.8, and the ranges of local dihedral angles, [Ψ], corresponding to these are described in Table 10.6.

Joint dimensions including groove angles are described in Table 10.7 and Figure 10.9. When selecting a profile (compatible with fatigue category used in design) as a function of thickness, the guidelines of 10.2.3.7 shall be observed. Alternative weld profiles that may be required for thicker sections are described in Figure 10.10. In the absence of special fatigue requirements, these profiles shall be applicable to branch thicknesses exceeding 5/8 in [16 mm].

Improved weld profiles meeting the requirements of 10.2.3.6 and 10.2.3.7 are described in Figure 10.11. In the absence of special fatigue requirements, these profiles shall be applicable to branch thicknesses exceeding 1–1/2 in [38 mm] (not required for static compression loading). Prequalified details for CJP groove welds in tubular T-, Y-, and K-connections utilizing box sections are further described in Figure 10.7. The foregoing details are subject to the limitation of 10.10.1.

NOTE: See the Commentary (C-10.14.4) for engineering guidance in the selection of a suitable profile.

The joint dimensions and groove angles shall not vary from the ranges detailed in Table 10.7 and shown in Figure 10.7 and Figures 10.9–10.11. The root face of joints shall be zero unless dimensioned otherwise. It may be detailed to exceed zero or the specified dimension by not more than 1/16 in [2 mm]. It may not be detailed less than the specified dimensions.

10.10.2.1 Joint Details. Details for CJP groove welds in tubular T-, Y-, and K-connections are described in 10.10.2. These details are prequalified for SMAW and FCAW. These details may also be used for GMAW-S qualified in conformance with 10.14.4.3.

Part C
Welding Procedure Specification (WPS) Qualification

10.11 Common Requirements for WPS and Welding Personnel Performance Qualification

10.11.1 Positions of Welds. All welds shall be classified as flat (F), horizontal (H), vertical (V), and overhead (OH), in conformance with the definitions shown in Figures 6.1 and 6.2.

Test assembly positions are shown in:

(1) Figure 10.12 (groove welds in pipe or tubing)

(2) Figure 10.13 (fillet welds in pipe or tubing)

10.12 Production Welding Positions Qualified

Tubular production welding positions qualified by a tubular test shall conform to the requirements of Table 10.8. Tubular production welding positions qualified by a plate test shall conform to the requirements in Clause 6 and Table 6.1.

10.13 Type of Qualification Tests, Methods of Testing, and Acceptance Criteria for WPS Qualification

The type and number of qualification tests required to qualify a WPS for a given thickness, diameter or both, shall conform to Table 10.9 (CJP), Table 10.10 (PJP), or Table 10.11 (Fillet). Details on the individual NDT and mechanical test requirements are found in 6.5.

The welded test assemblies shall have test specimens prepared by cutting the pipe or tubing as shown in Figure 10.14 or Figure 10.15. Methods of testing and acceptance criteria shall be per 6.10 with the following exceptions:

(1) For T-, Y- and K-connections melt-through is not limited.

(2) For tubulars, the full circumference of the weld shall be RT or UT examined in conformance with Clause 8, Part C and Clause 10, Part F, as applicable.

10.14 CJP Groove Welds for Tubular Connections

CJP groove welds shall be classified as follows:

(1) CJP butt joints with backing or backgouging (see 10.14.1).

(2) CJP butt joints without backing welded from one side only (see 10.14.2).

(3) T-, Y-, K-connections with backing or backgouging (see 10.14.3).

(4) T-, Y-, K-connections without backing welded from one side only (see 10.14.4).

10.14.1 CJP Butt Joints with Backing or Backgouging. A WPS with backing or backgouging shall be qualified using the detail shown in Figure 10.18(A) (with backgouging) or Figure 10.18(B) (with backing).

10.14.2 CJP Butt Joints without Backing Welded from One Side Only. A WPS without backing welded from one side only shall be qualified using the joint detail shown in Figure 10.18(A).

10.14.3 T-, Y-, or K-Connections with Backing or Backgouging. A WPS for tubular T-, Y-, or K-connections with backing or backgouging shall be qualified using:

(1) the appropriate nominal pipe OD selected from Table 10.9, and

(2) the joint detail of Figure 10.18(B), or

(3) for nominal pipe ODs equal to or greater than 24 in [600 mm], a plate qualification in conformance with 6.10 using the joint detail of Figure 10.18(B).

10.14.4 T-, Y-, or K-Connections without Backing Welded from One Side Only. When qualification is required, a WPS for T-, Y-, or K-connections without backing welded from one side only shall require the following:

10.14.4.1 WPSs without Prequalified Status. For a WPS whose essential variables are outside the prequalified range, qualification for CJP tubular groove welds shall require the following:

(1) Qualification in conformance with Figure 10.20 for pipes with outside diameters greater than or equal to 4 in [100 mm] or Figure 10.20 and Figure 10.22 for box tubes. Qualification in conformance with Figure 10.21 for pipes with outside diameters less than 4 in [100 mm] or Figure 10.22 for box tubes.

(2) A Sample Joint or Tubular Mock-Up. The sample joint or tubular mock-up shall provide at least one macroetch test section for each of the following conditions:

(a) The groove combining the greatest groove depth with the smallest groove angle, or combination of grooves to be used: test with welding position vertical.

(b) The narrowest root opening to be used with a 37.5° groove angle: one test welded in the flat position and one test welded in the overhead position.

(c) The widest root opening to be used with a 37.5° groove angle: one test to be welded in the flat position and one test to be welded in the overhead position.

(d) For matched box connections only, the minimum groove angle, corner dimension and corner radius to be used in combination: one test in horizontal position.

(3) The macroetch test specimens required in (1) and (2) above shall be examined for discontinuities and shall have:

(a) No cracks

(b) Thorough fusion between adjacent layers of weld metal and between weld metal and base metal

(c) Weld details conforming to the specified detail but with none of the variations prohibited in 7.23.

(d) No undercut exceeding the values allowed in 8.9.

(e) For porosity 1/32 in [1 mm] or larger, accumulated porosity shall not exceed 1/4 in [6 mm]

(f) No accumulated slag, the sum of the greatest dimension of which shall not exceed 1/4 in [6 mm]

Those specimens not conforming to (a) through (f) shall be considered unacceptable; (b) through (f) not applicable to backup weld.

10.14.4.2 CJP Groove Welds in a T-, Y-, or K-Connection WPS with Dihedral Angles Less than 30°. The sample joint described in 10.14.4.1(2)(a) shall be required. Three macroetch test sections shall be cut from the test specimens, shall conform to the requirements of 10.14.4.1(3) and shall show the required theoretical weld (with due allowance for backup welds to be discounted, as shown in Details C and D of Figures 10.9–10.11) (see Figure 10.19 for test joint details).

10.14.4.3 CJP Groove Welds in a T-, Y-, or K-Connection WPS Using GMAW-S. For T-, Y-, and K-connections, where GMAW-S is used, qualification in conformance with Clause 6 shall be required prior to welding the standard joint configurations detailed in 10.10.2. The joint tested shall incorporate a 37.5° single bevel groove, offset root and restriction ring as shown in Figure 10.20.

10.14.4.4 Weldments Requiring CVN Toughness. WPSs for butt joints (longitudinal or circumferential seams) within 0.5D of attached branch members, in tubular connection joint-cans requiring CVN testing under 10.7.2.2, shall be required to demonstrate weld metal CVN absorbed energy of 20 ft·lbf [27 J] at the LAST (Lowest Anticipated Service Temperature), or at 0°F [-18°C], whichever is lower. If AWS specifications for the welding materials to be used do not encompass this requirement, or if production welding is outside the range covered by prior testing, e.g., tests per AWS filler metal specifications, then weld metal CVN tests shall be made during WPS qualification, as described in Clause 6, Part D.

10.15 PJP and Fillet Welds Tubular T-, Y-, or K-Connections and Butt Joints

When PJP groove welds are specified, in T-, Y-, or K-connections or butt welds, qualification shall be in conformance with Table 10.10. When fillet welds are specified in T-, Y- or K-connections, qualification shall be in conformance with 6.13, Table 10.11 and Figure 10.16.

Part D
Performance Qualification

10.16 Production Welding Positions, Thicknesses, and Diameters Qualified

10.16.1 Welders and Welding Operators. The qualified tubular production welding positions qualified by a tubular test for welders and welding operators shall be in conformance with Table 10.12. The qualified tubular production welding positions qualified by a plate test for welders and welding operators shall be in conformance with Clause 6 and Table 6.10.

For tests on tubulars, the number and type of test specimens and the range of qualified production welding thicknesses and diameters for which a welder or welding operator is qualified shall be in conformance with Table 10.13. Mechanical test specimens shall be prepared by cutting the pipe or tubing as shown in Figure 10.23 and as specified in 6.17.1.2. If tests are performed using plate, the qualification limitations shall be in conformance with Table 6.11.

10.16.2 Tack Welders. Tack welder qualification shall qualify for tubular thickness greater than 1/8 in [3 mm] and all diameters, but does not include CJP butt joints and T-, Y-, and K-connections welded from one side. Tack welds in the foregoing exception shall be performed by welders fully qualified for the process and position in which the welding is to be done.

10.17 Weld Types for Welder and Welding Operator Performance Qualification

For the purpose of welder and welding operator qualification, weld types shall be classified as follows:

(1) CJP Groove Welds for Tubular Connections (see 10.18)

(2) PJP Groove Welds for Tubular Connections (see 10.19)

(3) Fillet Welds for Tubular Connections (see 10.20)

Plate welds parallel to the tubular centerline and tubular longseam welds do not require tubular qualification and may be qualified using Clause 6.

10.18 CJP Groove Welds for Tubular Connections

Welder or welding operator qualification tests shall use the following details:

(1) CJP groove butt joints with backing or backgouging in pipe. Use Figure 10.17(B).

(2) CJP groove butt joints without backing or backgouging. Use Figure 10.17(A).

(3) CJP groove butt joints or T-, Y-, and K-connections with backing in box tubing. Use Figure 10.17(B) in pipe (any diameter), plate or box tubing.

(4) CJP groove T-, Y-, and K-Connections welded from one side with backing in pipe. Use Figure 10.17(B) in pipe of the appropriate diameter.

(5) CJP groove T-, Y-, and K-connections welded from one side without backing in pipe. Use Figure 10.20 for nominal pipe diameter of ≥ 6 in [150 mm] or Figure 10.21 for nominal pipe ≤ 4 in [100 mm].

(6) CJP groove T-, Y-, and K-connection welded from one side without backing or backgouging in box tubing. The options are the following:

(a) Figure 10.20 in pipe (any diameter) or box tubing plus Figure 10.22 in box tubing.

(b) Figure 10.20 in box tubing with macroetch specimens removed from the locations shown in Figure 10.22.

See Table 10.13 for the production ranges of diameter and thickness qualified by the test assembly diameters and thicknesses.

10.18.1 Other Joint Details or WPSs. For joint details, WPSs, or assumed depth of sound welds that are more difficult than those described herein, a test described in 10.14.4.2 shall be performed by each welder in addition to the 6GR tests (see Figures 10.21 or 10.22). The test position shall be vertical.

10.19 PJP Groove Welds for Tubular Connections

Qualification for CJP groove welds on tubular connections shall qualify for all PJP groove welds.

10.20 Fillet Welds for Tubular Connections

See Table 10.13 for fillet weld qualification requirements.

10.21 Methods of Testing and Acceptance Criteria for Welder and Welding Operator Qualification

10.21.1 Macroetch Test for T-, Y-, and K-Connections. The corner macroetch test joint for T-, Y-, and K-connections on box tubing in Figure 10.22 shall have four macroetch test specimens cut from the weld corners at the locations shown in Figure 10.22. One face from each corner specimen shall be smooth for etching. If the welder tested on a 6GR coupon (Figure 10.21) using box tubing, the four required corner macroetch test specimens may be cut from the corners of the 6GR coupon in a manner similar to Figure 10.22. One face from each corner specimen shall be smooth for etching.

10.21.1.1 Macroetch Test Acceptance Criteria. For acceptable qualification, the test specimen, when inspected visually, shall conform to Clause 6 and the following requirements:

(1) Fillet welds and the corner macroetch test joint for T-, Y-, and K-connections on box tubing, Figure 10.22, shall have:

(a) No cracks

(b) Thorough fusion between adjacent layers of weld metals and between weld metal and base metal

(c) Weld profiles conforming to intended detail, but with none of the variations prohibited in 7.23

(d) No undercut exceeding 1/32 in [1 mm]

(e) For porosity 1/32 in [1 mm] or larger, accumulated porosity not exceeding 1/4 in [6 mm]

(f) No accumulated slag, the sum of the greatest dimensions of which shall not exceed 1/4 in [4 mm]

10.21.2 RT Test Procedure and Technique. Welded test pipe or tubing 4 in [100 mm] in diameter or larger shall be examined for a minimum of one-half of the weld perimeter selected to include a sample of all positions welded. For example, a test pipe or tube welded in the 5G, 6G, or 6GR position shall be radiographed from the top centerline to the bottom centerline on either side. Welded test pipe or tubing less than 4 in [100 mm] in diameter shall require 100% RT.

Part E
Fabrication

10.22 Backing

10.22.1 Full-Length Backing. Except as permitted below, steel backing shall be made continuous for the full length of the weld. All joints in the steel backing shall be CJP groove weld joints meeting all the requirements of Clause 7 of this code. For statically loaded applications, backing for welds to the ends of closed sections, such as hollow structural sections (HSS), are permitted to be made from one or two pieces with unspliced discontinuities where all of the following conditions are met:

(1) The closed section nominal wall thickness does not exceed 5/8 in [16 mm].

(2) The closed section outside perimeter does not exceed 64 in [1625 mm].

(3) The backing is transverse to the longitudinal axis of the closed section.

(4) The interruption in the backing does not exceed 1/4 in [6 mm].

(5) The weld with discontinuous backing is not closer than the HSS diameter or major cross section dimension from other types of connections.

(6) The interruption in the backing is not located in the corners.

For statically loaded box columns, discontinuous backing is permitted in the CJP welded corners, at field splices and at connection details. Discontinuous backing is permitted in other closed sections where approved by the Engineer.

NOTE: Commercially available steel backing for pipe and tubing is acceptable, provided there is no evidence of melting on exposed interior surfaces.

10.23 Tolerance of Joint Dimensions

10.23.1 Girth Weld Alignment (Tubular). Abutting parts to be joined by girth welds shall be carefully aligned. No two girth welds shall be located closer than one pipe diameter or 3 ft [1 m], whichever is less. There shall be no more than two girth welds in any 10 ft [3 m] interval of pipe, except as may be agreed upon by the Owner and Contractor. Radial offset of abutting edges of girth seams shall not exceed 0.2t (where t is the thickness of the thinner member) and the maximum allowable shall be 1/4 in [6 mm], provided that any offset exceeding 1/8 in [3 mm] is welded from both sides. However, with the approval of the Engineer, one localized area per girth seam may be offset up to 0.3t with a maximum of 3/8 in [10 mm], provided the localized area is under 8t in length. Filler metal shall be added to this region to provide a 4 to 1 transition and may be added in conjunction with making the weld. Offsets in excess of this shall be corrected as provided in 7.21.3. Longitudinal weld seams of adjoining sections shall be staggered a minimum of 90°, unless closer spacing is agreed upon by the Owner and fabricator.

10.23.2 Groove Dimensions

10.23.2.1 Tubular Cross-Sectional Variations. Variation in cross section dimension of groove welded joints, from those shown on the detailed drawings, shall be in conformance with 7.21.4.1 except:

(1) Tolerances for T-, Y-, and K-connections are included in the ranges given in 10.10.2.

(2) The tolerances shown in Table 10.14 apply to CJP tubular groove welds in butt joints, made from one side only, without backing.

Part F
Inspection

10.24 Visual Inspection

All welds shall be visually inspected and shall be acceptable if the criteria in Table 10.15 are satisfied.

10.25 NDT

10.25.1 Scope. Acceptance criteria for inspection of tubular connections are described in Part C of Clause 8, as applicable, and Part F of this clause. The acceptance criteria shall be specified in the contract documents on information furnished to the bidder.

10.25.2 Tubular Connection Requirements. For CJP groove butt joints welded from one side without backing, the entire length of all completed tubular production welds shall be examined by either RT or UT. The acceptance criteria shall conform to 8.12.1 for RT (see Figure 8.1) or 10.26.1 for UT, as applicable.

10.26 UT

10.26.1 Acceptance Criteria for Tubular Connections. Acceptance criteria for UT shall be as provided in contract documents. Class R or Class X, or both, may be incorporated by reference. Amplitude based acceptance criteria as given by 8.13.1 may also be used for groove welds in butt joints in tubing 24 in [600 mm] in diameter and over, provided all relevant provisions of Clause 8, Part F, are followed. However, these amplitude criteria shall not be applied to tubular T, Y-, and K-connections.

10.26.1.1 Class R (Applicable When UT is Used as an Alternate to RT). All indications having one-half (6 dB) or less amplitude than the standard sensitivity level (with due regard for 10.29.6) shall be disregarded. Indications exceeding the disregard level shall be evaluated as follows:

(1) Isolated random spherical reflectors, with 1 in [25 mm] minimum separation up to the standard sensitivity level shall be accepted. Larger reflectors shall be evaluated as linear reflectors.

(2) Aligned spherical reflectors shall be evaluated as linear reflectors.

(3) Clustered spherical reflectors having a density of more than one per square inch [645 square millimeters] with indications above the disregard levels (projected area normal to the direction of applied stress, averaged over a 6 in [150 mm] length of weld) shall be rejected.

(4) Linear or planar reflectors whose lengths (extent) exceed the limits of Figure 10.24 shall be rejected. Additionally, root reflectors shall not exceed the limits of Class X.

10.26.1.2 Class X (Experience-Based, Fitness for Purpose Criteria Applicable to T-, Y-, and K-Connections in Structures with Notch-Tough Weldments). All indications having half (6 dB) or less amplitude than the standard sensitivity level (with due regard for 10.29.6) shall be disregarded. Indications exceeding the disregard level shall be evaluated as follows:

(1) Spherical reflectors shall be as described in Class R, except that any indications within the following limits for linear or planar shall be acceptable.

(2) Linear or planar reflectors shall be evaluated by means of beam boundary techniques, and those whose dimensions exceeded the limits of Figure 10.25 shall be rejected. The root area shall be defined as that lying within 1/4 in [6 mm] or $t_w/4$, whichever is greater, of the root of the theoretical weld, as shown in Figure 10.9.

10.27 RT Procedures

10.27.1 Procedure. In addition to the requirements of 8.17, IQI selection shall conform to Tables 10.16 and 10.17 and Figures 8.4 and 8.5.

10.27.2 IQI Selection and Placement. IQIs shall be selected and placed on the weldment in the area of interest being radiographed as shown in Table 10.18. When a complete circumferential pipe weld is radiographed with a single exposure and the radiation source is placed at the center of the curvature, at least three equally spaced IQIs shall be used. Steel backing shall not be considered part of the weld or weld reinforcement in IQI selection.

10.28 Supplementary RT Requirements for Tubular Connections

10.28.1 Circumferential Groove Welds in Butt Joints. The technique used to radiograph circumferential butt joints shall be capable of covering the entire circumference. The technique shall preferably be single-wall exposure/ single-wall view. Where accessibility or pipe size prohibits this, the technique may be double-wall exposure/ single-wall view or double-wall exposure/double-wall view.

10.28.1.1 Single-Wall Exposure/Single-Wall View. The source of radiation shall be placed inside the pipe and the film on the outside of the pipe (see Figure 10.26). Panoramic exposure may be made if the source-to-object requirements are satisfied; if not, a minimum of three exposures shall be made. The IQI may be selected and placed on the source side of the pipe. If not practicable, it may be placed on the film side of the pipe.

10.28.1.2 Double-Wall Exposure/Single-Wall View. Where access or geometrical conditions prohibit single-wall exposure, the source may be placed on the outside of the pipe and film on the opposite wall outside the pipe (see Figure 10.27). A minimum of three exposures shall be required to cover the complete circumference. The IQI may be selected and placed on the film side of the pipe.

10.28.1.3 Double-Wall Exposure/Double-Wall View. When the outside diameter of the pipe is 3–1/2 in [90 mm] or less, both the source side and film side weld may be projected onto the film and both walls viewed for acceptance. The source of radiation shall be offset from the pipe by a distance that is at least seven times the outside diameter. The radiation beam shall be offset from the plane of the weld centerline at an angle sufficient to separate the images of the source side and film side welds. There shall be no overlap of the two zones interpreted. A minimum of two exposures 90° to each other shall be required (see Figure 10.28). The weld may also be radiographed by superimposing the two welds, in which case there shall be a minimum of three exposures 60° to each other (see Figure 10.29). In each of these two techniques, the IQI shall be placed on the source side of the pipe.

10.29 UT of Tubular T-, Y-, and K-Connections

10.29.1 Procedure. All UT shall be in conformance with a written procedure which has been prepared or approved by an individual certified as SNT-TC-1A, Level III, and experienced in UT of tubular structures. The procedure shall be based upon the requirements of this clause and Clause 8, Part F, as applicable. The procedure shall contain, as a minimum, the following information regarding the UT method and techniques:

(1) The type of weld joint configuration to be examined (i.e., the applicable range of diameter, thickness, and local dihedral angle). Conventional techniques are generally limited to diameters of 12–3/4 in [325 mm] and larger, thicknesses of 1/2 in [12 mm] and above, and local dihedral angles of 30° or greater. Special techniques for smaller sizes may be used, provided they are qualified as described herein, using the smaller size of application.

(2) Acceptance criteria for each type and size weld

(3) Type(s) of UT instrumentation (make and model)

(4) Transducer (search unit) frequency, size and shape of active area, beam angle, and type of wedge on angle beam probes. Procedures using transducers with frequencies up to 6 MHz, sized down to 1/4 in [6 mm], and of different shape than specified elsewhere, may be used, provided they are qualified as described herein.

(5) Surface preparation and couplant (where used)

(6) Type of calibration test block and reference reflector

(7) Method of calibration and required accuracy for distance (sweep), vertical linearity, beam spread, angle, sensitivity, and resolution

(8) Recalibration interval for each item in (7) above

(9) Method for determining acoustical continuity of base metal (see 10.29.4), and for establishing geometry as a function of local dihedral angle and thickness

(10) Scanning pattern and sensitivity (see 10.29.5)

(11) Transfer correction for surface curvature and roughness (where amplitude methods are used (see 10.29.3)

(12) Methods for determining effective beam angle (in curved material), indexing root area, and discontinuity locations

(13) Method of discontinuity length and height determination

(14) Method of discontinuity verification during excavation and repair

10.29.2 Personnel. In addition to personnel requirements of 8.14.6, when examination of T-, Y-, and K-connections is to be performed, the operator shall be required to demonstrate an ability to apply the special techniques required for such an examination. Practical tests for this purpose shall be performed upon mock-up welds that represent the type of welds to be inspected, including a representative range of dihedral angle and thickness to be encountered in production, using the applicable qualified and approved procedures. Each mock-up shall contain natural or artificial discontinuities that yield UT indications above and below the reject criteria specified in the approved procedure. Performance shall be judged on the basis of the ability of the operator to determine the size and classification of each discontinuity with an accuracy required to accept or reject each weldment and accurately locate the unacceptable discontinuities along the weld and within the cross section of the weld. At least 70% of the unacceptable discontinuities shall be correctly identified as unacceptable. Every discontinuity exceeding its maximum acceptable dimensions by a factor of two, or by an amplitude of 6 dB shall be located and reported.

10.29.3 Calibration. UT equipment qualification and calibration methods shall meet the requirements of the approved procedure and Clause 8, Part F, except as follows:

10.29.3.1 Range. Range (distance) calibration shall include, as a minimum, the entire sound path distance to be used during the specific examination. This may be adjusted to represent either the sound-path travel, surface distance, or equivalent depth below contact surface, displayed along the instrument horizontal scale, as described in the approved procedure.

10.29.3.2 Sensitivity Calibration. Standard sensitivity for examination of production welds using amplitude techniques shall be: basic sensitivity + distant amplitude correction + transfer correction. This calibration shall be performed at least once for each joint to be tested; except that, for repetitive testing of the same size and configuration, the calibration frequency of 8.24.3 may be used.

(1) **Basic Sensitivity**. Reference level screen height obtained using maximum reflection from the 0.060 in [1.5 mm] diameter hole in the IIW type block (or other block which results in the same basic calibration sensitivity) as described in 8.24 (or 8.27).

(2) **Distance Amplitude Correction.** The sensitivity level shall be adjusted to provide for attenuation loss throughout the range of sound path to be used by either distance amplitude correction curves, electronic means, or as described in 8.25.6.4. Where high frequency transducers are used, the greater attenuation shall be taken into account. Transfer correction may be used to accommodate UT through tight layers of paint not exceeding 10 mils [0.25 mm] in thickness.

10.29.4 Base Metal Examination. The entire area subject to UT scanning shall be examined by the longitudinal wave technique to detect laminar reflectors that could interfere with the intended, directed sound wave propagation. All areas containing laminar reflectors shall be marked for identification prior to weld examination and the consequences considered in selection of search unit angles and scanning techniques for examination of the welds in that area. The Engineer shall be notified of base material discontinuities that exceed the limits of 7.14.5.1.

10.29.5 Weld Scanning. Weld scanning of T-, Y-, and K-connections shall be performed from the branch member surface (see Figure 10.30). All examinations shall be made in leg I and II where possible. For initial scanning, the sensitivity shall be increased by 12 dB above that established in 10.29.3 for the maximum sound path. Indication evaluation shall be performed with reference to the standard sensitivity.

10.29.6 Optimum Angle. Indications found in the root areas of groove welds in butt joints and along the fusion face of all welds shall be further evaluated with either 70°, 60°, or 45° search angle, whichever is nearest to being perpendicular to the expected fusion face.

10.29.7 Discontinuity Evaluation. Discontinuities shall be evaluated by use of a combination of beam boundary and amplitude techniques. Sizes shall be given as length and height (depth dimension) or amplitude, as applicable. Amplitude shall be related to "standard calibration." In addition, discontinuities shall be classified as linear or planar versus spherical, by noting changes in amplitude as the transducer is swung in an arc centered on the reflector. The location (position) of discontinuities within the weld cross section, as well as from an established reference point along the weld axis, shall be determined.

10.29.8 Reports

10.29.8.1 Forms. A report form that clearly identifies the work and the area of inspection shall be completed by the UT operator at the time of inspection. A detailed report and sketch showing the location along the weld axis, location within the weld cross section, size (or indication rating), extent, orientation, and classification for each discontinuity shall be completed for each weld in which significant indications are found.

10.29.8.2 Reported Discontinuities. When specified, discontinuities approaching unacceptable size, particularly those about which there is some doubt in their evaluation, shall also be reported.

10.29.8.3 Incomplete Inspection. Areas for which complete inspection was not practicable shall also be noted, along with the reason why the inspection was incomplete.

10.29.8.4 Reference Marks. Unless otherwise specified, the reference position and the location and extent of unacceptable discontinuities shall also be marked physically on the workpiece.

Table 10.1
Fatigue Stress Design Parameters (see 10.2.3.2)

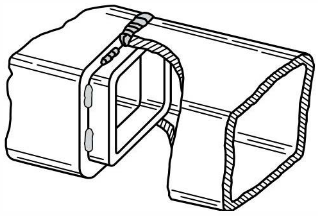
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 1—Welded Joints Transverse to Direction of Stress					
1.1 Base metal and filler metal in or adjacent to CJP groove welded butt splices with backing left in place. Tack welds inside groove Tack welds outside the groove and not closer than 1/2 in [12 mm] to edge of base metal	 D E	 22×10^8 11×10^8	 7 [48] 4.5 [31]	From the toe of the groove weld or the toe of the weld attaching backing	1.1 

Table 10.2
Available Stresses in Tubular Connection Welds (see 10.2.2 and 10.5.4)

Type of Weld	Tubular Application	Kind of Stress	Allowable Stress Design (ASD)	Load and Resistance Factor Design (LRFD)		Required Filler Metal Strength Level[a]
			Allowable Stress	Resistance Factor Φ	Nominal Strength	
CJP Groove Weld	Longitudinal butt joints (longitudinal seams)	Tension or compression parallel to axis of the weld[b]	Same as for base metal[c]	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[b]	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 CJP welds	Tension, compression or shear on base metal adjoining weld conforming to detail of Figures 10.7 and 10.9–10.11 (tubular weld made from outside only without backing)	Same as for base metal or as limited by connection geometry	Same as for base metal or as limited by connection geometry		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	$0.30\ F^{e}_{EXX}$	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 10.5)	$0.30\ F_{EXX}$ or as limited by connection geometry	0.75	$0.6\ F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal may be used
				or as limited by connection geometry		

(Continued)

Table 10.2 (Continued)
Available Stresses in Tubular Connection Welds (see 10.2.2 and 10.5.4)

<table>
<tr><th rowspan="2">Type of Weld</th><th rowspan="2">Tubular Application</th><th rowspan="2" colspan="2">Kind of Stress</th><th>Allowable Stress Design (ASD)</th><th colspan="2">Load and Resistance Factor Design (LRFD)</th><th rowspan="2">Required Filler Metal Strength Level[a]</th></tr>
<tr><th>Allowable Stress</th><th>Resistance Factor Φ</th><th>Nominal Strength</th></tr>
<tr><td>Plug and Slot Welds</td><td colspan="3">Shear parallel to faying surfaces (on effective area)</td><td>Base metal $0.40\ F_y$
Filler metal $0.3\ F_{EXX}$</td><td colspan="2">Not Applicable</td><td>Filler metal with a strength level equal to or less than matching filler metal may be used</td></tr>
<tr><td rowspan="7">PJP Groove Weld</td><td>Longitudinal seam of tubular members</td><td colspan="2">Tension or compression parallel to axis of the weld[b]</td><td>Same as for base metal[c]</td><td>0.9</td><td>F_y</td><td>Filler metal with a strength level equal to or less than matching filler metal may be used</td></tr>
<tr><td rowspan="4">Circumferential and longitudinal joints that transfer loads</td><td rowspan="2">Compression normal to the effective area</td><td>Joint not designed to bear</td><td>$0.50\ F_{EXX}$, except that stress on adjoining base metal shall not exceed $0.60\ F_y$</td><td rowspan="2">0.9</td><td rowspan="2">F_y</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>Joint designed to bear</td><td>Same as for base metal</td></tr>
<tr><td colspan="2">Shear on effective area</td><td rowspan="2">$0.30\ F_{EXX}$, except that stress on adjoining base metal shall not exceed $0.50\ F_y$ for tension, or $0.40\ F_y$ for shear</td><td>0.75</td><td>$0.6\ F_{EXX}$</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 on effective area</td><td>Base metal 0.9
Filler metal 0.8</td><td>F_y
$0.6\ F_{EXX}$</td></tr>
<tr><td rowspan="2">Structural T-, Y-, or K-connection in ordinary structures</td><td rowspan="2" colspan="2">Load transfer across the weld as stress on the effective throat (see 10.5)</td><td rowspan="2">$0.30\ F_{EXX}$ or as limited by connection geometry 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</td><td>Base metal 0.9
Filler metal 0.8</td><td>F_y
$0.6\ F_{EXX}$</td><td rowspan="2">Matching filler metal shall be used</td></tr>
<tr><td colspan="2">or as limited by connection geometry</td></tr>
</table>

[a] For matching filler metal see Table 5.4.
[b] Beam or torsional shear up to 0.30 minimum specified tensile strength of filler metal is allowed, except that shear on adjoining base metal shall not exceed $0.40\ F_y$ (LRFD; see shear).
[c] Groove and fillet welds parallel to the longitudinal axis of tension or compression members, except in connection areas, shall not be considered as transferring stress and hence may take the same stress as that in the base metal, regardless of electrode (filler metal) classification.
[e] Alternatively, see 4.6.4.2 and 4.6.4.3.

Table 10.3
Stress Categories for Type and Location of Material for Circular Sections (see 10.2.3.2)

Stress Category	Situation	Kinds of Stress[a]
A	Plain unwelded pipe	TCBR
B	Pipe with longitudinal seam	TCBR
B	Butt splices, CJP 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, CJP 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 CJP welds (except at tubular connections)	TCBR
DT	Connections designed as a simple T-, Y-, or K-connections with CJP groove welds conforming to Figures 10.9–10.11 (including overlapping connections in which the main member at each intersection meets punching shear requirements) (see Note b)	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 PJP 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 PJP 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 b)	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)
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 PJP groove welds (except at tubular connections)	Shear in weld (regardless of direction of loading) (see 10.5)
FT	Simple T-, Y-, or K-connections loaded in tension or bending, having fillet or PJP groove welds	Shear in weld (regardless of direction of loading)
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

(Continued)

Table 10.3 (Continued)
Stress Categories for Type and Location of Material for Circular Sections (see 10.2.3.2)

Stress Category	Situation	Kinds of Stress[a]
X_1	As for X_2, profile improved per 10.2.3.6 and 10.2.3.7	As for X_2
X_1	Unreinforced cone-cylinder intersection	Hot-spot stress at angle change; calculate per Note d
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 c).	Punching shear for main members; calculate per Note e
K_1	As for K_2, profile improved per 10.2.3.6 and 10.2.3.7	

[a] T = tension, C = compression, B = bending, R = reversal—i.e., total range of nominal axial and bending stress.
[b] Empirical curves (Figure 10.1) 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.
[c] Empirical curves (Figure 10.1) 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.

[d] Stress concentration factor – $SCF = \frac{1}{\cos\bar{\psi}} + 1.17\tan\bar{\psi}\sqrt{\gamma_b}$

Where

$\bar{\psi}$ = angle change at transition

γ_b = radius to thickness ratio of tube at transition

[e] Cyclic range of punching shear is given by

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

where

t and θ are defined in Figure 10.2, 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 as:		
Chord ovalizing parameter needed for Q_q	$\alpha = 1.0 + 0.7\ g/d_b$ $1.0 \le \alpha < 1.7$	For axial load in gap K-connections having all members in same plane and loads transverse to main member essentially balanced[f]
	$\alpha = 1.7$ $\alpha = 2.4$	For axial load in T- and Y connections For axial load in cross connections
	$\alpha = 0.67$ $\alpha = 1.5$	For in-plane bending[g] For out-of-plane bending[g]

[f] Gap g is defined in Figures 10.2(E), (F), and (H); d_b is branch diameter.
[g] For combinations of the in-plane bending and out-of-plane bending, use interpolated values of α and λ.

Table 10.4
Fatigue Category Limitations on Weld Size or Thickness and Weld Profile (Tubular Connections) (see 10.2.3.7)

Weld Profile	Level I Limiting Branch Member Thickness for Categories X_1, X_2, DT in [mm]	Level II Limiting Branch Member Thickness for Categories X_2, K_2 in [mm]
Standard flat weld profile Figure 10.9	0.375[10]	0.625 [16]
Profile with toe fillet Figure 10.10	0.625 [16]	1.50 [38] qualified for unlimited thickness for static compression loading
Concave profile, as welded, Figure 10.11 with disk test per 10.2.3.6(1)	1.00 [25]	unlimited
Concave smooth profile Figure 10.11 fully ground per 10.2.3.6(2)	unlimited	—

Table 10.5
Z Loss Dimensions for Calculating Prequalified PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes (see 10.5.3.1)

Joint Included Angle ϕ	Position of Welding: V or OH			Position of Welding: H or F		
	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[a]	0	0	GMAW-S[a]	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[a]	1/8	3	GMAW-S[a]	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[a]	3/8	10	GMAW-S[a]	1/4	6

[a] See 10.9.1(2) for qualification requirements for welding prequalified PJP T-, Y-, K-Connections details with GMAW-S.

Table 10.6
Joint Detail Applications for Prequalified CJP T-, Y-, and K-Tubular Connections
(see 10.10.2 and Figure 10.8)

Detail	Applicable Range of Local Dihedral Angle, Ψ	
A	180° to 135°	
B	150° to 50°	
C	75° to 30°	
D	40° to 15°	} Not prequalified for groove angles under 30°

Notes:
1. The applicable joint detail (A, B, C, or D) for a particular part of the connection shall be determined by the local dihedral angle, Ψ, which changes continuously in progressing around the branch member.
2. The angle and dimensional ranges given in Detail A, B, C, or D include maximum allowable tolerances.
3. See Clause 3 for definition of local dihedral angle.

Table 10.7
Prequalified Joint Dimensions and Groove Angles for CJP Groove Welds in Tubular T-, Y-, and K-Connections Made by SMAW, GMAW-S, and FCAW (see 10.10.2)

		Detail A $\Psi = 180° - 135°$		Detail B $\Psi = 150° - 50°$		Detail C $\Psi = 75° - 30°$[a]	Detail D $\Psi = 40° - 15°$[a]
End preparation (ω)				90°[c,b]		(Footnote b)	
	max.			10° or		10°	
	min.			45° for $\Psi > 105°$			
		FCAW-S SMAW[c]	GMAW-S FCAW-G[d]	FCAW-S SMAW[c]	GMAW-S FCAW-G[d]	(Footnote e)	W max. / ϕ
Fit-up or root opening (R)	max.	3/16 in [5 mm]	3/16 in [5 mm]	1/4 in [6 mm]	1/4 in [6 mm] for $\phi > 45°$ 5/16 in [8 mm] for $\phi \leq 45°$	FCAW-S SMAW (1)	1/8 in [3 mm] 25°–40° 3/16 in [5 mm] 15°–25°
	min.	1/16 in [2 mm] No min. for $\phi > 90°$	1/16 in [2 mm] No min. for $\phi > 120°$	1/16 in [2 mm]	1/16 in [2 mm]	GMAW-S FCAW-G (2)	1/8 in [3 mm] 30°–40° 1/4 in [6 mm] 25°–30° 3/8 in [10 mm] 20°–25° 1/2 in [12 mm] 15°–20°
Joint included angle φ	max.	90°		60° for $\Psi \leq 105°$		40°; if more use Detail B	
	min.	45°		37-1/2°; if less use Detail C		1/2 Ψ	
Completed weld	t_w	$\geq t_b$		$\geq t_b$ for $\Psi > 90°$ $\geq t_b /\sin \Psi$ for $\Psi < 90°$		$\geq t_b /\sin \Psi$ but need not exceed 1.75 t_b	
	L	$\geq t_b /\sin \Psi$ but need not exceed 1.75 t_b				Weld may be built up to meet this	$\geq 2t_b$

[a] Not prequalified for groove angles (ϕ) under 30°.
[b] Otherwise as needed to obtain required ϕ.
[c] These root details apply to SMAW and FCAW-S.
[d] These root details apply to GMAW-S and FCAW-G.
[e] Initial passes of back-up weld discounted until width of groove (W) is sufficient to assure sound weld.

Notes:
1. For GMAW-S see 10.14.4.3. These details are not intended for GMAW (spray transfer).
2. See Figure 10.9 for minimum standard profile (limited thickness).
3. See Figure 10.10 for alternate toe-fillet profile.
4. See Figure 10.11 for improved profile (see 10.2.3.6 and 10.2.3.7).

Table 10.8
WPS Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests (see 10.12)

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
						Butt Joint		T-, Y-, K-Connections			Butt Joint		T-, Y-, K-Connections		
	Weld Type	Test Positions	Groove CJP	Groove PJP	Fillet[a]	CJP	PJP	CJP	PJP	Fillet[a]	CJP	PJP	CJP	PJP	Fillet[a]
TUBULAR	CJP Groove	1G Rotated	F	F	F	F[b]	F		F	F	F[b]	F		F	F
TUBULAR	CJP Groove	2G	F, H	F, H	F, H	(F, H)[b]	F, H		F, H	F, H	(F, H)[b]	F, H		F, H	F, H
TUBULAR	CJP Groove	5G	F, V, OH	F, V, OH	F, V, OH	(F, V, OH)[b]	F, V, OH		F, V, OH	F, V, OH	(F, V, OH)[b]	F, V, OH		F, V, OH	F, V, OH
TUBULAR	CJP Groove	(2G + 5G)	All	All	All	All[b]	All	All[c]	All[d]	All	All[b]	All	All[e]	All[d, f]	All
TUBULAR	CJP Groove	6G	All	All	All	All[b]	All		All[d]	All	All[b]	All		All[d, f]	All
TUBULAR	CJP Groove	6GR	All[g]	All	All	All[g]	All	All[c]	All	All	All[b]	All	All[e]	All	All
TUBULAR	Fillet	1F Rotated			F					F					F
TUBULAR	Fillet	2F			F, H					F, H					F, H
TUBULAR	Fillet	2F Rotated			F, H					F, H					F, H
TUBULAR	Fillet	4F			F, H, OH					F, H, OH					F, H, OH
TUBULAR	Fillet	5F			All					All					All

CJP—Complete Joint Penetration
PJP—Partial Joint Penetration

[a] Fillet welds in production T-, Y-, or K-connections shall conform to Figure 10.5. WPS qualification shall conform to 10.15.
[b] Production butt joint details without backing or backgouging require qualification testing of the joint detail shown in Figure 10.18(A).
[c] For production joints of CJP T-, Y-, and K-connections that conform to either 10.9, 10.10, or 10.11 and Table 10.7, use Figure 10.20 detail for testing. For other production joints, see 10.14.4.1.
[d] For production joints of PJP T-, Y-, and K-connections that conform to Figure 10.6, use either the Figure 10.18(A) or Figure 10.18(B) detail for testing.
[e] For production joints of CJP T-, Y-, and K-connections that conform to Figure 10.7, and Table 10.7, use Figures 10.20 and 10.22 detail for testing, or, alternatively, test the Figure 10.20 joint and cut macroetch specimens from the corner locations shown in Figure 10.22. For other production joints, see 10.14.4.1.
[f] For matched box connections with corner radii less than twice the chord member thickness, see 10.9.1.1.
[g] Limited to prequalified joint details (see 10.9 or 10.10).

Table 10.9
WPS Qualification-CJP Groove Welds: Number and Type of Test Specimens and Range of Thickness and Diameter Qualified (See 10.13) (Dimensions in Inches)

1. Tests on Pipe or Tubing[a,b]

	Nominal Pipe Size or Diam., in	Nominal Wall Thickness, T, in	Number of Specimens: Reduced Section Tension (see Fig. 6.10)	Number of Specimens: Root Bend (see Fig. 6.8)	Number of Specimens: Face Bend (see Fig. 6.8)	Number of Specimens: Side Bend (see Fig. 6.9)	Nominal Diameter[e] of Pipe or Tube Size Qualified, in	Nominal Plate, Pipe or Tube Wall Thickness[c,d] Qualified, in: Min.	Nominal Plate, Pipe or Tube Wall Thickness[c,d] Qualified, in: Max.
Job Size Test Pipes	< 24	1/8 ≤ T ≤ 3/8	2	2	2	(Footnote f)	Test diam. and over	1/8	2T
		3/8 < T < 3/4	2			4	Test diam. and over	T/2	2T
		T ≥ 3/4	2			4	Test diam. and over	3/8	Unlimited
	≥ 24	1/8 ≤ T ≤ 3/8	2	2	2	(Footnote f)	Test diam. and over	1/8	2T
		3/8 < T < 3/4	2			4	24 and over	T/2	2T
		T ≥ 3/4	2			4	24 and over	3/8	Unlimited
Standard Test Pipes	2 in Sch. 80 or 3 in Sch. 40		2	2	2		3/4 through 4	1/8	3/4
	6 in Sch. 120 or 8 in Sch. 80		2			4	4 and over	3/16	Unlimited

[a] All pipe or tube welds shall be visually inspected (see 6.10.1) and subject to NDT (see 6.10.2).
[b] See Table 10.8 for the groove details required for qualification of tubular butt and T-, Y-, K-connection joints.
[c] For square groove welds that are qualified without backgouging, the maximum thickness qualified shall be limited to the test thickness.
[d] CJP groove weld qualification on any thickness or diameter shall qualify any size of fillet or PJP groove weld for any thickness or diameter (see 6.12.3).
[e] Qualification with any pipe diameter shall qualify all box section widths and depths.
[f] For 3/8 in wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.

Table 10.9 (Continued)
WPS Qualification—CJP Groove Welds: Number and Type of Test Specimens and Range of Thickness and Diameter Qualified (see 10.13) (Dimensions in Millimeters)

1. Tests on Pipe or Tubing[a, b]

	Nominal Pipe Size or Diam., mm	Nominal Wall Thickness, T, mm	Number of Specimens: Reduced Section Tension (see Fig. 6.10)	Number of Specimens: Root Bend (see Fig. 6.8)	Number of Specimens: Face Bend (see Fig. 6.8)	Number of Specimens: Side Bend (see Fig. 6.9)	Nominal Diameter[e] of Pipe or Tube Size Qualified, mm	Nominal Plate, Pipe or Tube Wall Thickness[c,d] Qualified, mm: Min.	Nominal Plate, Pipe or Tube Wall Thickness[c,d] Qualified, mm: Max.
Job Size Test Pipes	< 600	3 ≤ T ≤ 10	2	2	2	(Footnote f)	Test diam. and over	3	2T
		10 < T < 20	2			4	Test diam. and over	T/2	2T
		T ≥ 20	2			4	Test diam. and over	10	Unlimited
	≥ 600	3 ≤ T ≤ 10	2	2	2	(Footnote f)	Test diam. and over	3	2T
		10 < T < 20	2			4	600 and over	T/2	2T
		T ≥ 20	2			4	600 and over	10	Unlimited
Standard Test Pipes	DN 50 × 5.5 mm WT or DN 80 × 5.5 mm WT		2	2	2		20 through 100	3	20
	DN 150 × 14.3 mm WT or DN 200 × 12.7 mm WT		2			4	100 and over	5	Unlimited

[a] All pipe or tube welds shall be visually inspected (see 6.10.1) and subject to NDT (see 6.10.2).
[b] See Table 10.8 for the groove details required for qualification of tubular butt and T-, Y-, K-connection joints.
[c] For square groove welds that are qualified without backgouging, the maximum thickness qualified shall be limited to the test thickness.
[d] CJP groove weld qualification on any thickness or diameter shall qualify any size of fillet or PJP groove weld for any thickness or diameter (see 6.12.3).
[e] Qualification with any pipe diameter shall qualify all box section widths and depths.
[f] For 10 mm wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.

Table 10.10
WPS Qualification—PJP Groove Welds: Number and Type of Test Specimens and Range of Thickness Qualified (See 10.13)

Test Groove Depth, T in [mm]	Number of Specimens[a, b]					Qualification Ranges[c,d]		
	Macroetch for Weld Size (S) 6.12.3	Reduced-Section Tension (see Fig. 6.10)	Root Bend (see Fig. 6.8)	Face Bend (see Fig. 6.8)	Side Bend (see Fig. 6.9)	Groove Depth	Nominal Pipe or Tubing Thickness, in [mm] Min.	Max.
$1/8 \leq T \leq 3/8$ $[3 \leq T \leq 10]$	3	2	2	2		D	1/8 [3]	2T
$3/8 < T \leq 1$ $[10 < T \leq 25]$	3	2			4	D	1/8 [3]	Unlimited

[a] One pipe or tubing per position shall be required (see Figure 10.18). Use the production PJP groove detail for qualification. All pipes or tubing shall be visually inspected (see 6.10.1).
[b] If a PJP bevel- or J-groove weld is to be used for T-joints or double-bevel- or double-J-groove weld is to be used for corner joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate a T-joint configuration.
[c] See the pipe diameter qualification requirements of Table 10.9.
[d] Any PJP qualification shall also qualify any fillet weld size on any thickness.

Table 10.11
WPS Qualification—Fillet Welds: Number and Type of Test Specimens and Range of Thickness Qualified (see 10.13)

Test Specimen	Fillet Size	Number of Welds per WPS	Test Specimens Required[a]			Sizes Qualified	
			Macroetch 6.13.1 6.10.4	All-Weld-Metal Tension (see Figure 6.14)	Side Bend (see Figure 6.9)	Pipe Thickness[b]	Fillet Size
Pipe T-test[c] (Figure 10.16)	Single pass, max. size to be used in construction	1 in each position to be used (see Table 10.8)	3 faces (except for 4F & 5F, 4 faces req'd)			Unlimited	Max. tested single pass and smaller
	Multiple pass, min. size to be used in construction	1 in each position to be used (see Table 10.8)	3 faces (except for 4F & 5F, 4 faces req'd)			Unlimited	Min. tested multiple pass and larger

[a] All welded test pipes shall be visually inspected per 6.10.1.
[b] The minimum thickness qualified shall be 1/8 in [3 mm].
[c] See Table 10.9 for pipe diameter qualification.

Table 10.12
Welder and Welding Operator Qualification—Production Welding Positions Qualified by Pipe and Box Tube Tests (see 10.16.1)

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
						Butt Joint		T-, Y-, K-Connections			Butt Joint		T-, Y-, K-Connections		
	Weld Type	Test Positions[a]	Groove CJP	Groove PJP	Fillet[b]	CJP[c]	PJP[c]	CJP[c, d]	PJP[c, d]	Fillet[b]	CJP	PJP	CJP	PJP[d]	Fillet[b]
TUBULAR	Groove[e] (Pipe or Box)	1G Rotated[f]	F	F	F, H	F	F		F	F, H	F	F		F	F, H
TUBULAR	Groove[e] (Pipe or Box)	2G[f]5G[f]	F, H	F, H	F, H	F, H	F, H		F, H	F, H	F, H	F, H		F, H	F, H
TUBULAR	Groove[e] (Pipe or Box)	6G[f]	F, V, OH	F,-V, OH	F, V, OH	F, V, OH	F, V, OH		F, V, OH	F, V, OH	F, V, OH	F, V, OH		F, V, OH	F, V, H
TUBULAR	Groove[e] (Pipe or Box)	(2G + 5G)[f]	All	All	All	All	All		All	All	All	All		All	All
TUBULAR	Groove[e] (Pipe or Box)		All	All	All	All	All		All	All	All	All		All	All
TUBULAR	Groove[e] (Pipe or Box)	6GR (Fig. 10.20)	All	All	All	All[g]	All	All	All	All	All[g]	All		All	All
TUBULAR	Groove[e] (Pipe or Box)	6GR (Figs. 10.20 & 10.22)	All	All	All	All[g]	All	All	All	All	All[g]	All	All[d, h]	All	All
TUBULAR	Pipe Fillet	1F Rotated			F					F					F
TUBULAR	Pipe Fillet	2F			F, H					F, H					F, H
TUBULAR	Pipe Fillet	2F Rotated			F, H					F, H					F, H
TUBULAR	Pipe Fillet	4F			F, H, OH					F, H, OH					F, H, OH
TUBULAR	Pipe Fillet	5F			All					All					All

CJP-—Complete Joint Penetration
PJP—Partial Joint Penetration

[a] See Figures 10.12 and 10.13.
[b] See 10.14 for dihedral angle restrictions for tubular T-, Y-, K-connections.
[c] Qualification using box tubing (Figure 10.20) also qualifies welding pipe equal to or greater than 24 in [600 mm] in diameter.
[d] Not qualified for welds having groove angles less than 30° (see 10.14.4.2).
[e] Groove weld qualification shall also qualify plug and slot welds for the test positions indicated.
[f] Qualification for welding production joints without backing or backgouging shall require using the Figure 10.22(A) joint detail. For welding production joints with backing or backgouging, either Figure 10.22(A) or Figure 10.22(B) joint detail may be used for qualification.
[g] Not qualified for joints welded from one side without backing, or welded from two sides without backgouging.
[h] Pipe or box tubing is required for the 6GR qualification (Figure 10.20). If box tubing is used per Figure 10.20, the macroetch test may be performed on the corners of the test specimen (similar to Figure 10.22).

Table 10.13
Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in Inches) (see 10.16)

Tests on Pipe or Tubing[a]

Production CJP Groove Butt Joints			Number of Specimens[b]						Qualified Dimensions			
			1G and 2G Positions Only			5G, 6G, and 6GR Positions Only			Nominal Pipe or Tube Size Qualified, in		Nominal Plate, Pipe or Tube Wall Thickness[c] Qualified, in	
Type of Test Weld	Nominal Size of Test Pipe, in	Nominal Test Thickness, in	Face Bend[d]	Root Bend[d]	Side Bend[d]	Face Bend[d]	Root Bend[d]	Side Bend[d]	Min.	Max.	Min.	Max.
Groove	≤ 4	Unlimited	1	1	Footnote e	2	2	Footnote e	3/4	4	1/8	3/4
Groove	> 4	≤ 3/8	1	1	Footnote e	2	2	Footnote e	Footnote f	Unlimited	1/8	3/4
Groove	> 4	> 3/8			2			4	Footnote f	Unlimited	3/16	Unlimited

Production T-, Y-, or K-Connection CJP Groove Welds			Number of Specimens[b]		Qualified Dimensions					
					Nominal Pipe or Tube Size Qualified, in		Nominal Wall or Plate Thickness[c] Qualified, in		Dihedral Angles Qualified[g]	
Type of Test Weld	Nominal Size of Test Pipe, in	Nominal Test Thickness, in	Side Bend[d]	Macroetch	Min.	Max.	Min.	Max.	Min.	Max.
Pipe Groove (Fig. 10.20)	≥ 6 O.D.	≥ 1/2	4		4	Unlimited	3/16	Unlimited	30°	Unlimited
Pipe Groove (Fig. 10.21)	< 4 O.D.	≥ 0.203	Footnote h		3/4	< 4	1/8	Unlimited	30°	Unlimited
Box Groove (Fig. 10.22)	Unlimited	≥ 1/2	4	4	Unlimited (Box only)	Unlimited (Box only)	3/16	Unlimited	30°	Unlimited

Production T-, Y-, or K-Connection Fillet Welds			Number of Specimens[b]				Qualified Dimensions					
							Nominal Pipe or Tube Size Qualified, in		Nominal Wall or Plate Thickness Qualified, in		Dihedral Angles Qualified[g]	
Type of Test Weld	Nominal Size of Test Pipe, D	Nominal Test Thickness, in	Fillet Weld Break	Macroetch	Root Bend[d]	Face Bend[d]	Min.	Max.	Min.	Max.	Min.	Max.
5G position (Groove)	Unlimited	≥ 1/8			2[e]	2[e]	Footnote f	Unlimited	1/8[c]	Unlimited[c]	30°	Unlimited
Option 1 —Fillet (Fig. 6.25)[i]		≥ 1/2	1	1			24	Unlimited	1/8	Unlimited	60°	Unlimited
Option 2 —Fillet (Fig. 6.22)[i]		3/8			2		24	Unlimited	1/8	Unlimited	60°	Unlimited
Option 3 —Fillet (Fig. 10.16)	Unlimited	≥ 1/8		1			D	Unlimited	1/8	Unlimited	30°	Unlimited

[a] See Table 10.12 for appropriate groove details.
[b] All welds shall be visually inspected (see 6.23.1).
[c] Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
[d] Radiographic examination of the test pipe or tubing may be made in lieu of the bend tests (see 6.17.1.1).
[e] For 3/8 in wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.
[f] The minimum pipe size qualified shall be 1/2 the test diameter or 4 in, whichever is greater.
[g] For dihedral angles < 30°, see 10.18.1; except 6GR test not required.
[h] Two root and two face bends.
[i] Two plates required, each subject to the test specimen requirements described. One plate shall be welded in the 3F position and the other in the 4F position.

Table 10.13 (Continued)
Welder and Welding Operator Qualification-Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in Millimeters) (see 10.16)

Tests on Pipe or Tubing[a]

Production CJP Groove Butt Joints			Number of Specimens[b]						Qualified Dimensions			
			1G and 2G Positions Only			5G, 6G, and 6GR Positions Only			Nominal Pipe or Tube Size Qualified, mm		Nominal Plate, Pipe or Tube Wall Thickness[c] Qualified, mm	
Type of Test Weld	Nominal Size of Test Pipe, mm	Nominal Test Thickness, mm	Face Bend[d]	Root Bend[d]	Side Bend[d]	Face Bend[d]	Root Bend[d]	Side Bend[d]	Min.	Max.	Min.	Max.
Groove	≤ 100	Unlimited	1	1	Footnote e	2	2	Footnote e	20	100	3	20
Groove	> 100	≤ 10	1	1	Footnote e	2	2	Footnote e	Footnote f	Unlimited	3	20
Groove	> 100	> 10			2			4	Footnote f	Unlimited	5	Unlimited

Production T-, Y-, or K-Connection CJP Groove Welds			Number of Specimens[b]		Qualified Dimensions					
					Nominal Pipe or Tube Size Qualified, mm		Nominal Wall or Plate Thickness[c] Qualified, mm		Dihedral Angles Qualified[g]	
Type of Test Weld	Nominal Size of Test Pipe, mm	Nominal Test Thickness, mm	Side Bend[d]	Macroetch	Min.	Max.	Min.	Max.	Min.	Max.
Pipe Groove (Fig. 10.20)	≥ 150 O.D.	≥ 12	4		100	Unlimited	5	Unlimited	30°	Unlimited
Pipe Groove (Fig. 10.21)	< 100 O.D.	≥ 5	Footnote h		20	< 100	3	Unlimited	30°	Unlimited
Box Groove (Fig. 10.22)	Unlimited	≥ 12	4	4	Unlimited (Box only)	Unlimited (Box only)	5	Unlimited	30°	Unlimited

Production T-, Y-, or K-Connection Fillet Welds			Number of Specimens[b]				Qualified Dimensions					
							Nominal Pipe or Tube Size Qualified, mm		Nominal Wall or Plate Thickness Qualified, mm		Dihedral Angles Qualified[g]	
Type of Test Weld	Nominal Size of Test Pipe, D	Nominal Test Thickness, mm	Fillet Weld Break	Macroetch	Root Bend[d]	Face Bend[d]	Min.	Max.	Min.	Max.	Min.	Max.
5G position (Groove)	Unlimited	≥ 3			2[e]	2[e]	Footnote f	Unlimited	3[c]	Unlimited[c]	30°	Unlimited
Option 1—Fillet (Fig. 10.21)		≥ 12	1	1			600	Unlimited	3	Unlimited	60°	Unlimited
Option 2—Fillet (Fig. 10.18)[i]		10			2		600	Unlimited	3	Unlimited	60°	Unlimited
Option 3—Fillet (Fig. 10.16)	Unlimited	≥ 3		1			D	Unlimited	3	Unlimited	30°	Unlimited

[a] See Table 10.12 for appropriate groove details.
[b] All welds shall be visually inspected (see 6.23.1).
[c] Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
[d] Radiographic examination of the test pipe or tubing may be made in lieu of the bend tests (see 6.17.1.1).
[e] For 10 mm wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.
[f] The minimum pipe size qualified shall be 1/2 the test diameter or 100 mm, whichever is greater.
[g] For dihedral angles < 30°, see 10.18.1; except 6GR test not required.
[h] Two root and two face bends.
[i] Two plates required, each subject to the test specimen requirements described. One plate shall be welded in the 3F position and the other in the 4F position.

Table 10.14
Tubular Root Opening Tolerances, Butt Joints Welded Without Backing (see 10.23.2.1)

	Root Face of Joint		Root Opening of Joints without Steel Backing		Groove Angle of Joint
	in	mm	in	mm	deg
SMAW	± 1/16	± 2	± 1/16	± 2	± 5
GMAW	± 1/32	± 1	± 1/16	± 2	± 5
FCAW	± 1/16	± 2	± 1/16	± 2	± 5

Note: Root openings wider than allowed by the above tolerances, but not greater than the thickness of the thinner part, may be built up by welding to acceptable dimensions prior to the joining of the parts by welding.

Table 10.15
Visual Inspection Acceptance Criteria (see 10.24)

Discontinuity Category and Inspection Criteria	Tubular Connections (All Loads)
(1) Crack Prohibition Any crack shall be unacceptable, regardless of size or location.	X
(2) Weld/Base Metal Fusion Complete fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X
(4) Weld Profiles Weld profiles shall be in conformance with 7.23.	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A514, A517, and A709 Grade HPS 100W [HPS 690W] steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in [mm] — U, allowable decrease from L, in [mm] ≤ 3/16 [5] — ≤ 1/16 [2] 1/4 [6] — ≤ 3/32 [2.5] ≥ 5/16 [8] — ≤ 1/8 [3] In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, underrun shall be prohibited at the ends for a length equal to twice the width of the flange.	X
(7) Undercut (A) For material less than 1 in [25 mm] thick, undercut shall not exceed 1/32 in [1 mm], with the following exception: undercut shall not exceed 1/16 in [2 mm] for any accumulated length up to 2 in [50 mm] in any 12 in [300 mm]. For material equal to or greater than 1 in [25 mm] thick, undercut shall not exceed 1/16 in [2 mm] for any length of weld.	
(B) In primary members, undercut shall be no more than 0.01 in [0.25 mm] deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in [1 mm] deep for all other cases.	X
(8) **Porosity** (A) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in [1 mm] or greater in diameter shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.	
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.	X
(C) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in [100 mm] of length and the maximum diameter shall not exceed 3/32 in [2.5 mm].	X

Note: An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

Table 10.16
Hole-Type IQI Requirements (see 10.27.1)

Nominal Material Thickness[a] Range, in	Nominal Material Thickness[a] Range, mm	Film Side	
		Designation	Essential Hole
Up to 0.25 incl.	Up to 6 incl.	7	4T
Over 0.25 to 0.375	Over 6 through 10	10	4T
Over 0.375 to 0.50	Over 10 through 12	12	4T
Over 0.50 to 0.625	Over 12 through 16	12	4T
Over 0.625 to 0.75	Over 16 through 20	15	4T
Over 0.75 to 0.875	Over 20 through 22	17	4T
Over 0.875 to 1.00	Over 22 through 25	17	4T
Over 1.00 to 1.25	Over 25 through 32	20	4T
Over 1.25 to 1.50	Over 32 through 38	25	2T
Over 1.50 to 2.00	Over 38 through 50	30	2T
Over 2.00 to 2.50	Over 50 through 65	35	2T
Over 2.50 to 3.00	Over 65 through 75	40	2T
Over 3.00 to 4.00	Over 75 through 100	45	2T
Over 4.00 to 6.00	Over 100 through 150	50	2T
Over 6.00 to 8.00	Over 150 through 200	60	2T

[a] Single-wall radiographic thickness.

Table 10.17
Wire IQI Requirements (see 10.27.1)

Nominal Material Thickness[a] Range, in	Nominal Material Thickness[a] Range, mm	Film Side Essential Wire Identity
Up to 0.25 incl.	Up to 6 incl.	5
Over 0.25 to 0.375	Over 6 to 10	6
Over 0.375 to 0.625	Over 10 to 16	7
Over 0.625 to 0.75	Over 16 to 20	8
Over 0.75 to 1.50	Over 20 to 38	9
Over 1.50 to 2.00	Over 38 to 50	10
Over 2.00 to 2.50	Over 50 to 65	11
Over 2.50 to 4.00	Over 65 to 100	12
Over 4.00 to 6.00	Over 100 to 150	13
Over 6.00 to 8.00	Over 150 to 200	14

[a] Single-wall radiographic thickness

Table 10.18
IQI Selection and Placement (see 10.27.2)

	Equal T $L \geq 10$ in [250 mm]		Equal T $L < 10$ in [250 mm]		Unequal T $L \geq 10$ in [250 mm]		Unequal T $L < 10$ in [250 mm]	
IQI Types	Hole	Wire	Hole	Wire	Hole	Wire	Hole	Wire
Number of IQIs Pipe Girth	3	3	3	3	3	3	3	3
ASTM Standard Selection—	E1025	E747	E1025	E747	E1025	E747	E1025	E747
Tables	10.16	10.17	10.16	10.17	10.16	10.17	10.16	10.17
Figure	8.6		8.7		8.8		8.9	

Notes:
1. T = Nominal base metal thickness (T1 and T2 of Figures).
2. L = Weld Length in area of interest of each radiograph.
3. T may be increased to provide for the thickness of allowable weld reinforcement provided shims are used under hole IQIs per 8.17.3.3.

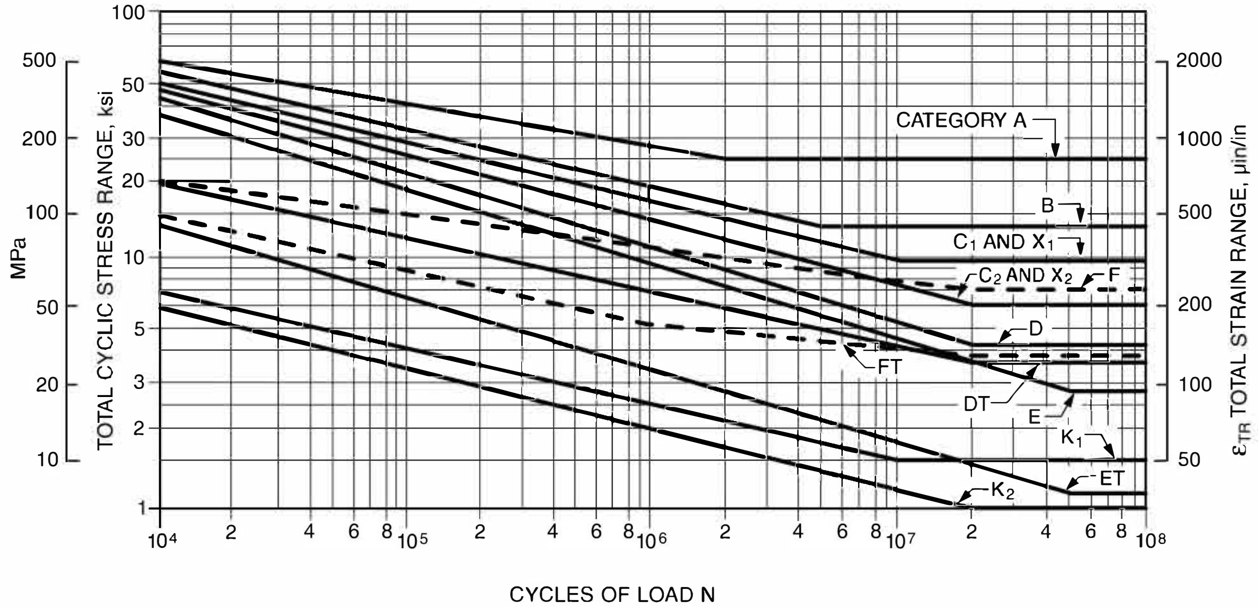
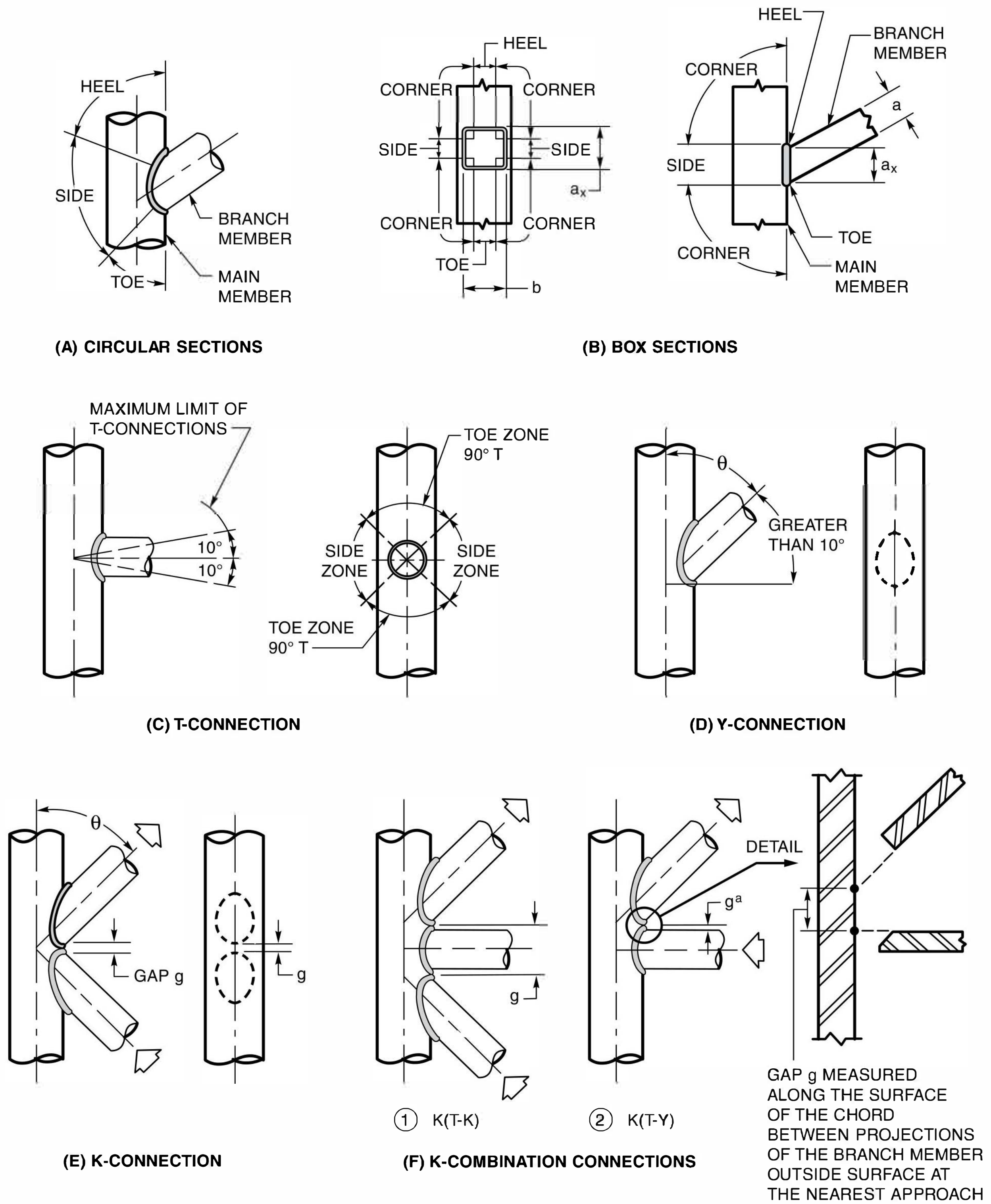
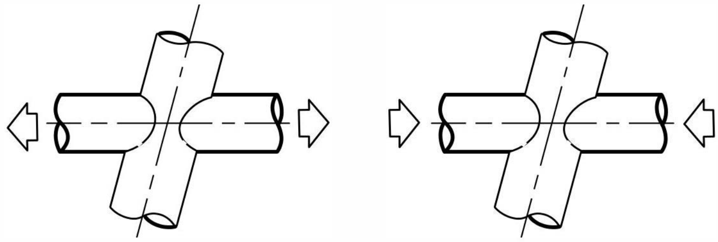


Figure 10.1—Allowable Fatigue Stress and Strain Ranges for Stress Categories (see Table 10.3), Tubular Structures for Atmospheric Service (see 10.2.3.3)

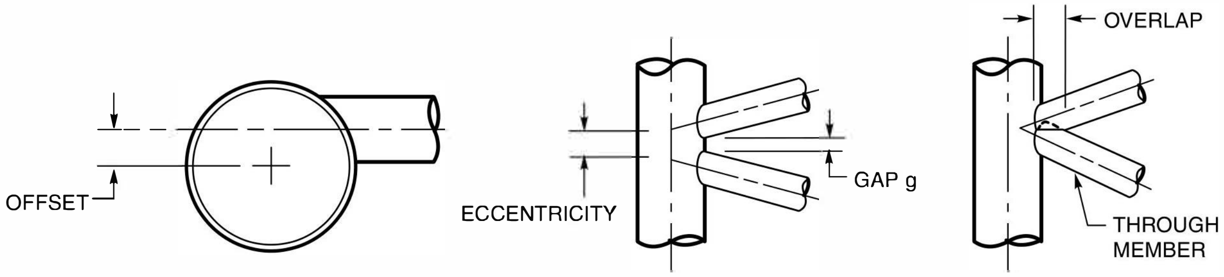


[a] Relevant gap is between braces whose loads are essentially balanced. Type (2) may also be referred to as an N-connection.

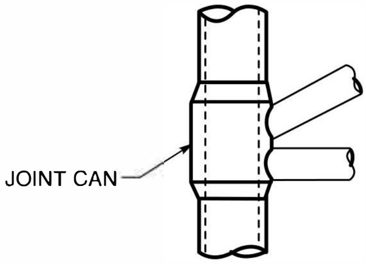
Figure 10.2—Parts of a Tubular Connection (see 10.3)



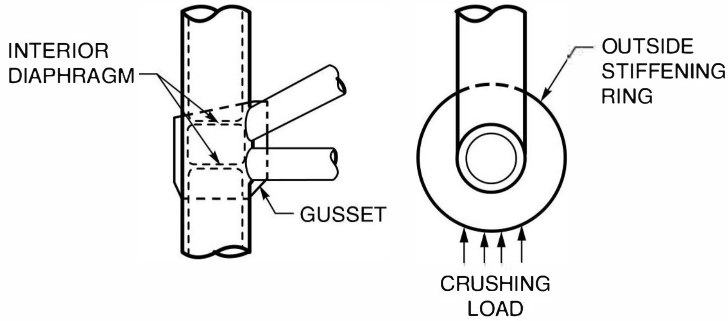
(G) CROSS CONNECTIONS



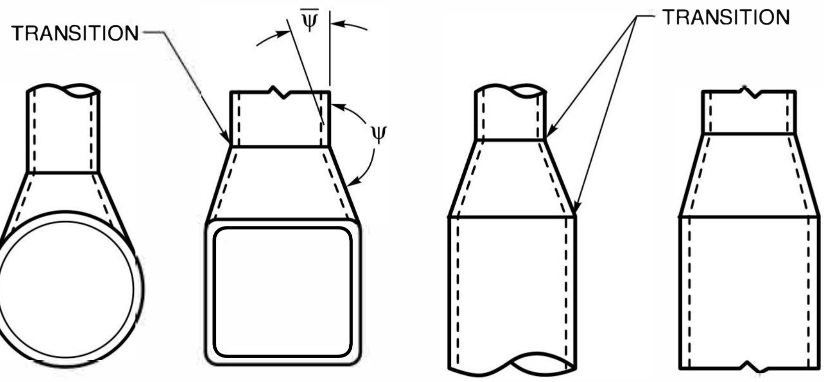
(H) DEVIATIONS FROM CONCENTRIC CONNECTIONS



(I) SIMPLE TUBULAR CONNECTION

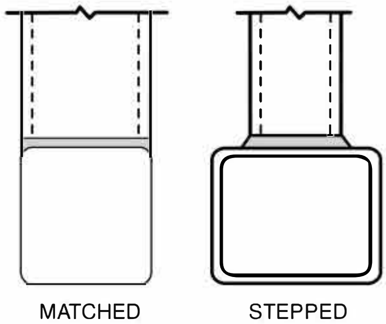


(J) EXAMPLES OF COMPLEX REINFORCED CONNECTIONS

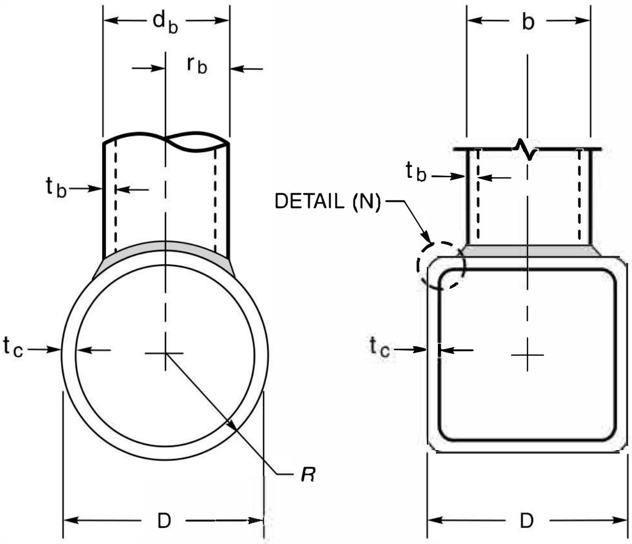


(K) FLARED CONNECTIONS AND TRANSITIONS

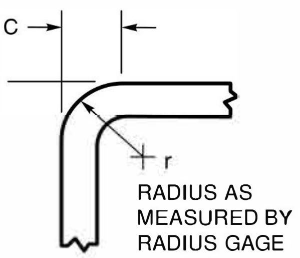
Figure 10.2 (Continued)—Parts of a Tubular Connection (see 10.3)



(L) CONNECTION TYPES FOR BOX SECTIONS



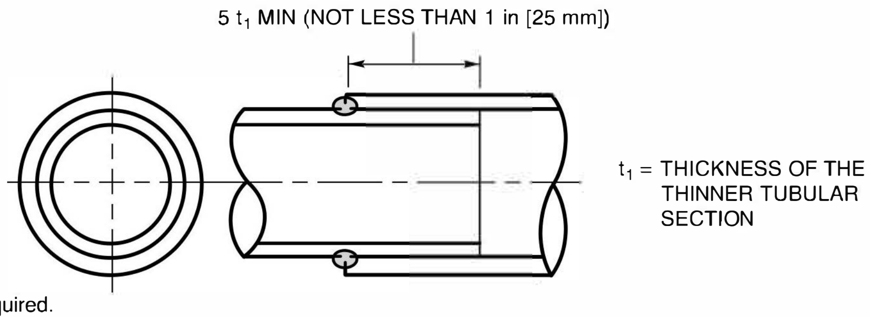
(M) GEOMETRIC PARAMETERS



(N) CORNER DIMENSION OR RADIUS MEASUREMENT

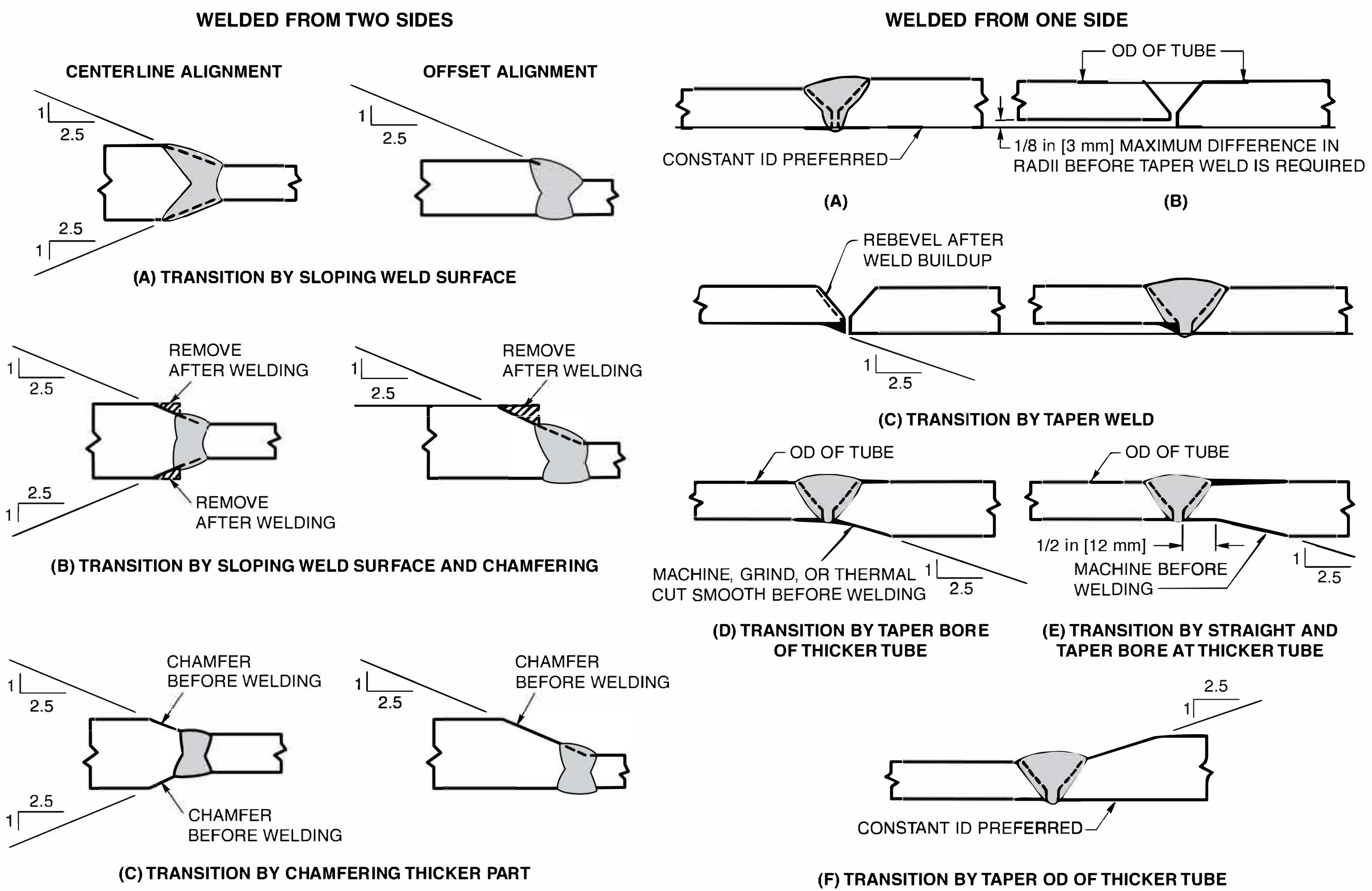
PARAMETER	CIRCULAR SECTIONS	BOX SECTIONS
β	r_b/R OR d_b/D	b/D
η	—	a_x/D
γ	R/t_c	$D/2t_c$
τ	t_b/t_c	t_b/t_c
θ	ANGLE BETWEEN MEMBER CENTERLINES	
ψ	LOCAL DIHEDRAL ANGLE AT A GIVEN POINT ON WELDED JOINT	
C	CORNER DIMENSION AS MEASURED TO THE POINT OF TANGENCY OR CONTACT WITH A 90° SQUARE PLACED ON THE CORNER	

Figure 10.2 (Continued)—Parts of a Tubular Connection (see 10.3)



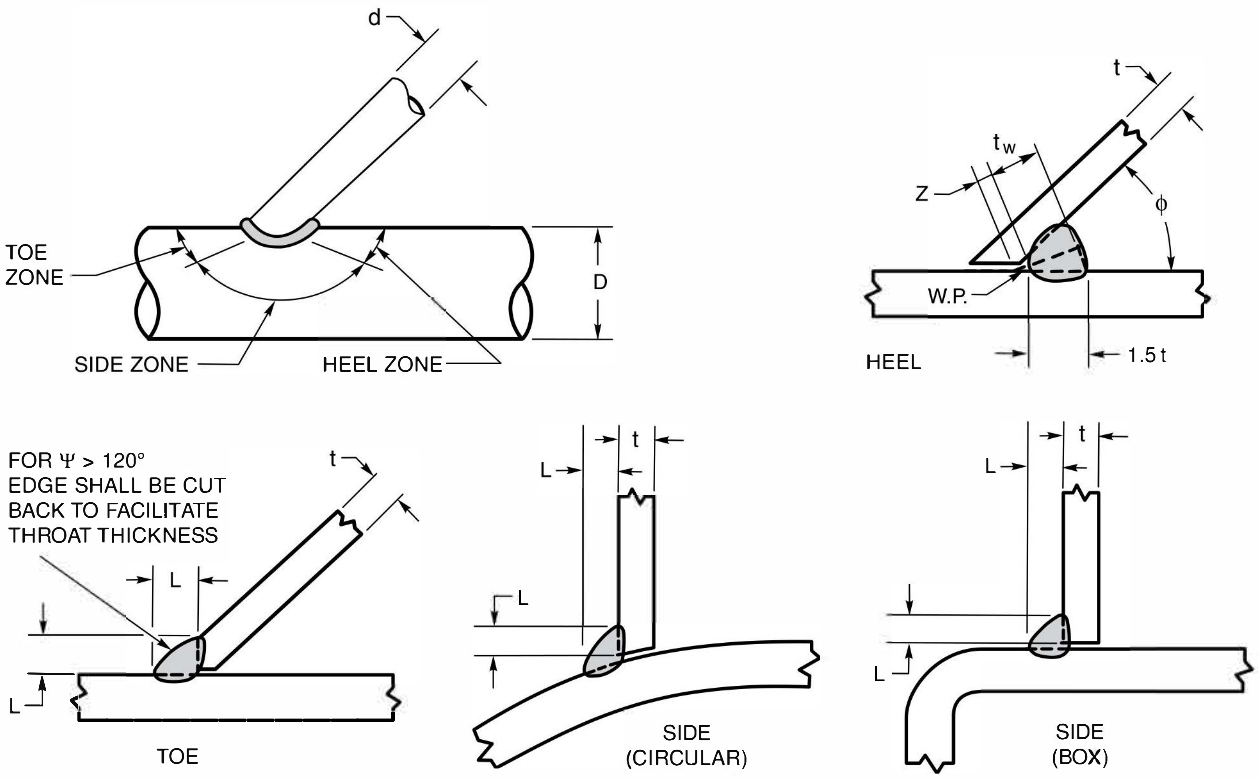
Note: L = size as required.

Figure 10.3—Fillet Welded Lap Joint (Tubular) [see 10.5.2.3 and 10.8.1(2)



Notes:
1. Groove may be of any allowed or qualified type and detail.
2. Transition slopes shown are the maximum allowed.
3. In (B), (D), and (E) groove may be any allowed or qualified type and detail. Transition slopes shown are maximum allowed.

Figure 10.4—Transition of Thickness of Butt Joints in Parts of Unequal Thickness (Tubular) (see 10.6)



	MIN L FOR		
	E = 0.7 t	E = t	E = 1.07t
HEEL < 60°	1.5t	1.5t	LARGER OF 1.5t OR 1.4t + Z
SIDE ≤ 100°	t	1.4t	1.5t
SIDE 100 – 110°	1.1t	1.6t	1.75t
SIDE 110 – 120°	1.2t	1.8t	2.0t
TOE >120°	t BEVEL	1.4t BEVEL	FULL BEVEL 60–90° GROOVE

Notes:
1. t = thickness of thinner part.
2. L = minimum size (see 10.2.1 which may require increased weld size for combinations other than 36 ksi [250 MPa] base metal and 70 ksi [485 MPa] electrodes).
3. Root opening 0 in to 3/16 in [5 mm] (see 7.21).
4. Not prequalified for ϕ < 30°. For ϕ < 60°, the Z loss dimensions in Table 10.5 apply. See Table 10.12 for welder qualification position requirements.
5. See 10.5.2.2 for limitations on β = d/D.
6. Ψ = dihedral angle.

Figure 10.5—Fillet Welded Prequalified Tubular Joints Made by SMAW, GMAW, and FCAW (see 10.8.1)

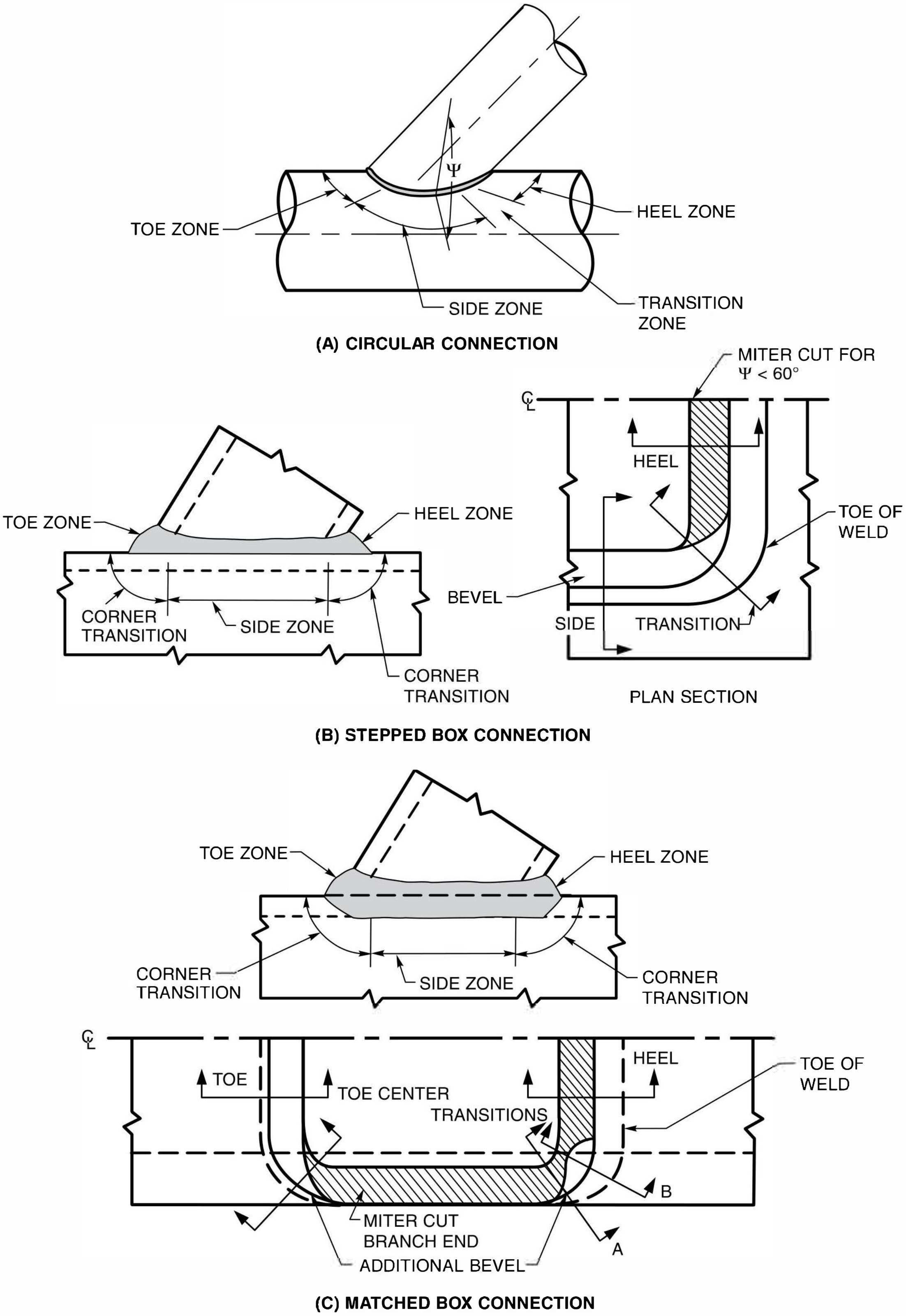


Figure 10.6—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 10.9.1)

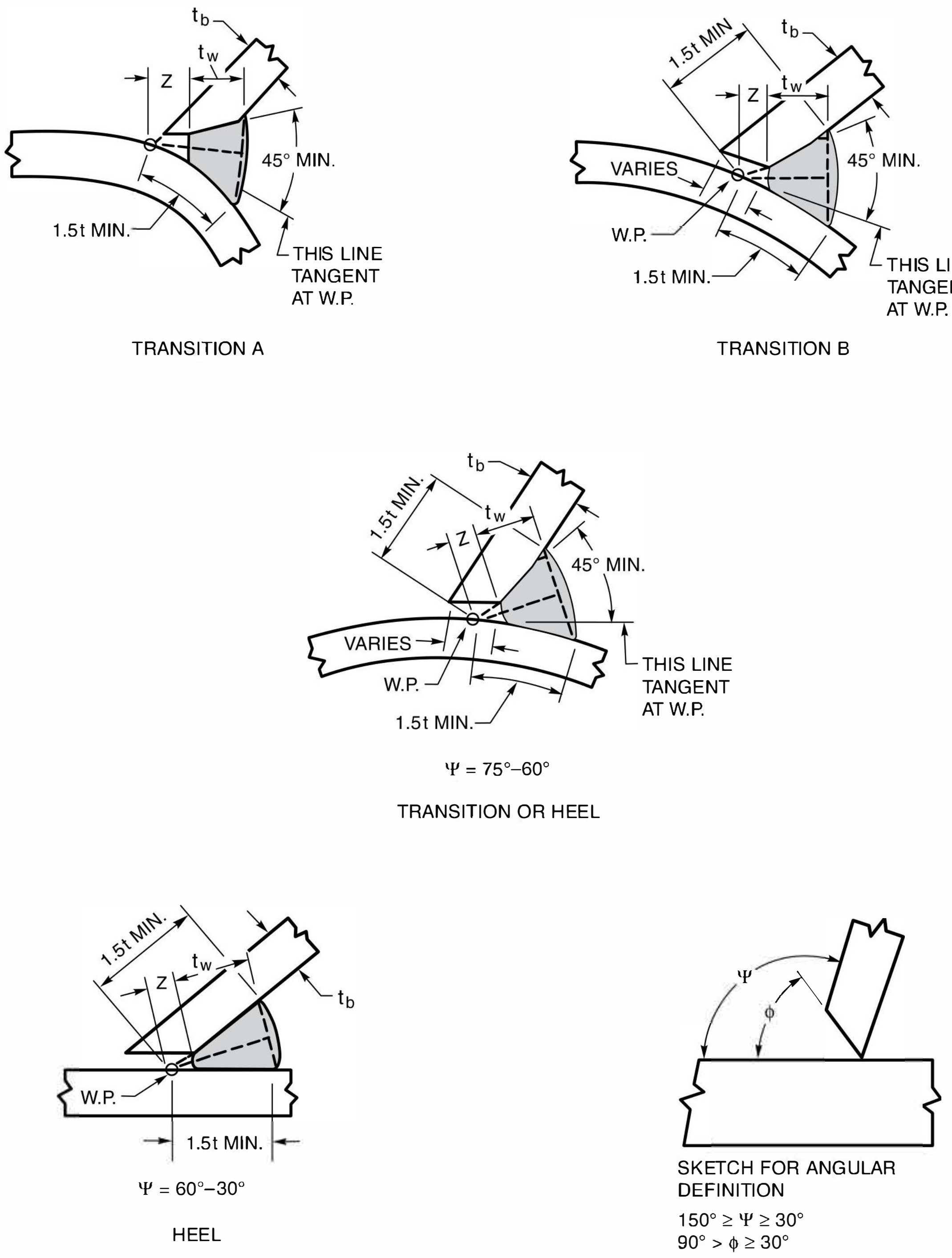
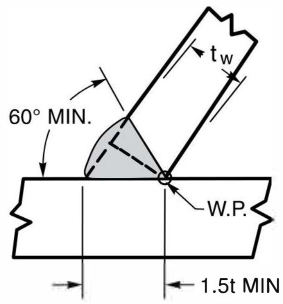
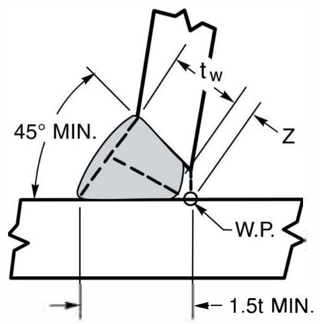


Figure 10.6 (Continued)—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 10.9.1)



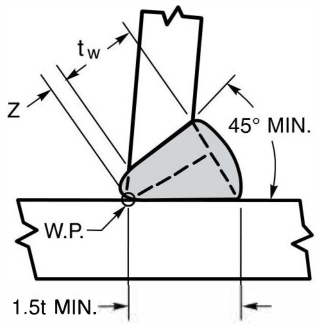
Ψ = 150°–105°

TOE



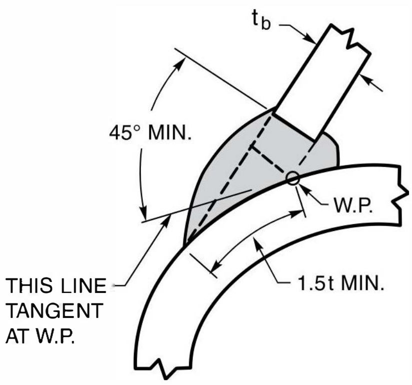
Ψ = 105°–90°

TOE OR HEEL

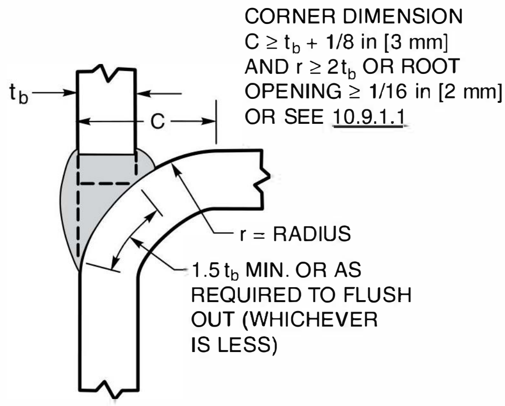


Ψ = 90°–75°

SIDE OR HEEL



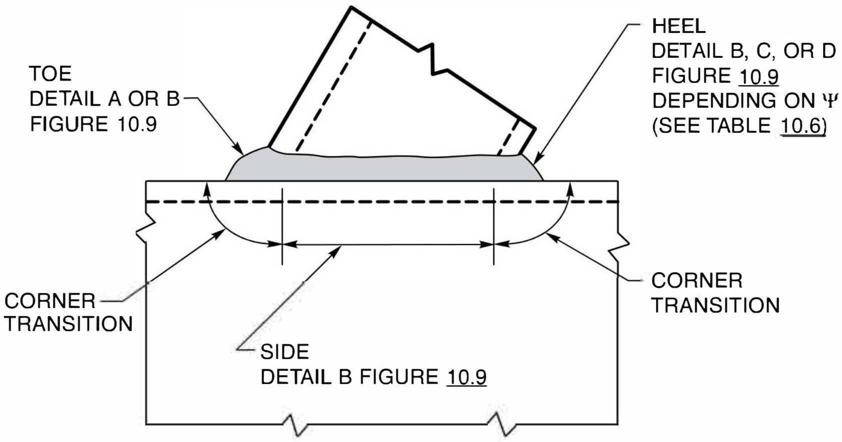
TOE CORNER



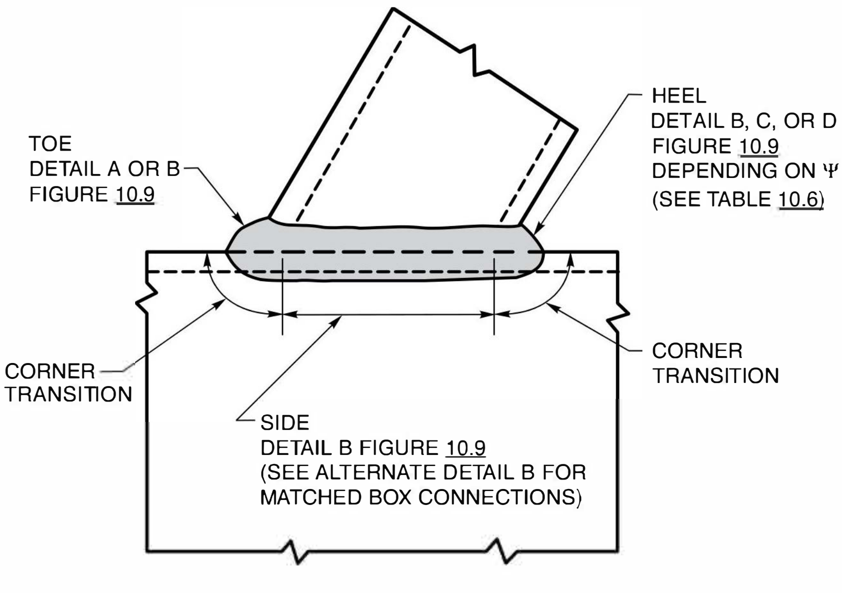
SIDE MATCHED

Notes:
1. t = thickness of thinner section.
2. Bevel to feather edge except in transition and heel zones.
3. Root opening: 0 in to 3/16 in [0 mm to 5 mm].
4. Not prequalified for under 30°.
5. Weld size (effective throat) $t_w \geq t$; Z Loss Dimensions shown in Table 10.5.
6. Calculations per 10.2.1 shall be done for leg length less than 1.5t, as shown.
7. For Box Section, joint preparation for corner transitions shall provide a smooth transition from one detail to another. Welding shall be carried continuously around corners, with corners fully built up and all weld starts and stops within flat faces.
8. See Clause 3 for definition of local dihedral angle, Ψ.
9. W.P. = work point.

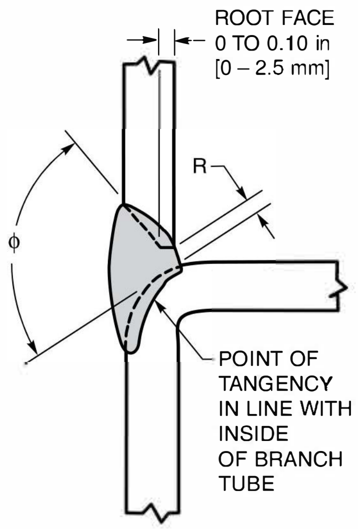
Figure 10.6 (Continued)—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 10.9.1)



STEPPED BOX CONNECTION



MATCHED BOX CONNECTION



ALTERNATE DETAIL B
(FOR MATCHED BOX SECTIONS)

Notes:
1. Details A, B, C, D as shown in Figure 10.9 and all notes from Table 10.7 apply.
2. Joint preparation for corner welds shall provide a smooth transition from one detail to another. Welding shall be carried continuously around corners, with corners fully built up and all arc starts and stops within flat faces.
3. References to Figure 10.9 include Figures 10.10 and 10.11 as appropriate to thickness (see 10.2.3.7).

Figure 10.7—Prequalified Joint Details for CJP T-, Y-, and K-Tubular Connections (see 10.10.2)

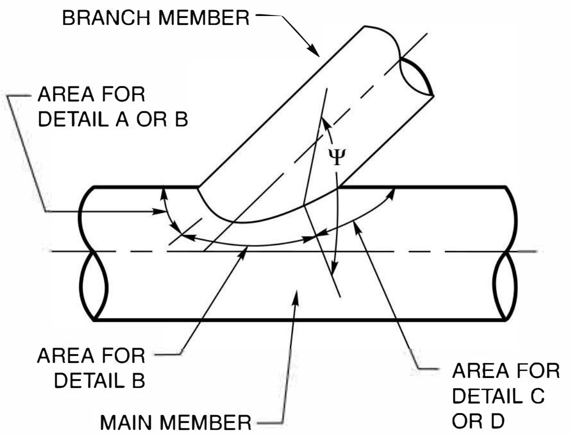
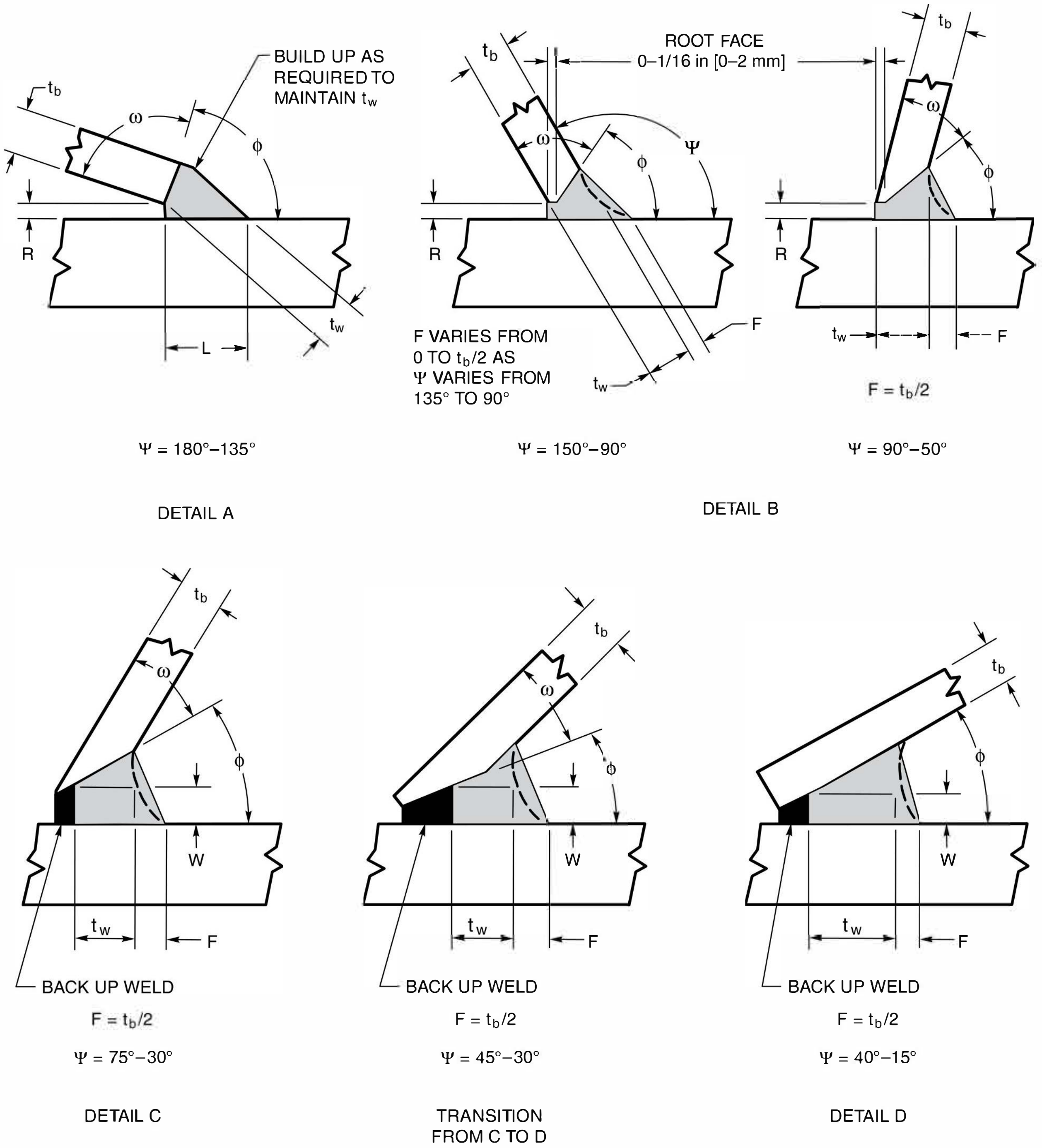
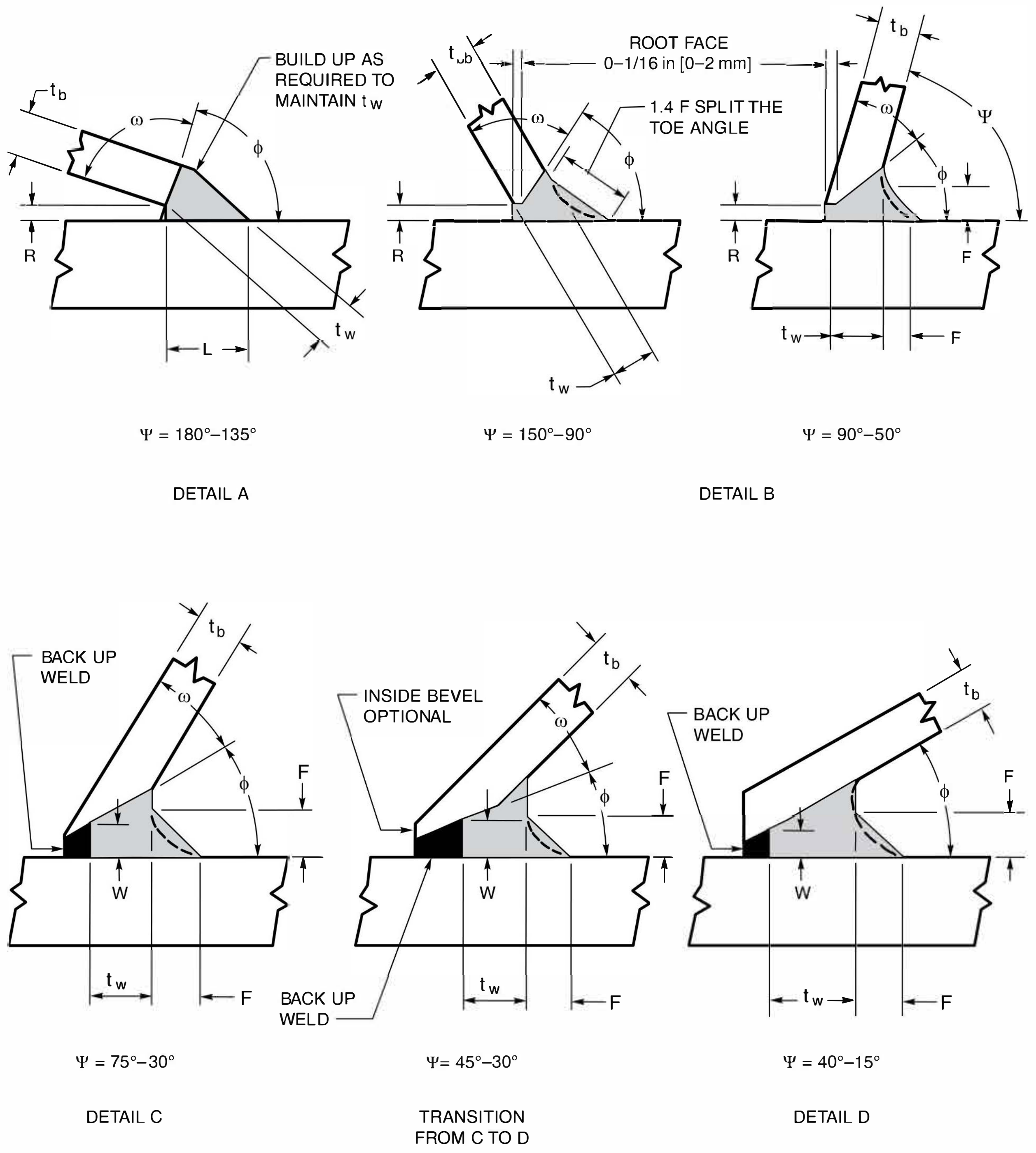


Figure 10.8—Definitions and Detailed Selections for Prequalified CJP T-, Y-, and K-Tubular Connections (see 10.10.2 and Table 10.6)



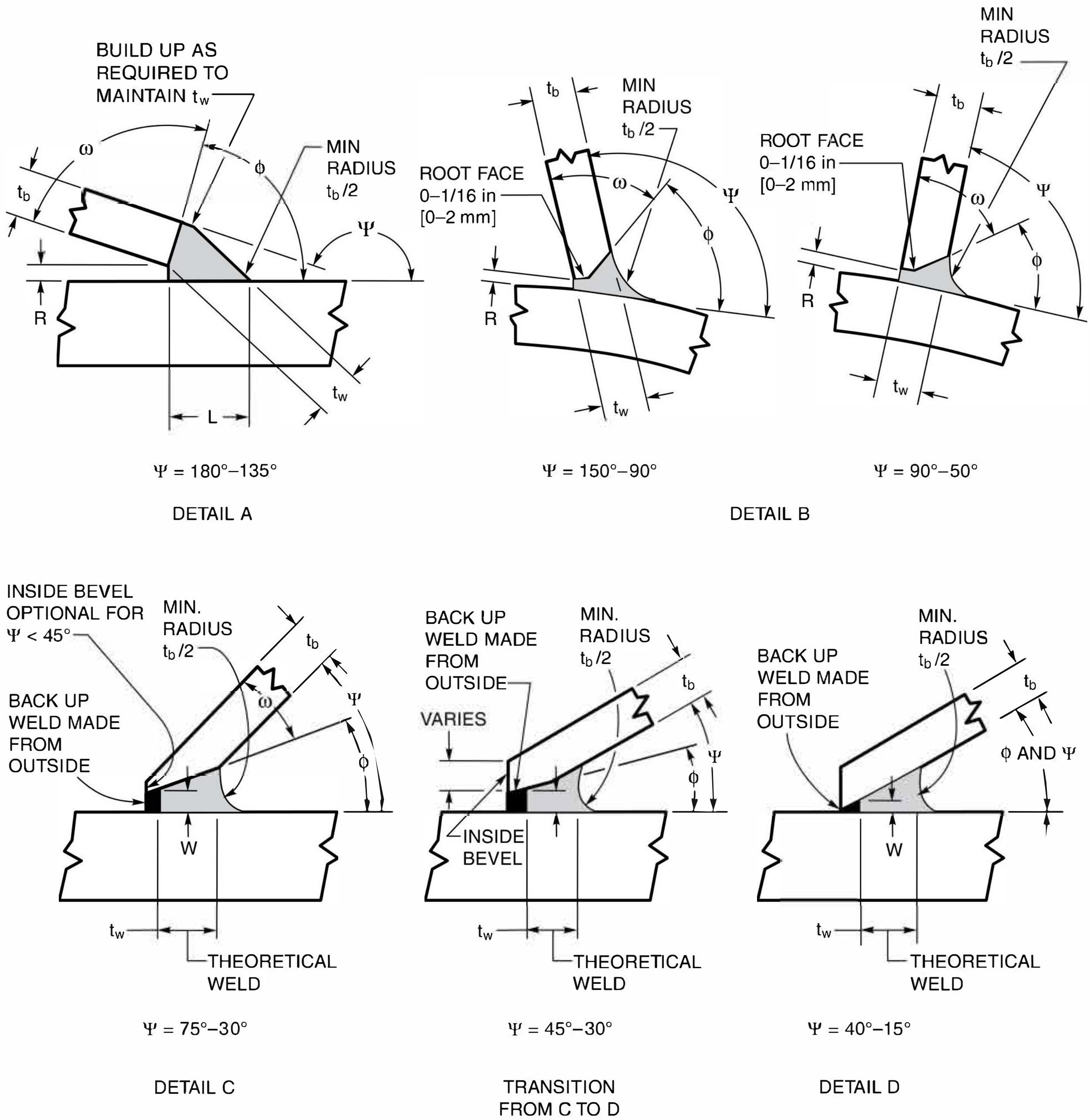
Notes:
1. See Table 10.7 for dimensions t_w, L, R, W, ω, ϕ.
2. Minimum standard flat weld profile shall be as shown by solid line.
3. A concave profile, as shown by dashed lines, shall also be applicable.
4. Convexity, overlap, etc. shall be subject to the limitations of 7.23.
5. Branch member thickness, t_b, shall be subject to limitations of 10.2.3.7.

Figure 10.9—Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Standard Flat Profiles for Limited Thickness (see 10.10.2)



Notes:
1. Sketches illustrate alternate standard profiles with toe fillet.
2. See 10.2.3.7 for applicable range of thickness t_b.
3. Minimum fillet weld size, $F = t_b/2$, shall also be subject to limits of Table 7.7.
4. See Table 10.7 for dimensions t_w, L, R, W, ω, ϕ.
5. Convexity and overlap shall be subject to the limitations of 7.23.
6. Concave profiles, as shown by dashed lines shall also be acceptable.

Figure 10.10—Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Profile with Toe Fillet for Intermediate Thickness (see 10.10.2)



Notes:
1. Illustrating improved weld profiles for 10.2.3.6(1) as welded and 10.2.3.6(2) fully ground.
2. For heavy sections or fatigue critical applications as indicated in 10.2.3.7.
3. See Table 10.7 for dimensions t_b, L, R, W, ω, φ.

Figure 10.11—Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Concave Improved Profile for Heavy Sections or Fatigue (see 10.10.2)

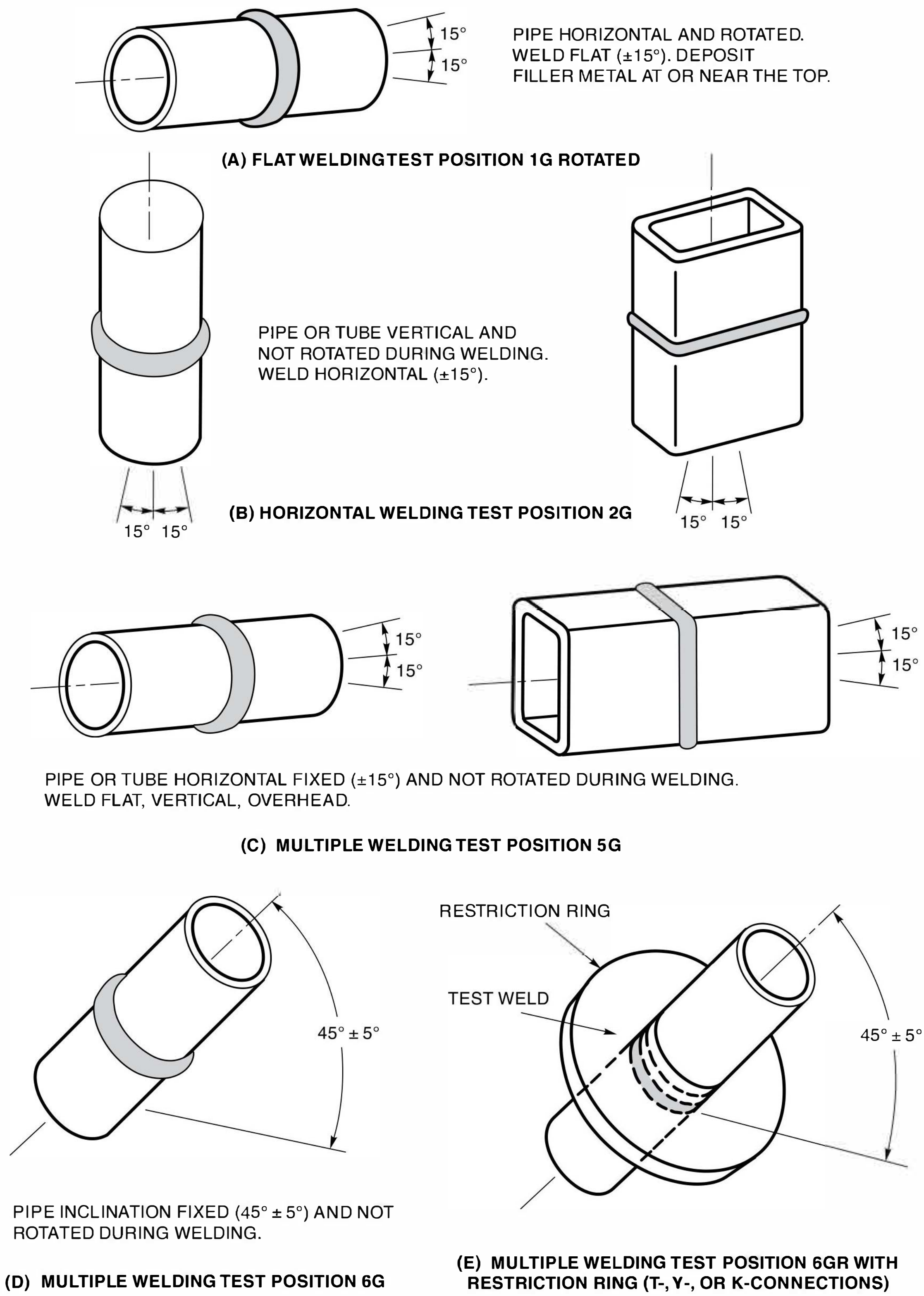
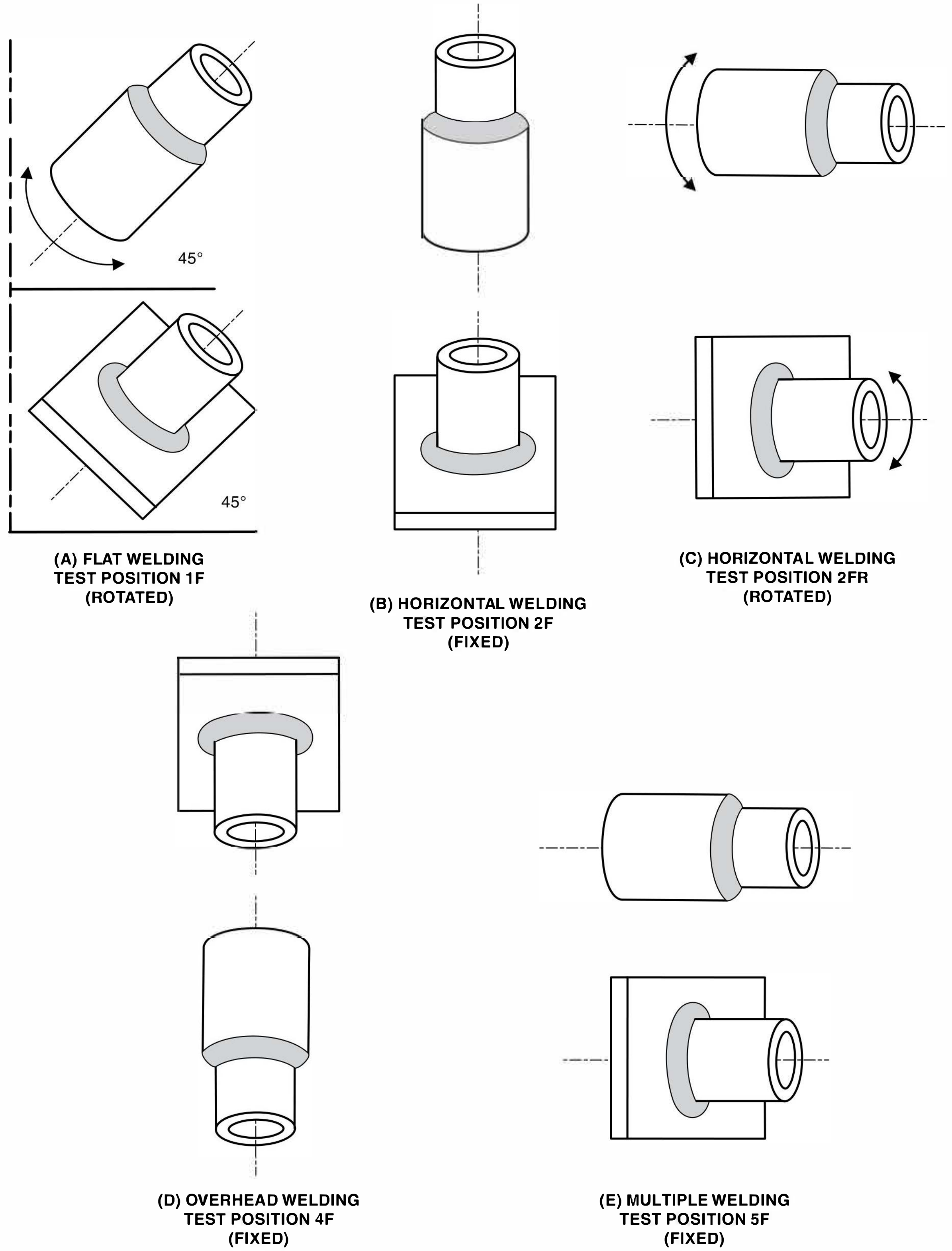
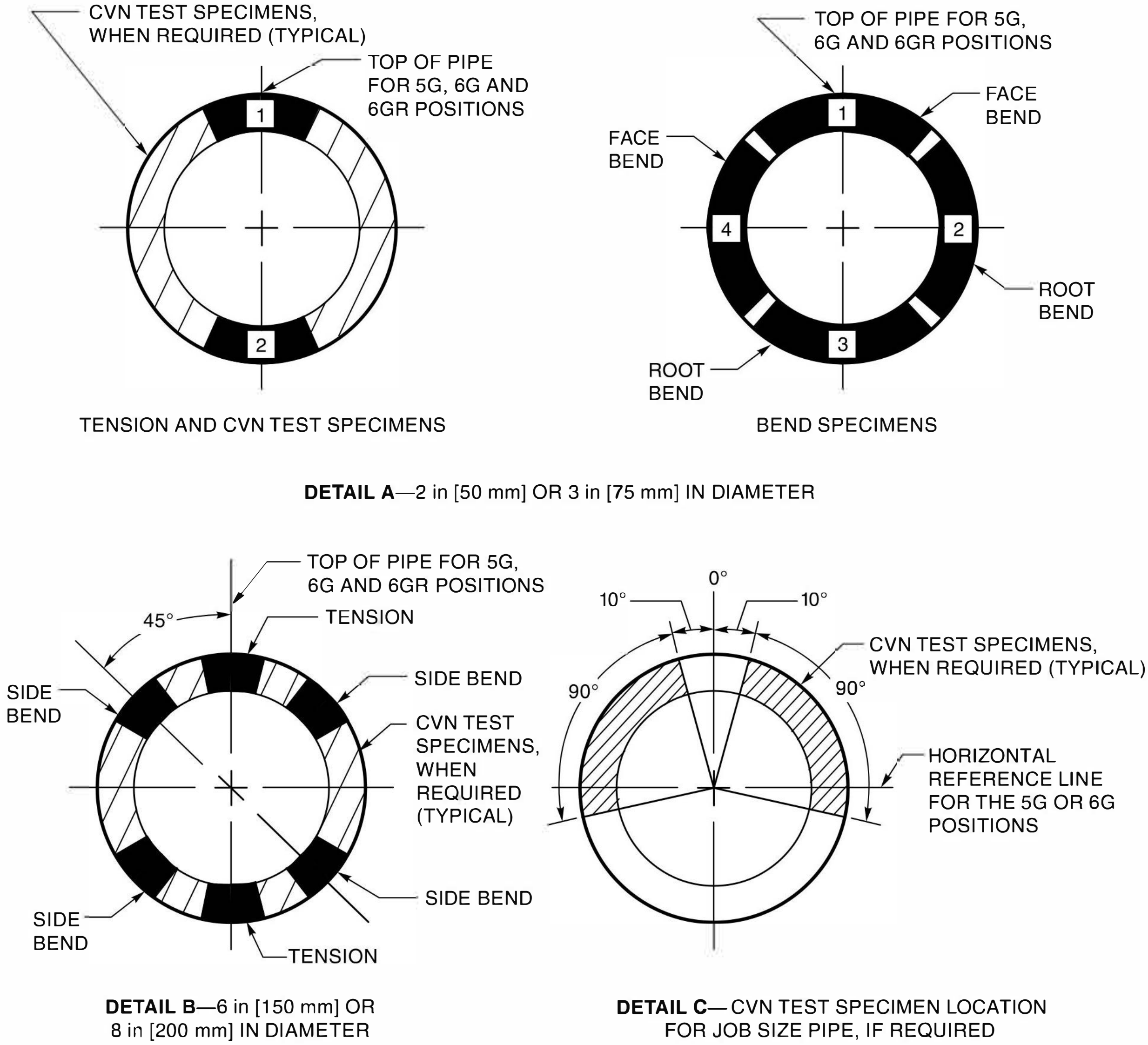


Figure 10.12—Positions of Test Pipe or Tubing for Groove Welds (see 10.11.1)



Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, Figure B.20, Miami: American Welding Society.

Figure 10.13—Positions of Test Pipes or Tubing for Fillet Welds (see 10.11.1)



Note: Duplicate test pipes or tubes or larger job size pipe may be required when CVN testing is specified on contract documents or specifications.

Figure 10.14—Location of Test Specimens on Welded Test Pipe—WPS Qualification (see 10.13)

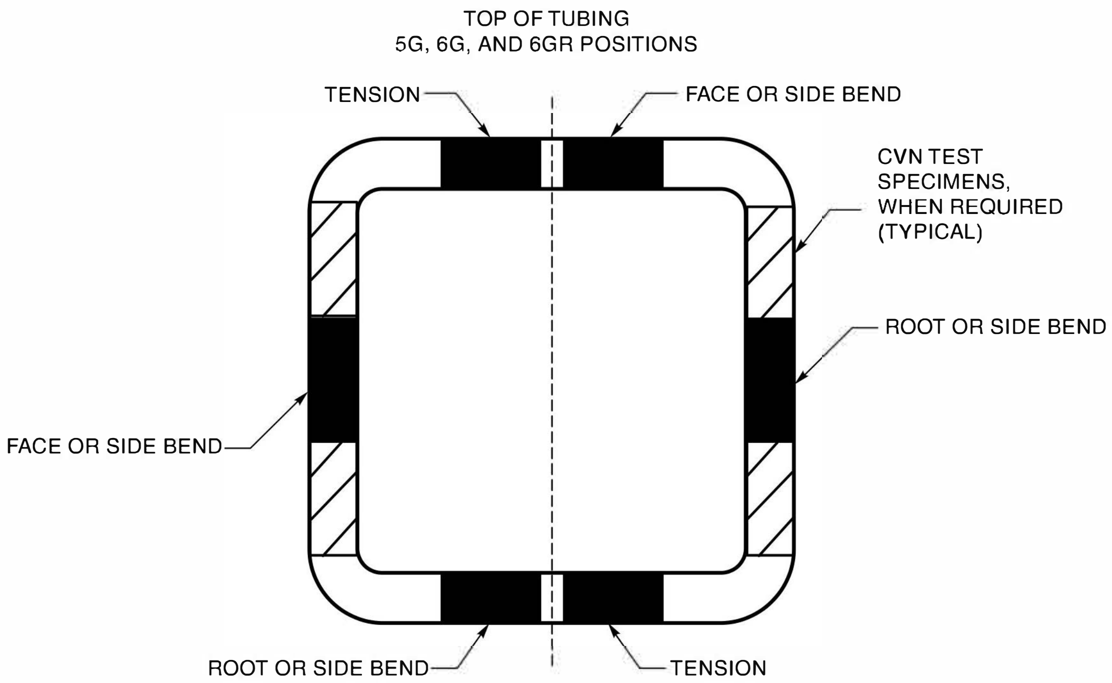
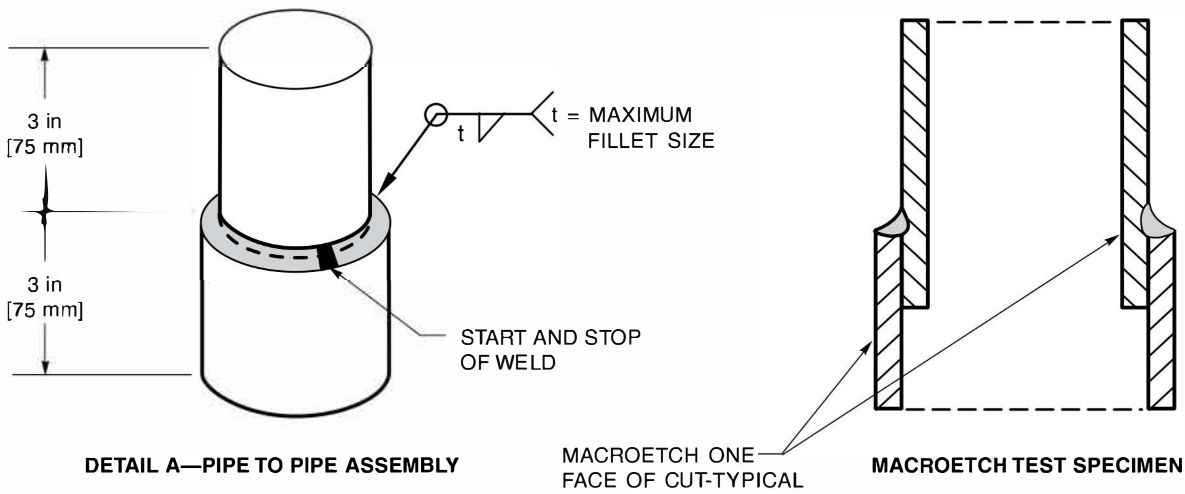
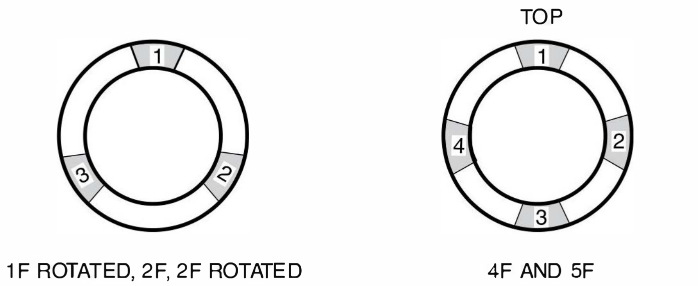


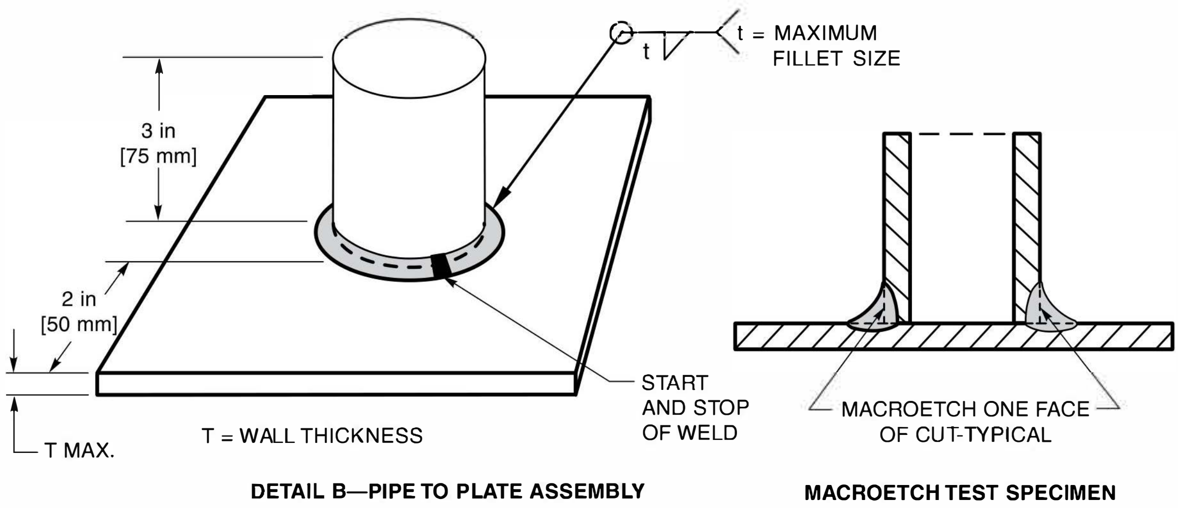
Figure 10.15—Location of Test Specimens for Welded Box Tubing—WPS Qualification (see 10.13)



Notes:
1. See Table 10.8 for position requirements.
2. Pipe shall be of sufficient thickness to prevent melt-through.

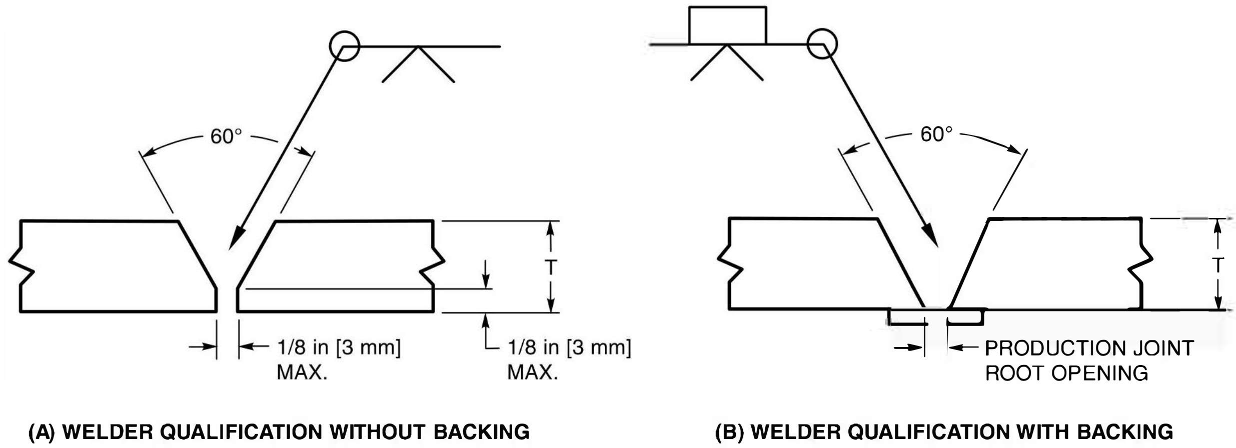


LOCATION OF TEST SPECIMENS ON WELDED PIPE – WPS QUALIFICATION



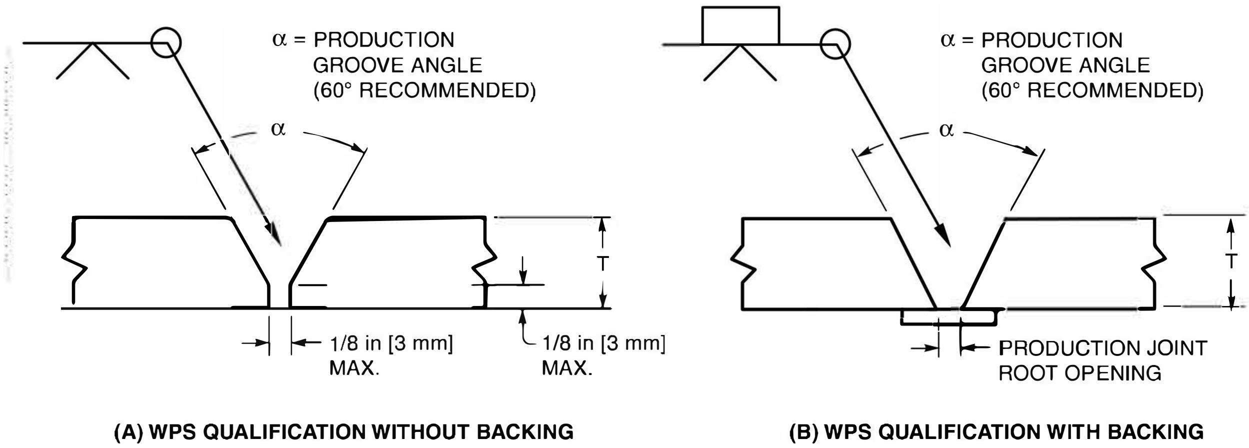
Notes:
1. See Table 10.8 for position requirements.
2. Pipe shall be of sufficient thickness to prevent melt-through.
3. All dimensions are minimums.

Figure 10.16—Pipe Fillet Weld Soundness Test—WPS Qualification (see 6.13.2 and 10.15)



Note: T = qualification pipe or box tube wall thickness

Figure 10.17—Tubular Butt Joint—Welder Qualification with and without Backing (see 10.18)



Note: T = qualification pipe or box tube wall thickness

Figure 10.18—Tubular Butt Joint—WPS Qualification with and without Backing (see 10.14.1 and 10.14.2)

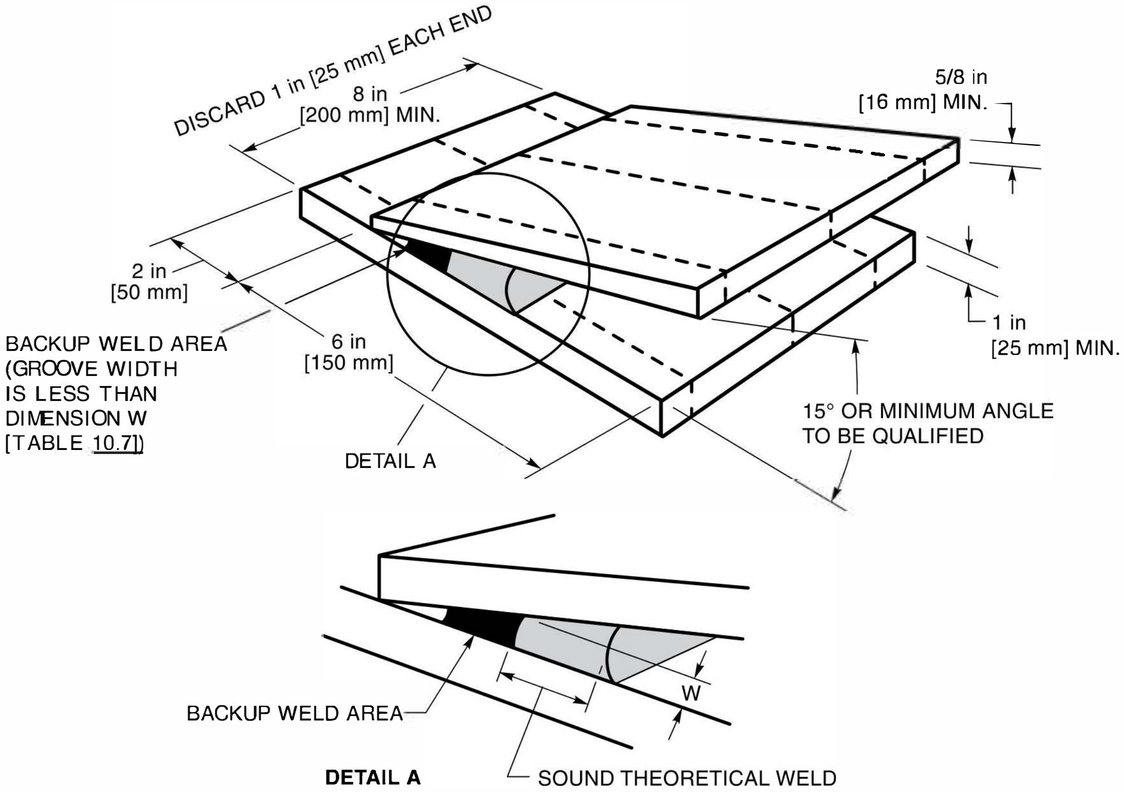


Figure 10.19—Acute Angle Heel Test (Restraints not Shown) (see 10.14.4.2)

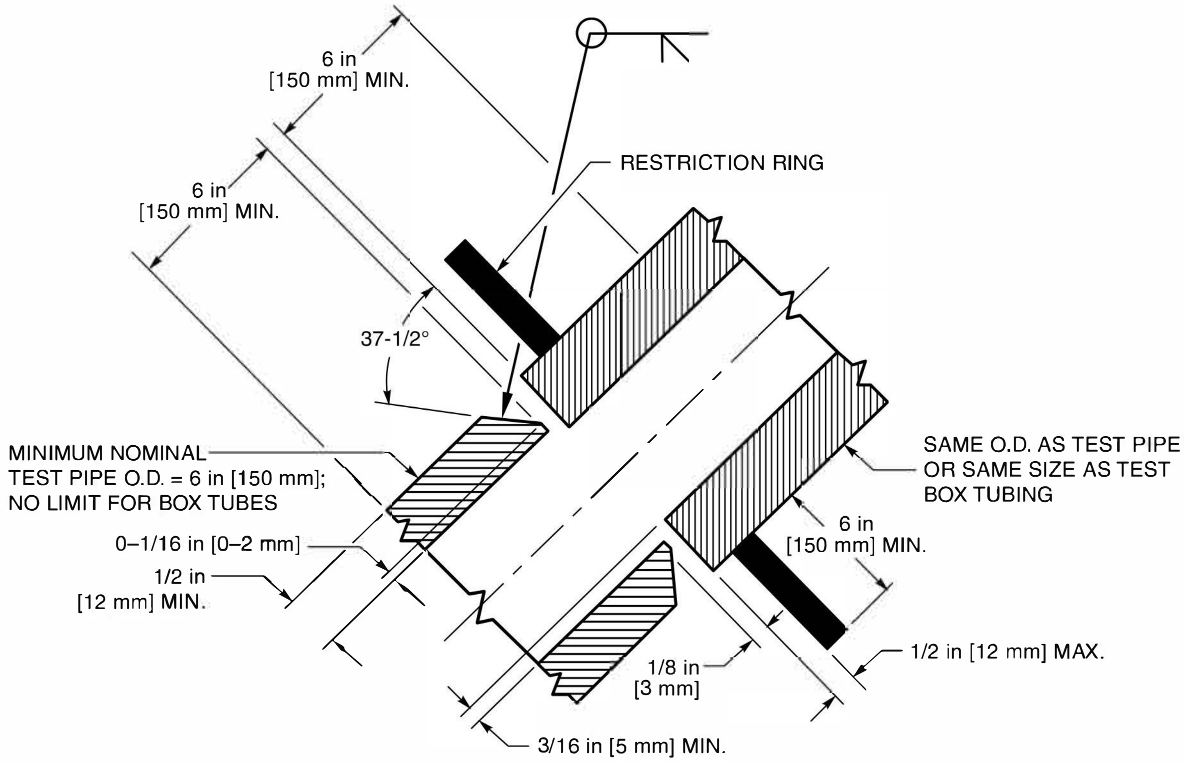


Figure 10.20—Test Joint for T-, Y-, and K-Connections without Backing on Pipe or Box Tubing ($\geq$ 6 in [150 mm] O.D.)—Welder and WPS Qualification (see 10.14.4.1 and 10.18)

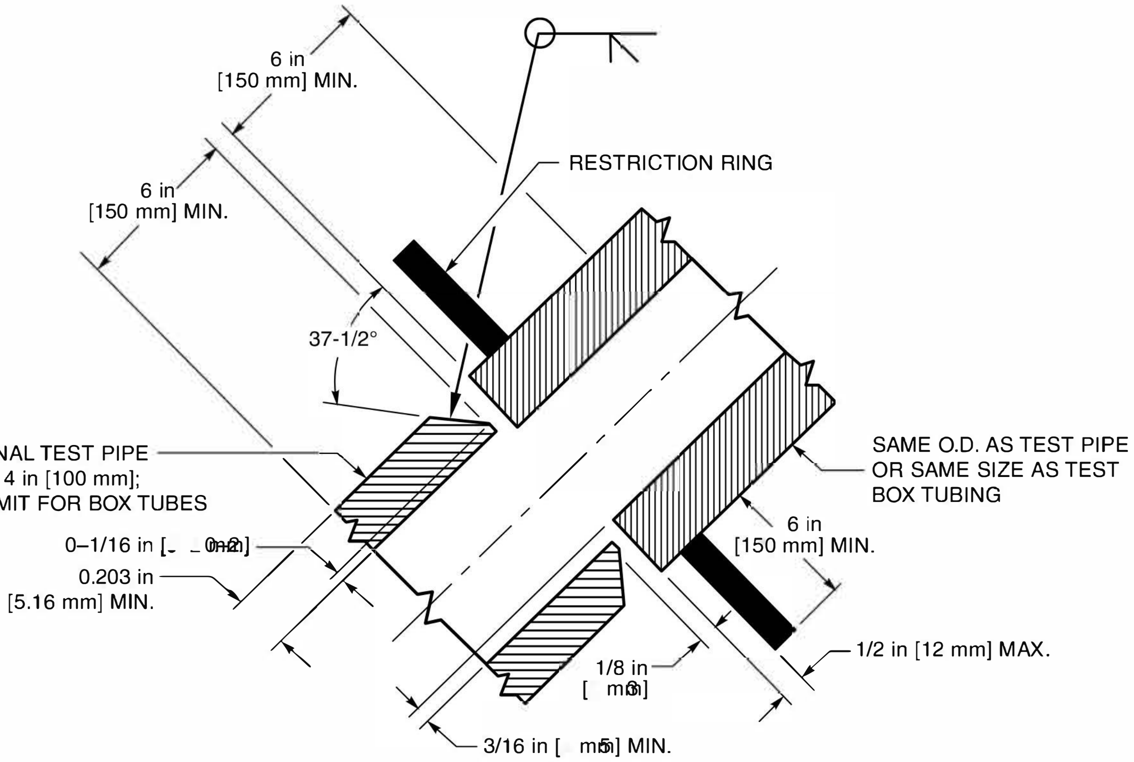


Figure 10.21—Test Joint for T-, Y-, and K-Connections without Backing on Pipe or Box Tubing (< 4 in [100 mm] O.D.)—Welder and WPS Qualification (see 10.14.4.1 and 10.18)

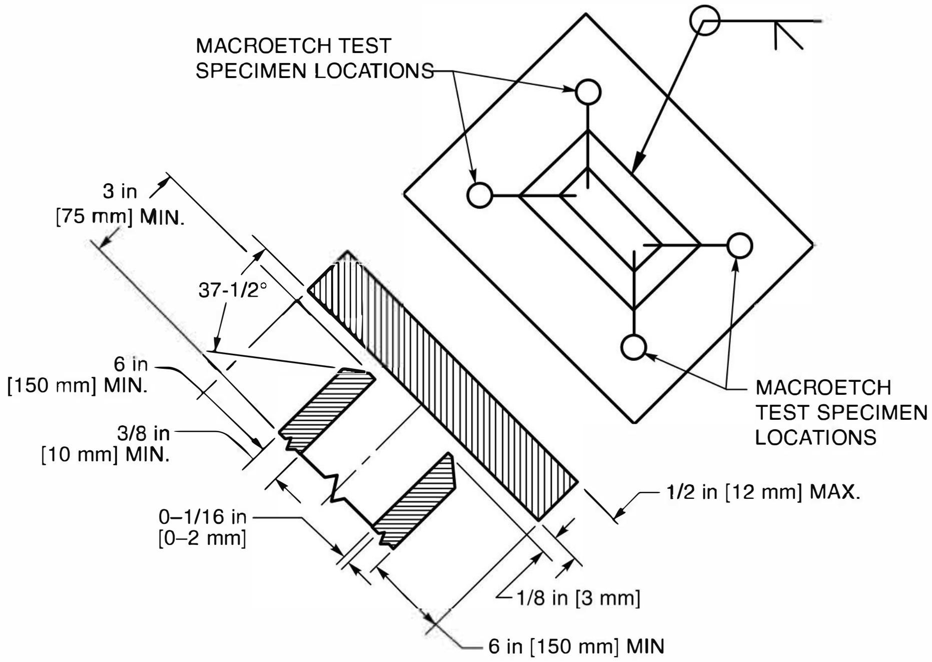
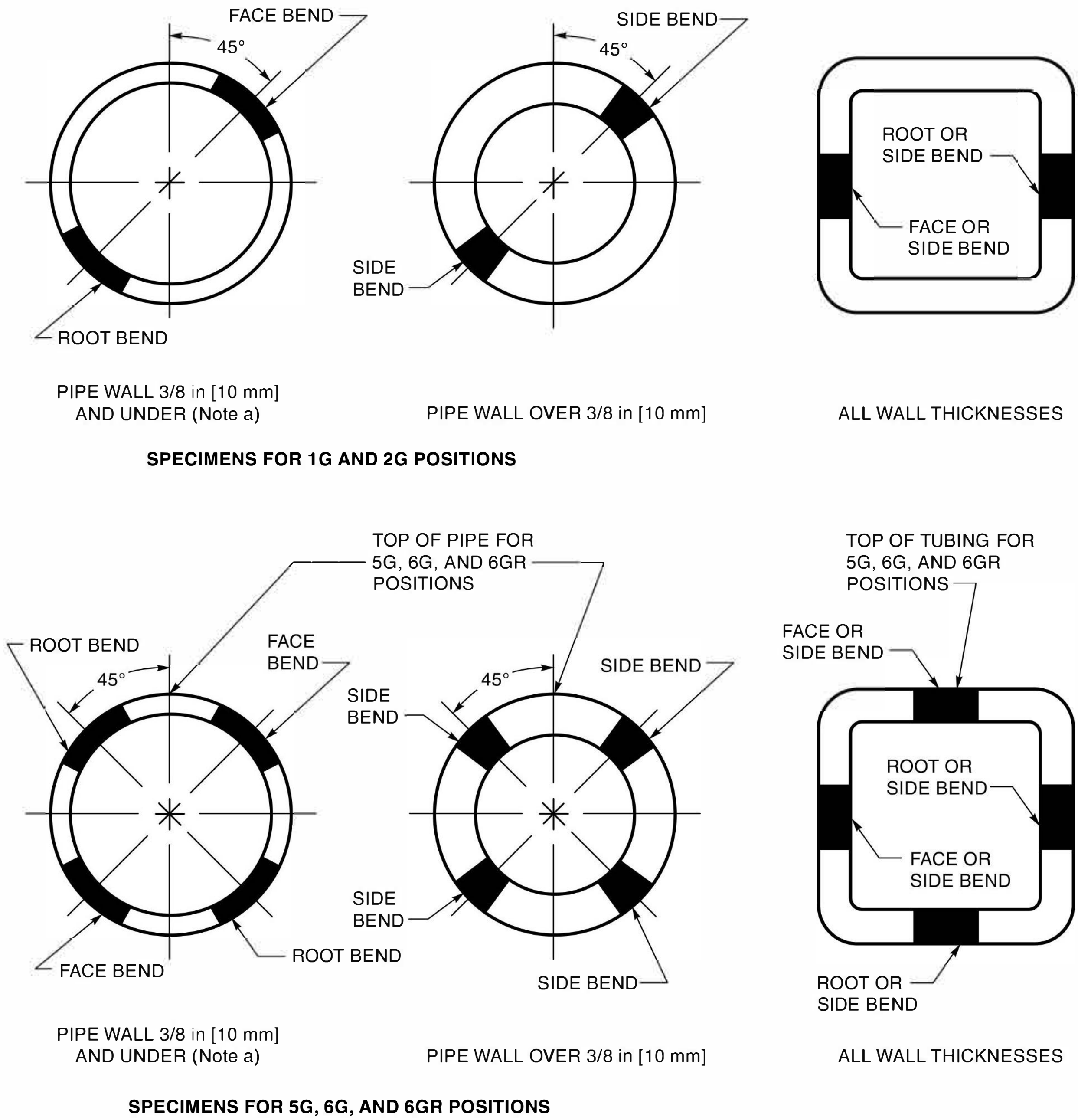
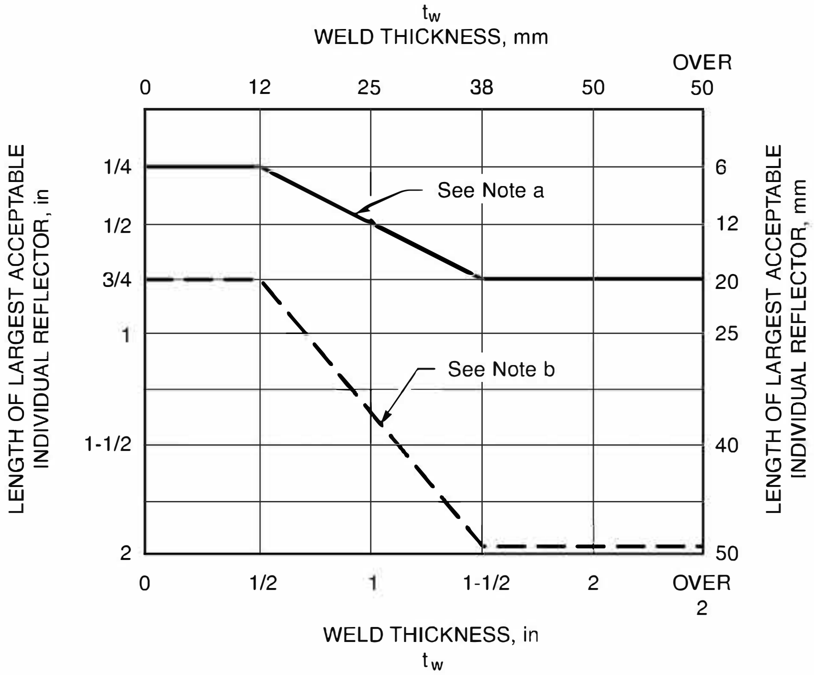


Figure 10.22—Corner Macroetch Test Joint for T-, Y-, and K-Connections without Backing on Box Tubing for CJP Groove Welds—Welder and WPS Qualification (see 10.14.4.1 and 10.18)



[a] For 3/8 in [10 mm] wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.

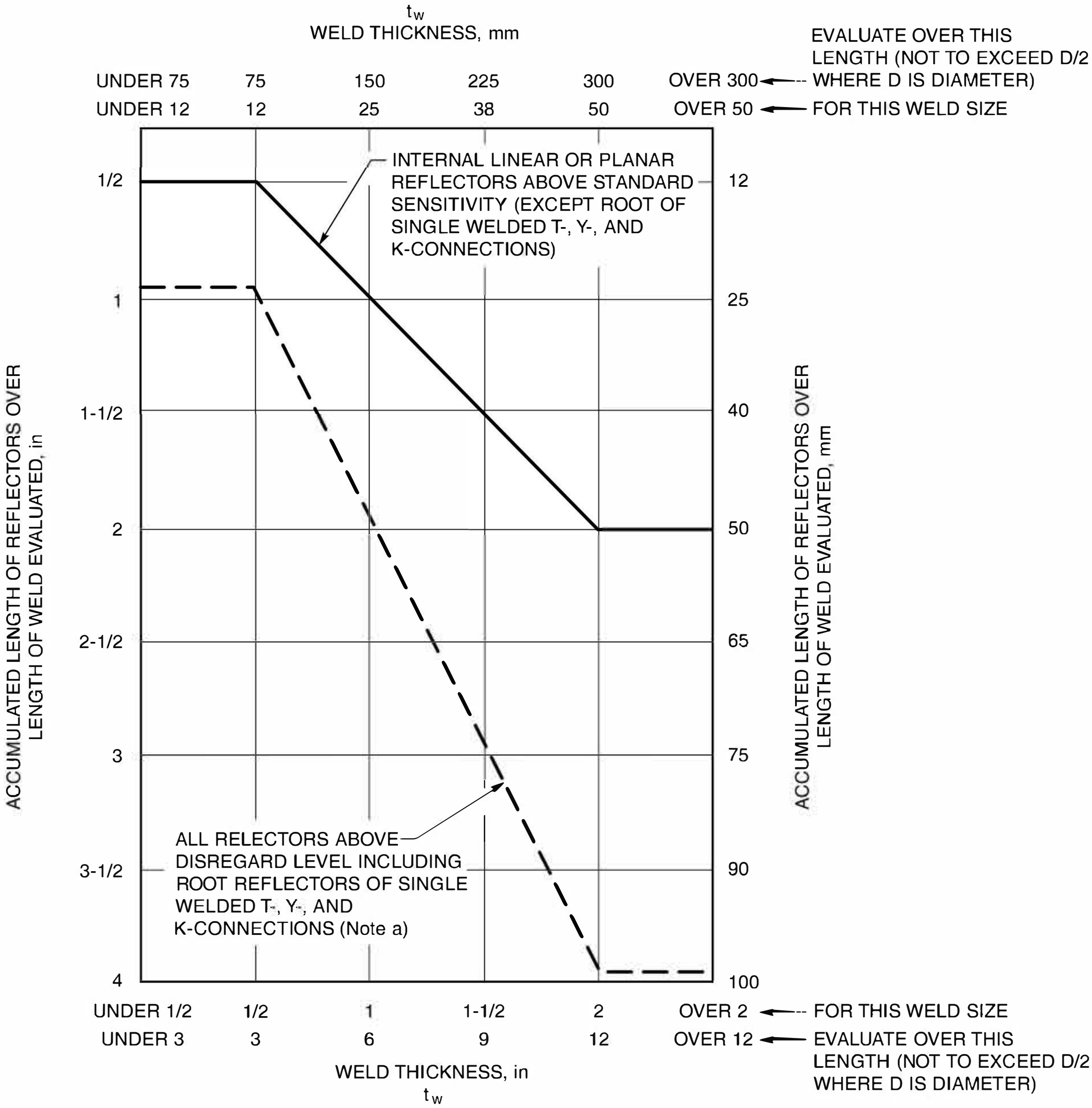
Figure 10.23—Location of Test Specimens on Welded Test Pipe and Box Tubing—Welder Qualification (see 10.16)



[a] Internal linear or planar reflectors above standard sensitivity.

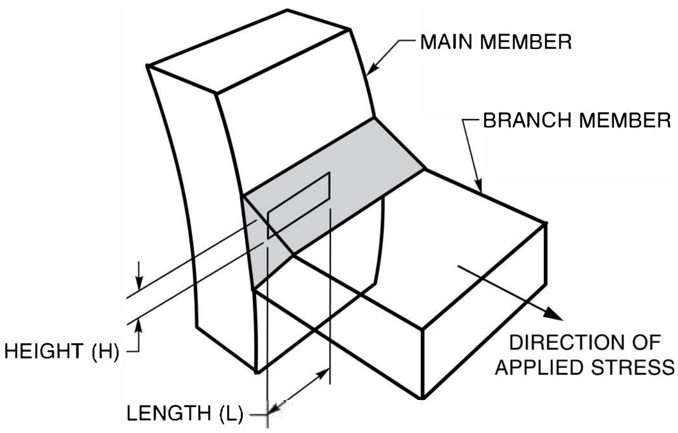
[b] Minor reflectors (above disregard level up to and including standard sensitivity). Adjacent reflectors separated by less than their average length shall be treated as continuous.

Figure 10.24—Class R Indications (see 10.26.1.1)



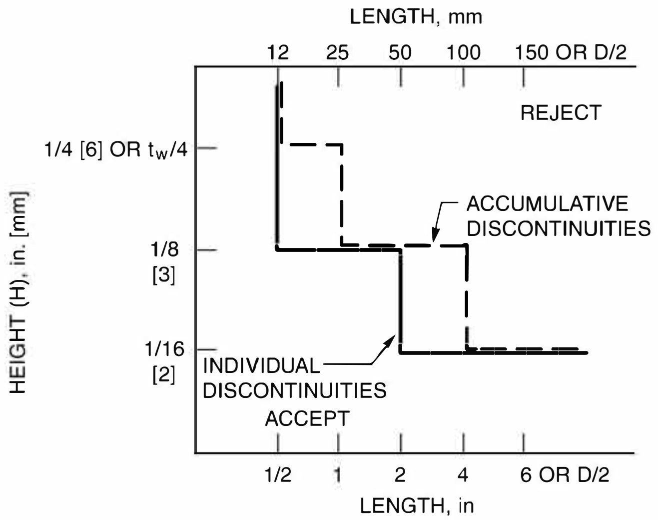
[a] Root area discontinuities falling outside theoretical weld (dimensions "t_w" or "L" in Figures 10.9, 10.10, and 10.11) are to be disregarded.

Figure 10.24 (Continued)—Class R Indications (see 10.26.1.1)



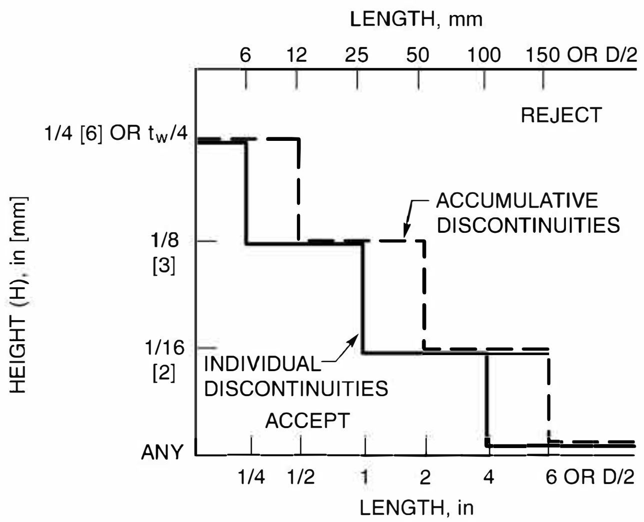
L AND H BASED ON A RECTANGLE WHICH TOTALLY ENCLOSES INDICATED DISCONTINUITY

1. Aligned discontinuities separated by less than (L1 + L2)/2 and parallel discontinuities separated by less than (H1 + H2)/2 shall be evaluated as continuous.
2. Accumulative discontinuities shall be evaluated over 6 in [150 mm] or D/2 length of weld (whichever is less), where tube diameter = D.



T-, Y-, AND K-ROOT DISCONTINUITIES

1. For CJP weld in single welded T-, Y-, and K-tubular connections made without backing.
2. Discontinuities in the backup weld in the root, Details C and D of Figures 10.9, 10.10, and 10.11 shall be disregarded.



INTERNAL REFLECTORS AND ALL OTHER WELDS

Discontinuities that are within H or $t_w/6$ of the outside surface shall be sized as if extending to the surface of the weld.

Figure 10.25—Class X Indications (see 10.26.1.2)

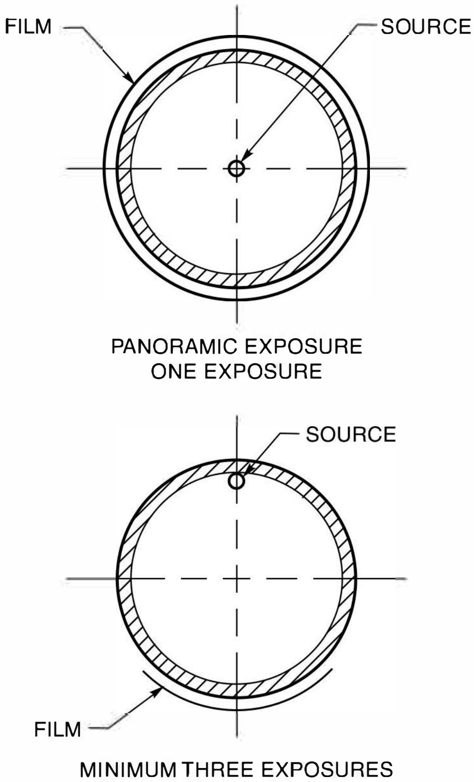


Figure 10.26—Single-Wall Exposure—Single-Wall View (see 10.28.1.1)

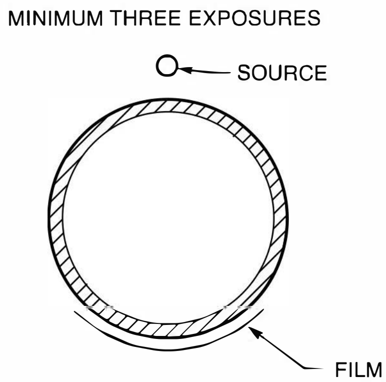


Figure 10.27—Double-Wall Exposure—Single-Wall View (see 10.28.1.2)

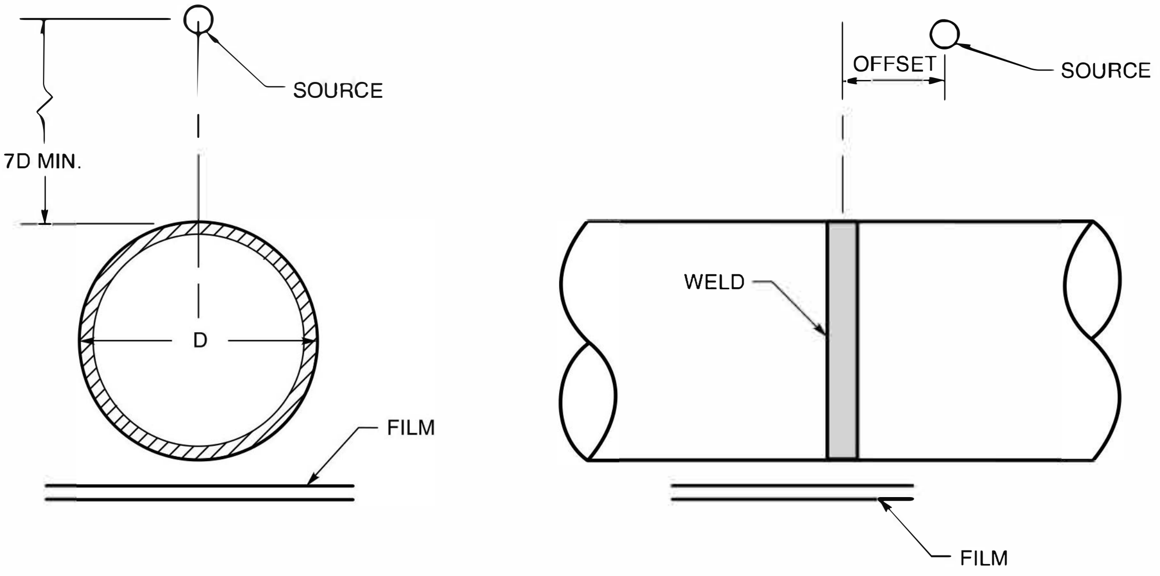


Figure 10.28—Double-Wall Exposure—Double-Wall (Elliptical) View, Minimum Two Exposures (see 10.28.1.3)

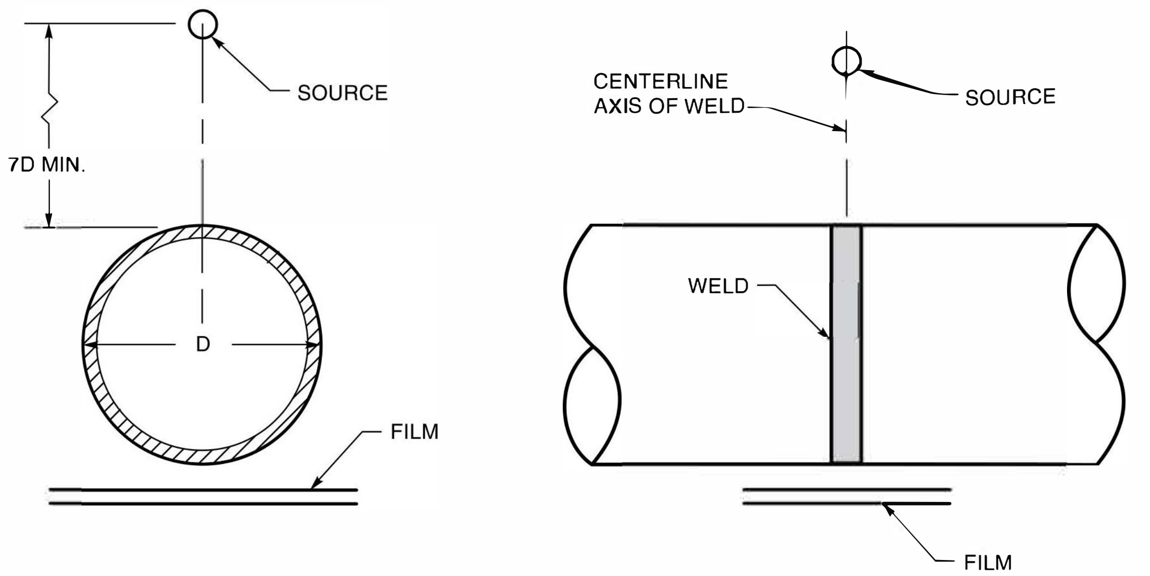
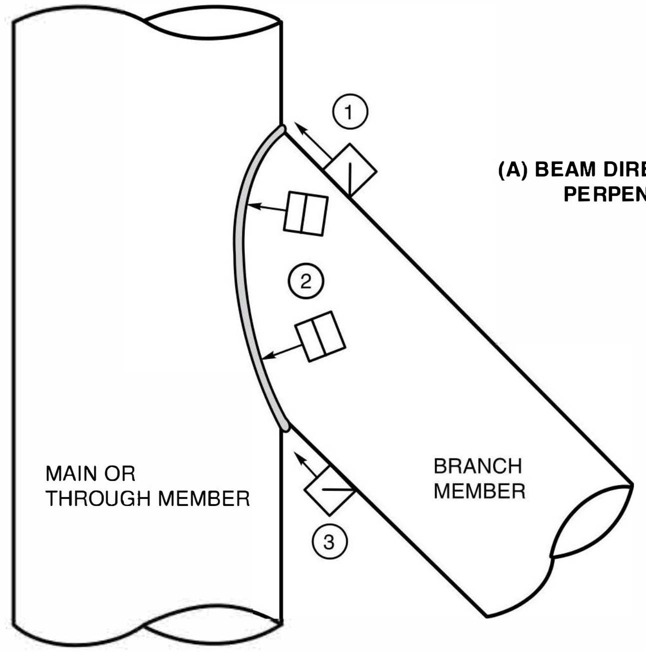
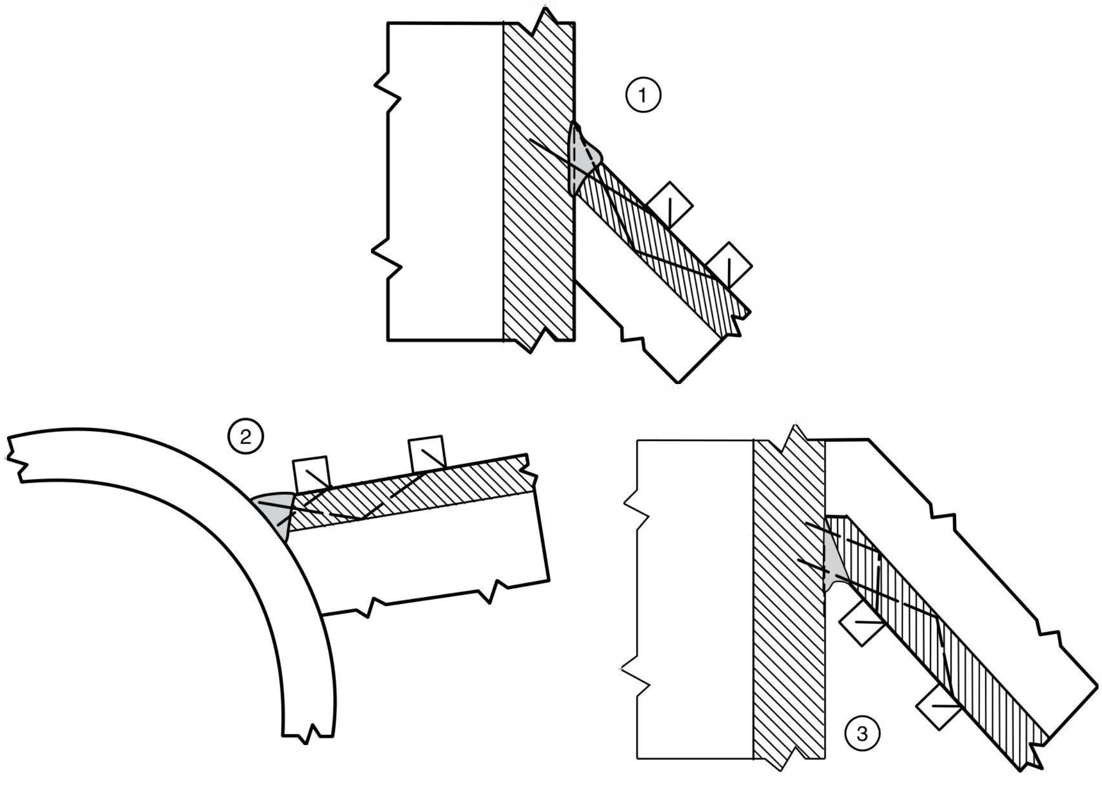


Figure 10.29—Double-Wall Exposure—Double-Wall View, Minimum Three Exposures (see 10.28.1.3)



(A) BEAM DIRECTION. MAINTAIN SOUND PERPENDICULAR TO WELD.



(B) V-PATHS. USE SINGLE AND MULTIPLE LEGS AND VARIOUS ANGLES AS REQUIRED TO COVER THE COMPLETE WELD INCLUDING THE ROOT AREA.

Figure 10.30—Scanning Techniques (see 10.29.5)

11. Strengthening and Repair of Existing Structures

11.1 Scope

Strengthening or repairing an existing structure shall consist of modifications to meet design requirements specified by the Engineer. This clause includes requirements for a comprehensive plan for the work, including design, workmanship, inspection, and documentation. The use of fatigue life enhancement methods is also described.

11.2 General

The Engineer shall prepare a comprehensive plan for the work. Such plans shall include, but are not limited to, design, workmanship, inspection, and documentation. Except as modified in this section, all provisions of this code shall apply equally to the strengthening and repairing of existing structures, including heat straightening of distorted members.

11.3 Base Metal

11.3.1 Investigation. Before preparing drawings and specifications for strengthening or repairing existing structures, the types of base metal used in the original structure shall be determined either from existing drawings, specifications or from representative base metal tests.

11.3.2 Suitability for Welding. The suitability of the base metal for welding shall be established (see Table C-11.1 for guidance).

11.3.3 Other Base Metals. Where base metals other than those listed in Table 5.3 are to be joined, special consideration by the Engineer shall be given to the selection of filler metal and WPSs.

11.4 Design for Strengthening and Repair

11.4.1 Design Process. The design process shall consider applicable governing code provisions and other parts of the general specifications. The Engineer shall specify the type and extent of survey necessary to identify existing conditions that require strengthening or repair in order to satisfy applicable criteria.

11.4.2 Stress Analysis. An analysis of stresses in the area affected by the strengthening or repair shall be made. Stress levels shall be established for all in-situ dead and live load cases. Consideration shall be made for accumulated damage that members may have sustained in past service.

11.4.3 Fatigue History. Members subject to cyclic loading shall be designed according to the requirements for fatigue stresses. The previous loading history shall be considered in the design. When the loading history is not available, it shall be estimated.

11.4.4 Restoration or Replacement. Determination shall be made whether the repairs should consist of restoring corroded or otherwise damaged parts or of replacing entire members.

11.4.5 Loading During Operations. The Engineer shall determine the extent to which a member will be allowed to carry loads while heating, welding or thermal cutting is performed. When necessary, the loads shall be reduced. The local and general stability of the member shall be investigated, considering the effect of elevated temperature extending over parts of the cross-sectional area.

11.4.6 Existing Connections. Existing connections in structures requiring strengthening or repair shall be evaluated for design adequacy and reinforced as necessary.

11.4.7 Use of Existing Fasteners. When design calculations show rivets or bolts will be overstressed by the new total load, only existing dead load shall be assigned to them. If rivets or bolts are overstressed by dead load alone or are subject to cyclic loading, then sufficient base metal and welding shall be added to support the total load.

11.5 Fatigue Life Enhancement

11.5.1 Methods. The following methods of reconditioning critical weld details may be used when written procedures have been approved by the Engineer:

(1) *Profile Improvement*. Reshaping the weld face by grinding with a carbide burr to obtain a concave profile with a smooth transition from base material to weld.

(2) *Toe Grinding*. Reshaping only the weld toes by grinding with a burr or pencil grinder.

(3) *Peening*. Shot peening of weld surface, or hammer peening of weld toes.

(4) *TIG Dressing*. Reshaping of weld toe by the remelting of existing weld metal with heat from a GTAW arc (no filler metal used).

(5) *Toe Grinding plus Hammer Peening*. When used together, the benefits are cumulative.

11.5.2 Stress Range Increase. The Engineer shall establish the appropriate increase in the allowable stress range.

11.6 Workmanship and Technique

11.6.1 Base Metal Condition. Base metal to be repaired and surfaces of existing base metal in contact with new base metal shall be cleaned of dirt, rust and other foreign matter except adherent paint film as per SSPC SP2 (Surface Preparation Specification #2—Hand Tool Cleaning). The portions of such surfaces which will be welded shall be thoroughly cleaned of all foreign matter including paint for at least 2 in [50 mm] from the root of the weld.

11.6.2 Member Discontinuities. When required by the Engineer, unacceptable discontinuities in the member being repaired or strengthened shall be corrected prior to heat straightening, heat curving, or welding.

11.6.3 Weld Repairs. If weld repairs are required, they shall be made in conformance with 7.25, as applicable.

11.6.4 Base Metal of Insufficient Thickness. Base metal having insufficient thickness to develop the required weld size or required capacity shall be, as determined by the Engineer:

(1) built up with weld metal to the required thickness,

(2) cut back until adequate thickness is available,

(3) reinforced with additional base metal, or

(4) removed and replaced with base metal of adequate thickness or strength.

11.6.5 Heat Straightening. When heat straightening or heat curving methods are used, the maximum temperature of heated areas as measured using temperature sensitive crayons or other positive means shall not exceed 1100°F [600°C] for quenched and tempered steel, nor 1200°F [650°C] for other steels. Accelerated cooling of steel above 600°F [315°C] shall be prohibited.

11.6.6 Welding Sequence. In strengthening or repairing members by the addition of base metal or weld metal, or both, welding and weld sequencing shall, as far as practicable, result in a balanced heat input about the neutral axis to minimize distortion and residual stresses.

11.7 Quality

11.7.1 Visual Inspection. All members and welds affected by the work shall be visually inspected in conformance with the Engineer's comprehensive plan.

11.7.2 NDT. The method, extent, and acceptance criteria of NDT shall be specified in the contract documents.

Annexes
Normative Information

These annexes contain information and requirements that are considered a part of the standard.

Informative Information

These annexes are not considered a part of the standard and are provided for informational purposes only.

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Annex A (Normative)
Effective Throats of Fillet Welds in Skewed T-Joints

This annex is part of this standard and includes mandatory elements for use with this standard.

Table A.1 is a tabulation showing equivalent leg size factors for the range of dihedral angles between 60° and 135°, assuming no root opening. Root opening(s) 1/16 in [2 mm] or greater, but not exceeding 3/16 in [5 mm], shall be added directly to the leg size. The required leg size for fillet welds in skewed joints shall be calculated using the equivalent leg size factor for correct dihedral angle, as shown in the example.

EXAMPLE
(U.S. Customary Units)

Given:	Skewed T-joint, angle: 75°; root opening: 1/16 (0.063) in	
Required:	Strength equivalent to 90° fillet weld of size: 5/16 (0.313) in	
Procedure:	(1) Factor for 75° from Table A.1: 0.86	
	(2) Equivalent leg size, w, of skewed joint, without root opening: w = 0.86 × 0.313	= 0.269 in
	(3) With root opening of:	+ 0.063 in
	(4) Required leg size, w of skewed fillet weld: [(2) + (3)]	= 0.332 in
	(5) Rounding up to a practical dimension: w = 3/8 in	

EXAMPLE
(SI Units)

Given:	Skewed T-joint, angle 75°; root opening: 2 mm	
Required:	Strength equivalent to 90° fillet weld of size: 8 mm	
Procedure:	(1) Factor for 75° from Table A.1: 0.86	
	(2) Equivalent leg size, w, of skewed joint, without root opening: w = 0.86 × 8	= 6.9 mm
	(3) With root opening of:	+ 2.0 mm
	(4) Required leg size, w of skewed fillet weld: [(2) + (3)]	= 8.9 mm
	(5) Rounding up to a practical dimension: w = 9.0 mm	

For fillet welds having equal measured legs (w_n), the distance from the root of the joint to the face of the diagrammatic weld (t_n) may be calculated as follows:

For root openings > 1/16 in [2 mm] and ≤ 3/16 in [5 mm], use

$$t_n = \frac{W_n - R_n}{2 \sin \frac{\psi}{2}}$$

For root openings <1/16 in [2 mm], use

$R_n = 0$ and $t'_n = t_n$

where the measured leg of such fillet weld (w_n) is the perpendicular distance from the surface of the joint to the opposite toe, and (R) is the root opening, if any, between parts (see Figure 5.4). Acceptable root openings are defined in 7.21.1.

Table A.1
Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints

Dihedral angle, Ψ	60°	65°	70°	75°	80°	85°	90°	95°
Comparable fillet weld size for same strength	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03
Dihedral angle, Ψ	100°	105°	110°	115°	120°	125°	130°	135°
Comparable fillet weld size for same strength	1.08	1.12	1 .16	1.19	1.23	1.25	1.28	1.31

Annex B (Normative)
Guideline on Alternative Methods for Determining Preheat

This annex is part of this standard and includes mandatory elements for use with this standard.

B1. Introduction

The purpose of this guide is to provide some optional alternative methods for determining welding conditions (principally preheat) to avoid cold cracking. The methods are based primarily on research on small scale tests carried out over many years in several laboratories world-wide. No method is available for predicting optimum conditions in all cases, but the guide does consider several important factors such as hydrogen level and steel composition not explicitly included in the requirements of Table 5.8. The guide may therefore be of value in indicating whether the requirements of Table 5.8 are overly conservative or in some cases not sufficiently demanding.

The user is referred to the Commentary for more detailed presentation of the background scientific and research information leading to the two methods proposed.

In using this guide as an alternative to Table 5.8, careful consideration shall be given to the assumptions made, the values selected, and past experience.

B2. Methods

Two methods are used as the basis for estimating welding conditions to avoid cold cracking:

(1) HAZ hardness control

(2) Hydrogen control

B3. HAZ Hardness Control

B3.1 The provisions included in this guide for use of this method are restricted to fillet welds.

B3.2 This method is based on the assumption that cracking will not occur if the hardness of the HAZ is kept below some critical value. This is achieved by controlling the cooling rate below a critical value dependent on the hardenability of the steel. Hardenability of steel in welding relates to its propensity towards formation of a hard HAZ and can be characterized by the cooling rate necessary to produce a given level of hardness. Steels with high hardenability can, therefore, produce hard HAZ at slower cooling rates than a steel with lower hardenability.

Equations and graphs are available in the technical literature that relate the weld cooling rate to the thickness of the steel members, type of joint, welding conditions and variables.

B3.3 The selection of the critical hardness will depend on a number of factors such as steel type, hydrogen level, restraint, and service conditions. Laboratory tests with fillet welds show that HAZ cracking does not occur if the HAZ Vickers Hardness No. (HV) is less than 350 HV, even with high-hydrogen electrodes. With low-hydrogen electrodes, hardnesses of 400 HV could be tolerated without cracking. Such hardness, however, may not be tolerable in service where there is an increased risk of stress corrosion cracking, brittle fracture initiation, or other risks for the safety or serviceability of the structure.

The critical cooling rate for a given hardness can be approximately related to the carbon equivalent (CE) of the steel (see Figure B.2). Since the relationship is only approximate, the curve shown in Figure B.2 may be conservative for plain carbon and plain carbon-manganese steels and thus allow the use of the high hardness curve with less risk.

Some low-alloy steels, particularly those containing columbium (niobium), may be more hardenable than Figure B.2 indicates, and the use of the lower hardness curve is recommended.

B3.4 Although the method can be used to determine a preheat level, its main value is in determining the minimum heat input (and hence minimum weld size) that prevents excessive hardening. It is particularly useful for determining the minimum size of single-pass fillet welds that can be deposited without preheat.

B3.5 The hardness approach does not consider the possibility of weld metal cracking. However, from experience it is found that the heat input determined by this method is usually adequate to prevent weld metal cracking, in most cases, in fillet welds if the electrode is not a high-strength filler metal and is generally of a low-hydrogen type [e.g., low-hydrogen (SMAW) electrode, GMAW, FCAW, SAW].

B3.6 Because the method depends solely on controlling the HAZ hardness, the hydrogen level and restraint are not explicitly considered.

B3.7 This method is not applicable to quenched and tempered steels [see B5.2(3) for limitations].

B4. Hydrogen Control

B4.1 The hydrogen control method is based on the assumption that cracking will not occur if the average quantity of hydrogen remaining in the joint after it has cooled down to about 120°F [50°C] does not exceed a critical value dependent on the composition of the steel and the restraint. The preheat necessary to allow enough hydrogen to diffuse out of the joint can be estimated using this method.

B4.2 This method is based mainly on results of restrained PJP groove weld tests; the weld metal used in the tests matched the parent metal. There has not been extensive testing of this method on fillet welds; however, by allowing for restraint, the method has been suitably adapted for those welds.

B4.3 A determination of the restraint level and the original hydrogen level in the weld pool is required for the hydrogen method.

In this guide, restraint is classified as high, medium, and low, and the category must be established from experience.

B4.4 The hydrogen control method is based on a single low-heat input weld bead representing a root pass and assumes that the HAZ hardens. The method is, therefore, particularly useful for high strength, low-alloy steels having quite high hardenability where hardness control is not always feasible. Consequently, because it assumes that the HAZ fully hardens, the predicted preheat may be too conservative for carbon steels.

B5. Selection of Method

B5.1 The following procedure is recommended as a guide for selection of either the hardness control or hydrogen control method.

Determine carbon and carbon equivalent:

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

to locate the zone position of the steel in Figure B.1 (see B6.1.1 for the different ways to obtain chemical analysis).

B5.2 The performance characteristics of each zone and the recommended action are as follows:

(1) **Zone I.** Cracking is unlikely, but may occur with high hydrogen or high restraint. Use hydrogen control method to determine preheat for steels in this zone.

(2) **Zone II.** The hardness control method and selected hardness shall be used to determine minimum energy input for single-pass fillet welds without preheat.

If the energy input is not practical, use hydrogen method to determine preheat.

For groove welds, the hydrogen control method shall be used to determine preheat.

For steels with high carbon, a minimum energy to control hardness and preheat to control hydrogen may be required for both types of welds, i.e., fillet and groove welds.

(3) **Zone III.** The hydrogen control method shall be used. Where heat input is restricted to preserve the HAZ properties (e.g., some quenched and tempered steels), the hydrogen control method should be used to determine preheat.

B6. Detailed Guide

B6.1 Hardness Method

B6.1.1 The carbon equivalent shall be calculated as follows:

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

The chemical analysis may be obtained from:

(1) Mill test certificates

(2) Typical production chemistry (from the mill)

(3) Specification chemistry (using maximum values)

(4) User tests (chemical analysis)

B6.1.2 The critical cooling rate shall be determined for a selected maximum HAZ hardness of either 400 HV or 350 HV from Figure B.2.

B6.1.3 Using applicable thicknesses for "flange" and "web" plates, the appropriate diagram shall be selected from Figure B.3 and the minimum energy input for single-pass fillet welds shall be determined. This energy input applies to SAW welds.

B6.1.4 For other processes, minimum energy input for single-pass fillet welds can be estimated by applying the following multiplication factors to the energy estimated for the SAW process in B6.1.3:

Welding Process	Multiplication Factor
SAW	1
SMAW	1.50
GMAW, FCAW	1.25

B6.1.5 Figure B.4 may be used to determine fillet sizes as a function of energy input.

B6.2 Hydrogen Control Method

B6.2.1 The value of the composition parameter, P_{cm}, shall be calculated as follows:

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

B6.2.2 The hydrogen level shall be determined and shall be defined as follows:

(1) **H1 Extra-Low Hydrogen.** These consumables give a diffusible hydrogen content of less than 5 ml/100g deposited metal when measured using ISO 3690–1976 or, a moisture content of electrode covering of 0.2% maximum in conformance with AWS A5.1 or A5.5. This may be established by testing each type, brand, or wire/flux combination used after removal from the package or container and exposure for the intended duration, with due consideration of actual storage conditions prior to immediate use. The following may be assumed to meet this requirement:

(a) low-hydrogen electrodes taken from hermetically sealed containers, dried at 700°F– 800°F [370°– 430°C] for one hour and used within two hours after removal,

(b) GMAW with clean solid wires.

(2) **H2 Low Hydrogen.** These consumables give a diffusible hydrogen content of less than 10 ml/100g deposited metal when measured using ISO 3690–1976, or a moisture content of electrode covering of 0.4% maximum in conformance with AWS A5.1. This may be established by a test on each type, brand of consumable, or wire/flux combination used. The following may be assumed to meet this requirement:

(a) Low-hydrogen electrodes taken from hermetically sealed containers conditioned in conformance with 7.3.2.1 of the code and used within four hours after removal,

(b) SAW with dry flux.

(3) **H3 Hydrogen Not Controlled.** All other consumables not meeting the requirements of H1 or H2.

B6.2.3 The susceptibility index grouping from Table B1 shall be determined.

B6.2.4 Minimum Preheat Levels and Interpass. Table B.2 gives the minimum preheat and interpass temperatures that shall be used. Table B.2 gives three levels of restraint. The restraint level to be used shall be determined in conformance with B6.2.5.

B6.2.5 Restraint. The classification of types of welds at various restraint levels should be determined on the basis of experience, engineering judgment, research, or calculation.

Three levels of restraint have been provided:

(1) **Low Restraint.** This level describes common fillet and groove welded joints in which a reasonable freedom of movement of members exists.

(2) **Medium Restraint.** This level describes fillet and groove welded joints in which, because of members being already attached to structural work, a reduced freedom of movement exists.

(3) **High Restraint.** This level describes welds in which there is almost no freedom of movement for members joined (such as repair welds, especially in thick material).

Table B.1
Susceptibility Index Grouping as Function of Hydrogen Level "H" and Composition Parameter P_{cm} (see B6.2.3)

	Susceptibility Index[a] Grouping[b]				
	Carbon Equivalent = P^{c}_{cm}				
Hydrogen Level, H	<0.18	<0.23	<0.28	<0.33	<0.38
H1	A	B	C	D	E
H2	B	C	D	E	F
H3	C	D	E	F	G

[a] Susceptibility index—12 P_{cm} + log10 H.
[b] Susceptibility Index Groupings, A through G, encompass the combined effect of the composition parameter, P_{cm}, and hydrogen level, H, in conformance with the formula shown in footnote a.

The exact numerical quantities are obtained from the footnote a formula using the stated values of P_{cm} and the following values of H, given in ml/100g of weld metal [see B6.2.2, (1), (2), (3)]:

H1—5; H2—10; H3—30.

For greater convenience, Susceptibility Index Groupings have been expressed in the table by means of letters, A through G, to cover the following narrow ranges:

A = 3.0; B = 3.1–3.5; C = 3.6–4.0; D = 4.1–4.5; E = 4.6–5.0; F = 5.1–5.5; G = 5.6–7.0

These groupings are used in Table B.2 in conjunction with restraint and thickness to determine the minimum preheat and interpass temperature.

[c] $P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$

Table B.2
Minimum Preheat and Interpass Temperatures for Three Levels of Restraint (see B6.2.4)

		Minimum Preheat an Interpass Temperature (°F)[a]						
	Thickness[b]	Susceptibility Index Grouping						
Level	in	A	B	C	D	E	F	G
Low	< 3/8	< 65	< 65	< 65	< 65	140	280	300
	3/8– 3/4 incl.	< 65	< 65	65	140	210	280	300
	> 3/4– 1-1/2 incl.	< 65	< 65	65	175	230	280	300
	> 1-1/2– 3 incl.	65	65	100	200	250	280	300
	> 3	65	65	100	200	250	280	300
Medium	< 3/8	< 65	< 65	< 65	< 65	160	280	320
	3/8– 3/4 incl.	< 65	< 65	65	175	240	290	320
	> 3/4– 1-1/2 incl.	< 65	65	165	230	280	300	320
	> 1-1/2– 3 incl.	65	175	230	265	300	300	320
	> 3	200	250	280	300	320	320	320
High	< 3/8	< 65	< 65	< 65	100	230	300	320
	3/8– 3/4 incl.	< 65	65	150	220	280	320	320
	> 3/4– 1-1/2 incl.	65	185	240	280	300	320	320
	> 1-1/2– 3 incl.	240	265	300	300	320	320	320
	> 3	240	265	300	300	320	320	320

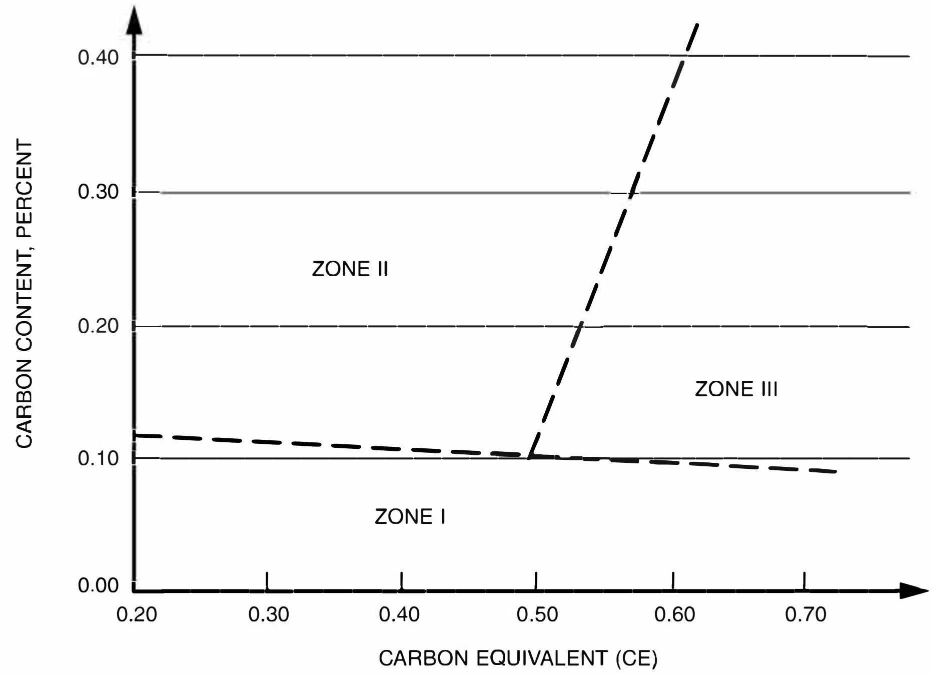
(Continued)

[a] "<" indicates that preheat and interpass temperatures lower than the temperature shown may be suitable to avoid hydrogen cracking. Preheat and interpass temperatures that are both lower than the listed temperature and lower than Table 5.8 shall be qualified by test.
[b] Thickness is that of the thicker part welded.

Table B.2 (Continued)
Minimum Preheat and Interpass Temperatures for Three Levels of Restraint (see B6.2.4)

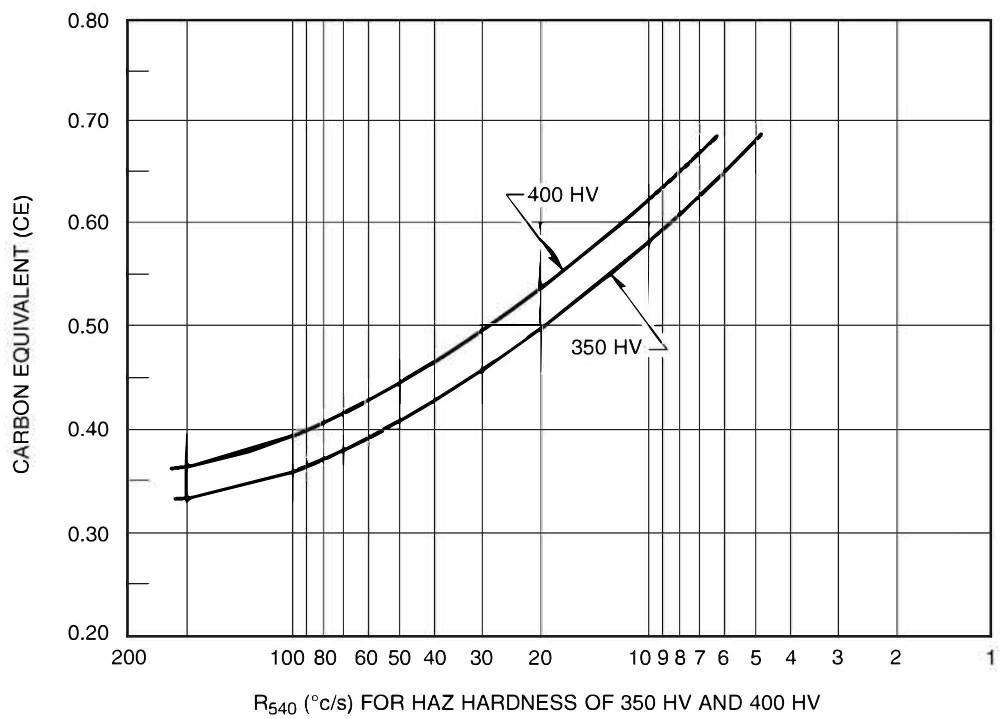
		Minimum Preheat an Interpass Temperature (°C)[a]						
	Thickness[b]	Susceptibility Index Grouping						
Level	mm	A	B	C	D	E	F	G
Low	< 10	< 20	< 20	< 20	< 20	60	140	150
	10–20 incl.	< 20	< 20	20	60	100	140	150
	> 20–38 incl.	< 20	< 20	20	80	110	140	150
	> 38–75 incl.	20	20	40	95	120	140	150
	> 75	20	20	40	95	120	140	150
Medium	< 10	< 20	< 20	< 20	< 20	70	140	160
	10–20 incl.	< 20	< 20	20	80	115	145	160
	> 20– 38 incl.	20	20	75	110	140	150	160
	> 38– 75 incl.	20	80	110	130	150	150	160
	> 75	95	120	140	150	160	160	160
High	< 10	< 20	< 20	20	40	110	150	160
	10–20 incl.	<20	20	65	105	140	160	160
	> 20– 38 incl.	20	85	115	140	150	160	160
	> 38– 75 incl.	115	130	150	150	160	160	160
	> 75	115	130	150	150	160	160	160

[a] "<" indicates that preheat and interpass temperatures lower than the temperature shown may be suitable to avoid hydrogen cracking. Preheat and interpass temperatures that are both lower than the listed temperature and lower than Table 5.8 shall be qualified by test.
[b] Thickness is that of the thicker part welded.



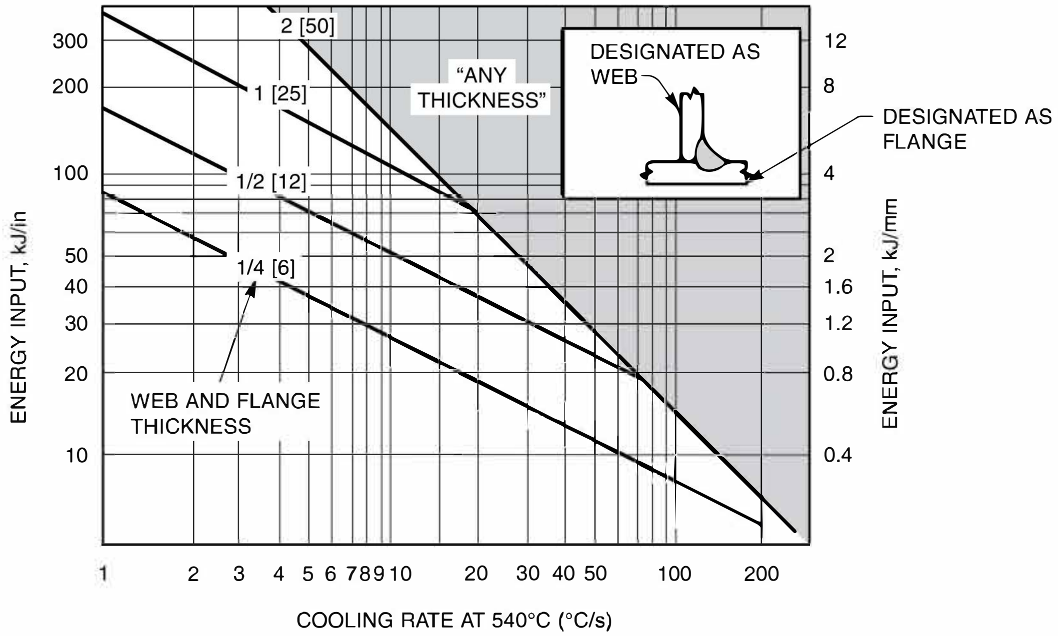
Notes:
1. CE = C + (Mn + Si)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15.
2. See B5.2(1), (2), or (3) for applicable zone characteristics.

Figure B.1—Zone Classification of Steels (see B5.1)



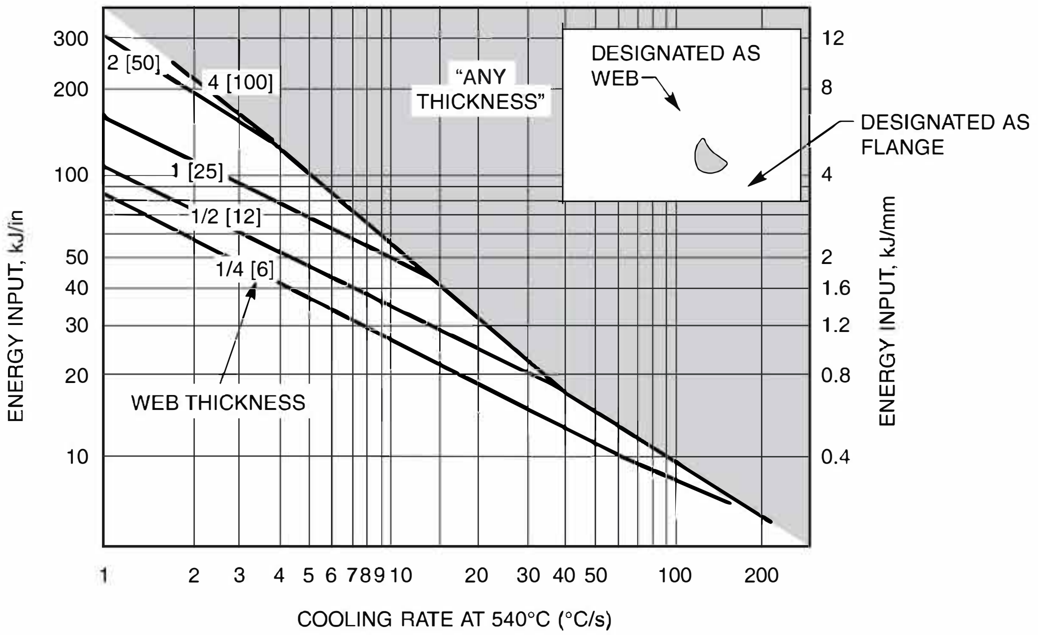
Note: CE = C + (Mn + Si)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15.

Figure B.2—Critical Cooling Rate for 350 HV and 400 HV (see B3.3)



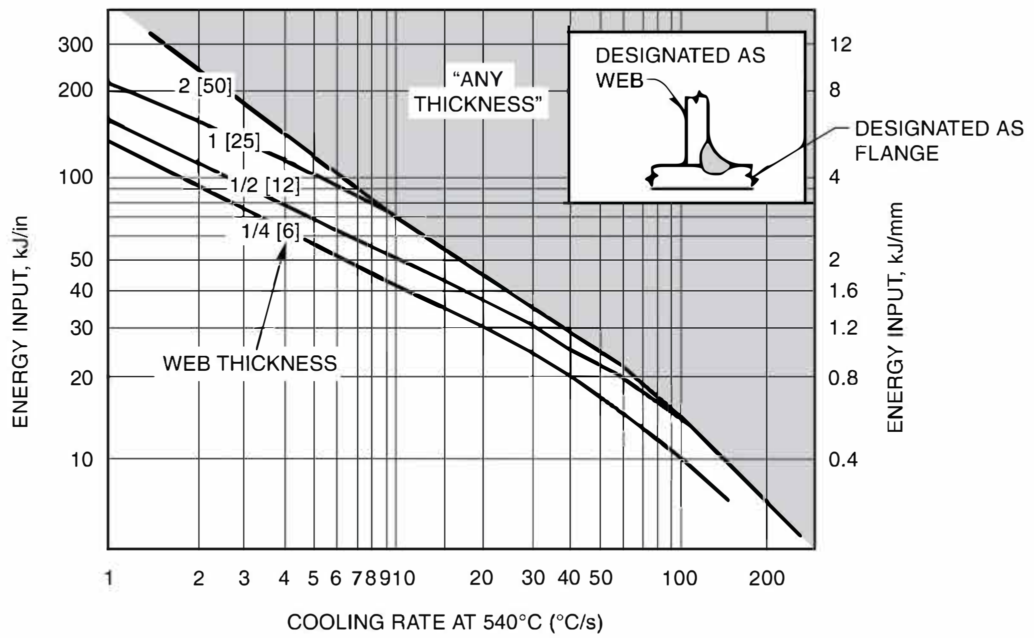
Note: Energy input determined from chart shall not imply suitability for practical applications. For certain combination of thicknesses melting may occur through the thickness.

(A) SINGLE-PASS SAW FILLET WELDS WITH WEB AND FLANGE OF SAME THICKNESS



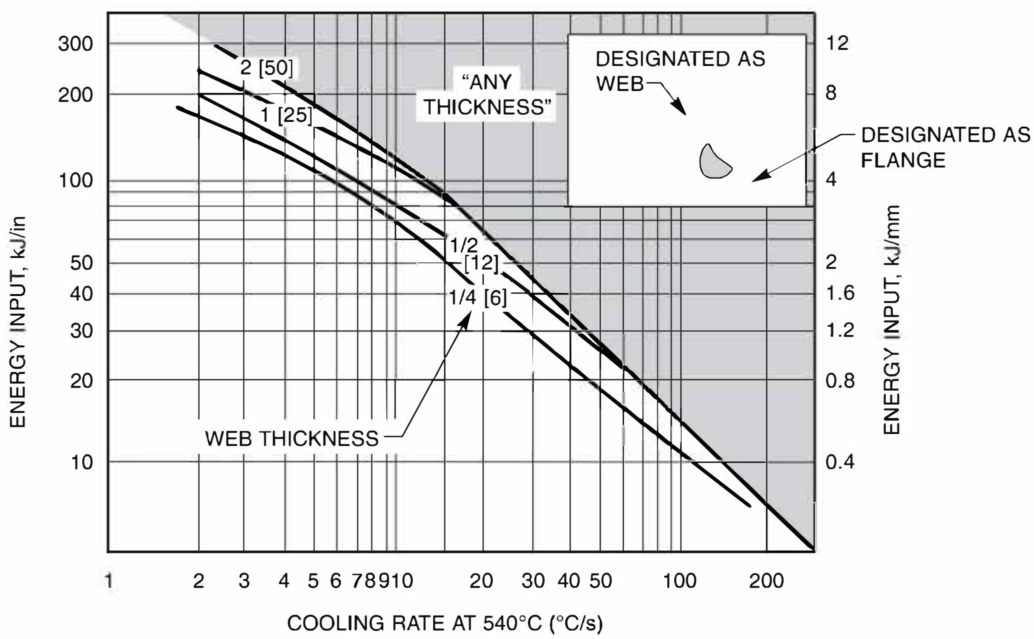
(B) SINGLE-PASS SAW FILLET WELDS WITH 1/4 in [6 mm] FLANGES AND VARYING WEB THICKNESSES

Figure B.3—Graphs to Determine Cooling Rates for Single-Pass SAW Fillet Welds (see B6.1.3)



Note: Energy input determined from chart shall not imply suitability for practical applications. For certain combination of thicknesses melting may occur through the thickness.

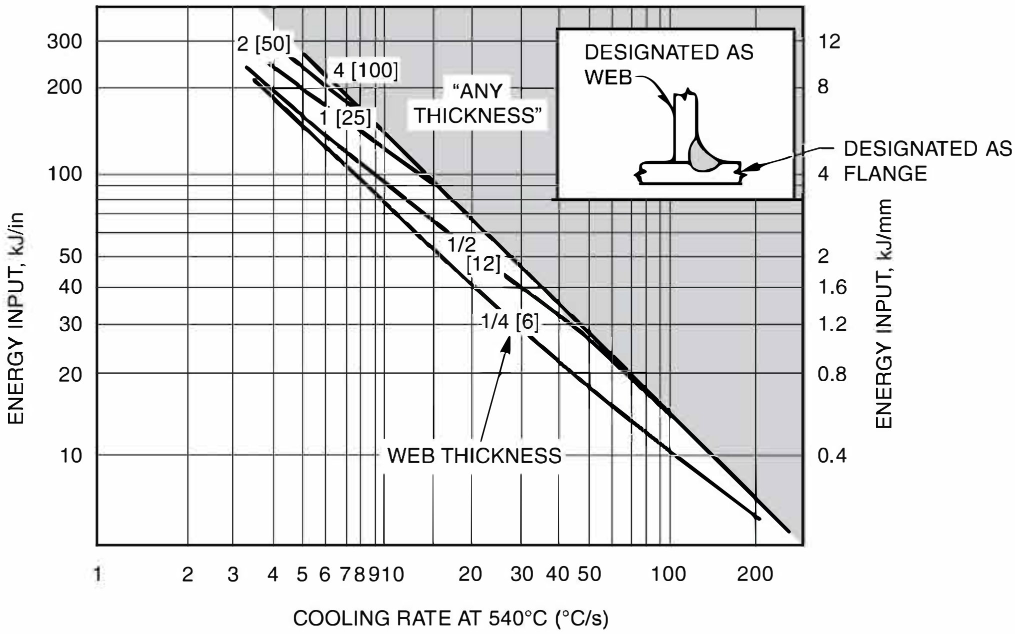
(C) SINGLE-PASS SAW FILLET WELDS WITH 1/2 in [12 mm] FLANGES AND VARYING WEB THICKNESSES



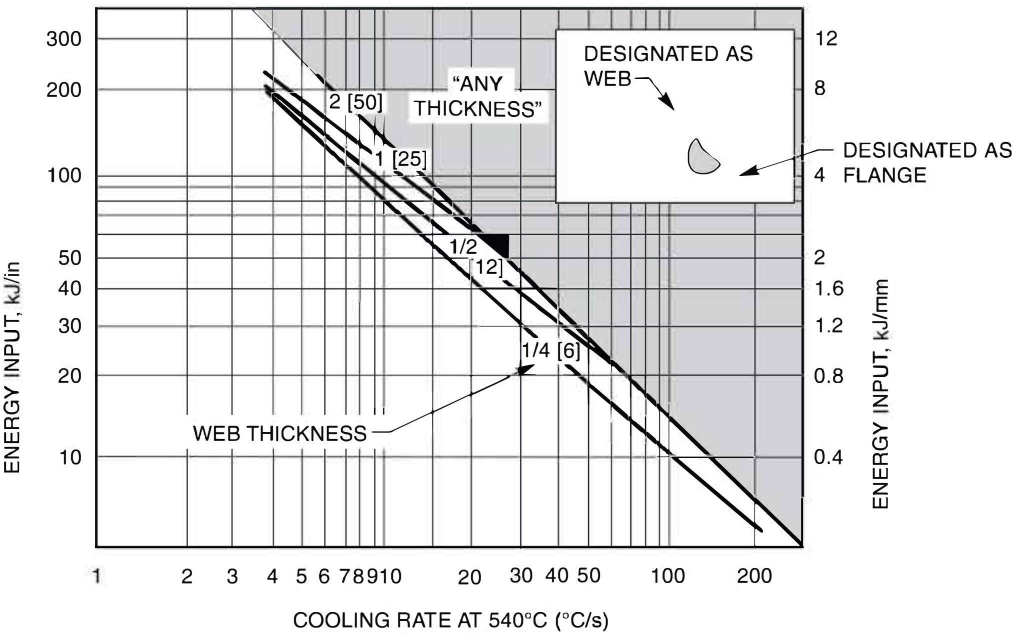
Note: Energy input determined from chart shall not imply suitability for practical applications. For certain combination of thicknesses melting may occur through the thickness.

(D) SINGLE-PASS SAW FILLET WELDS WITH 1 in [25 mm] FLANGES AND VARYING WEB THICKNESSES

Figure B.3 (Continued)—Graphs to Determine Cooling Rates for Single-Pass SAW Fillet Welds (B6.1.3)



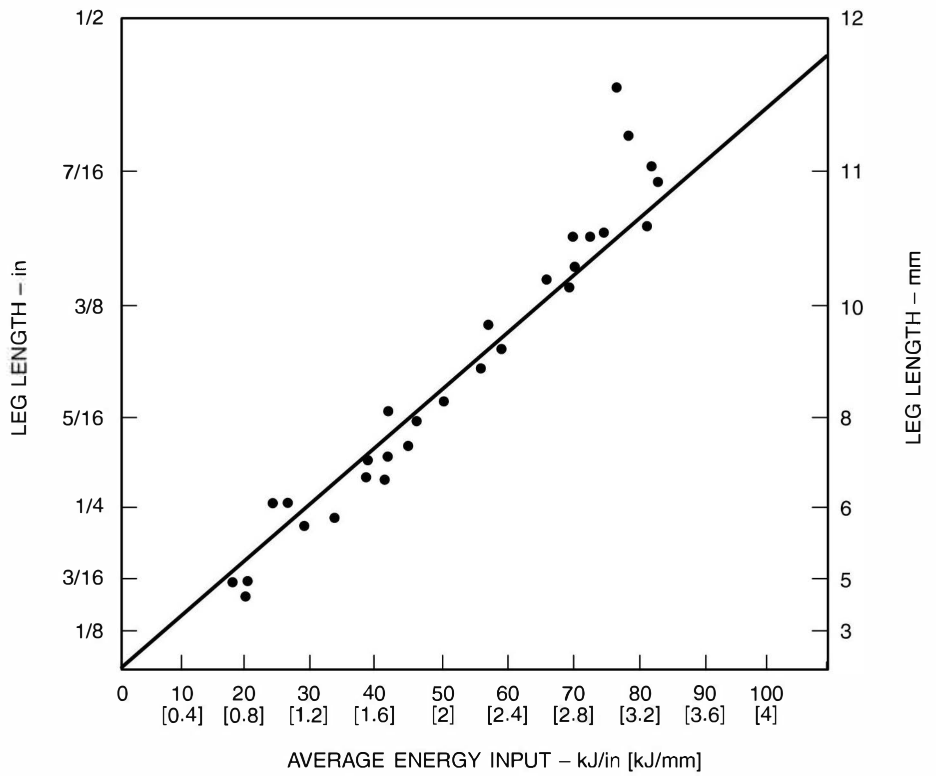
(E) SINGLE-PASS SAW FILLET WELDS WITH 2 in [50 mm] FLANGES AND VARYING WEB THICKNESSES



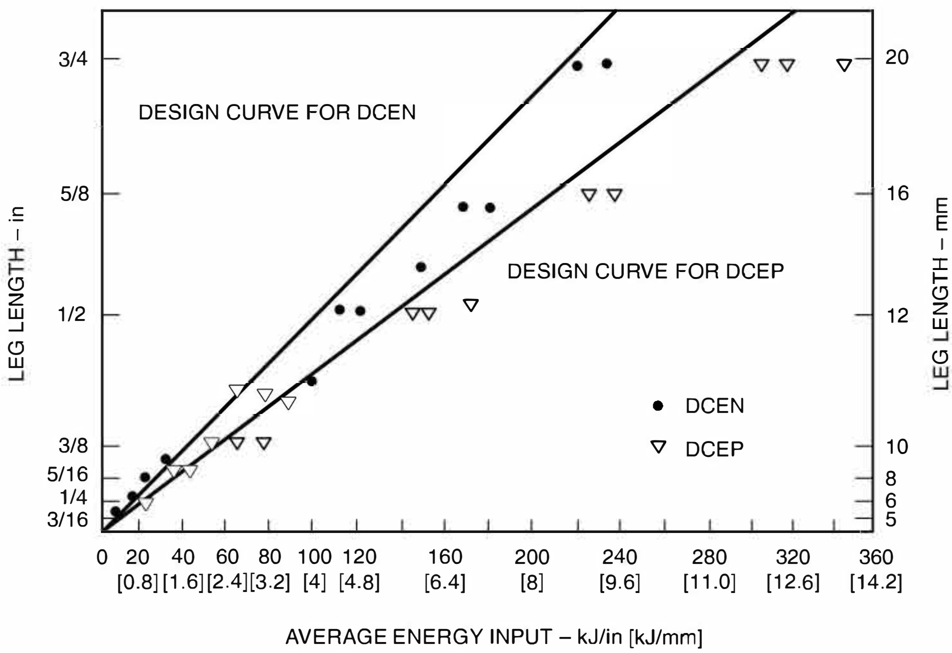
Note: Energy input determined from chart shall not imply suitability for practical applications. For certain combination of thicknesses melting may occur through the thickness.

(F) SINGLE-PASS SAW FILLET WELDS WITH 4 in [100 mm] FLANGES AND VARYING WEB THICKNESSES

Figure B.3 (Continued)—Graphs to Determine Cooling Rates for Single-Pass SAW Fillet Welds (see B6.1.3)



(A) SHIELDED METAL ARC WELDING (SMAW)



(B) SUBMERGED ARC WELDING (SAW)

Figure B.4—Relation Between Fillet Weld Size and Energy Input (see B6.1.5)

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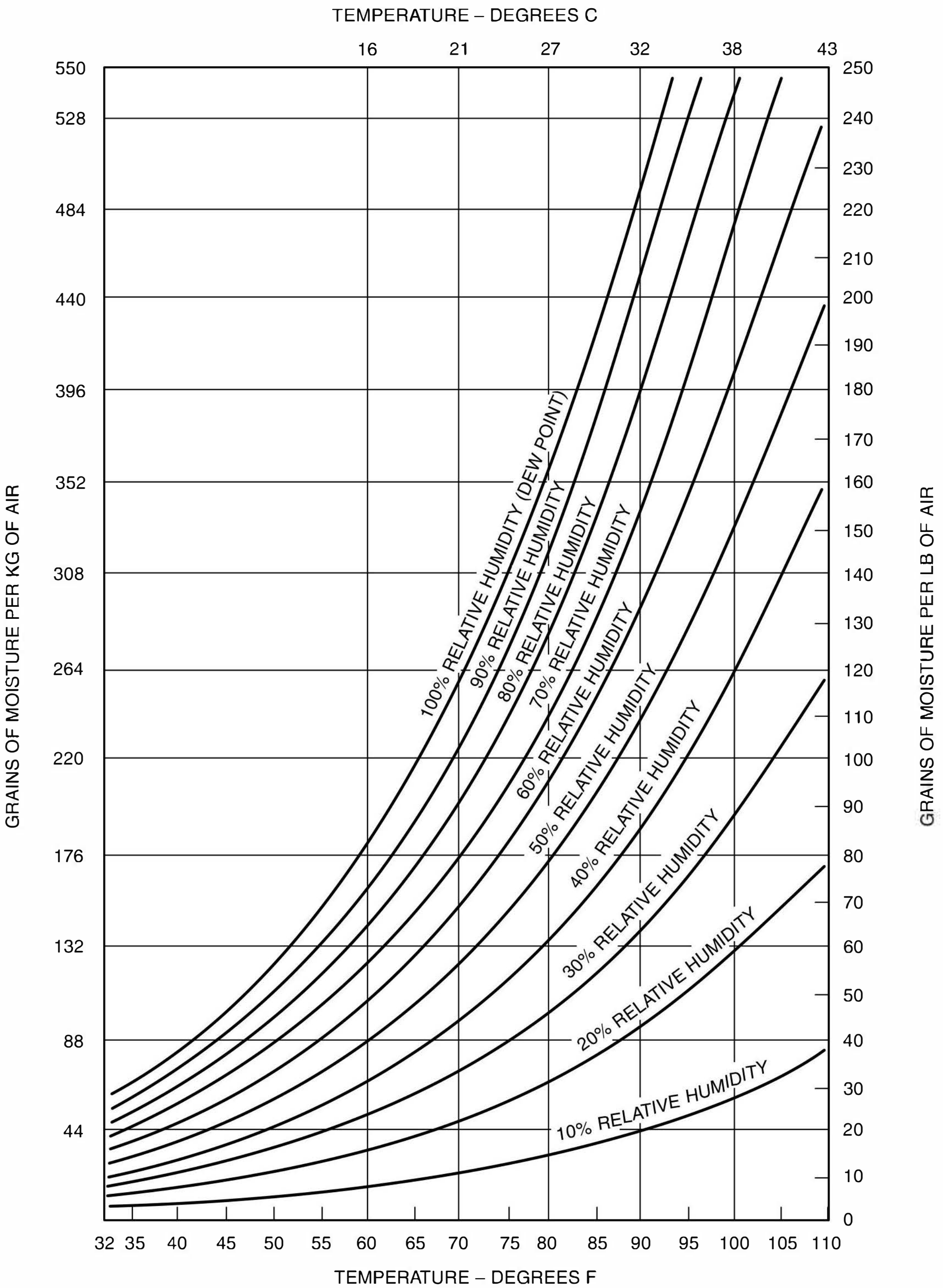
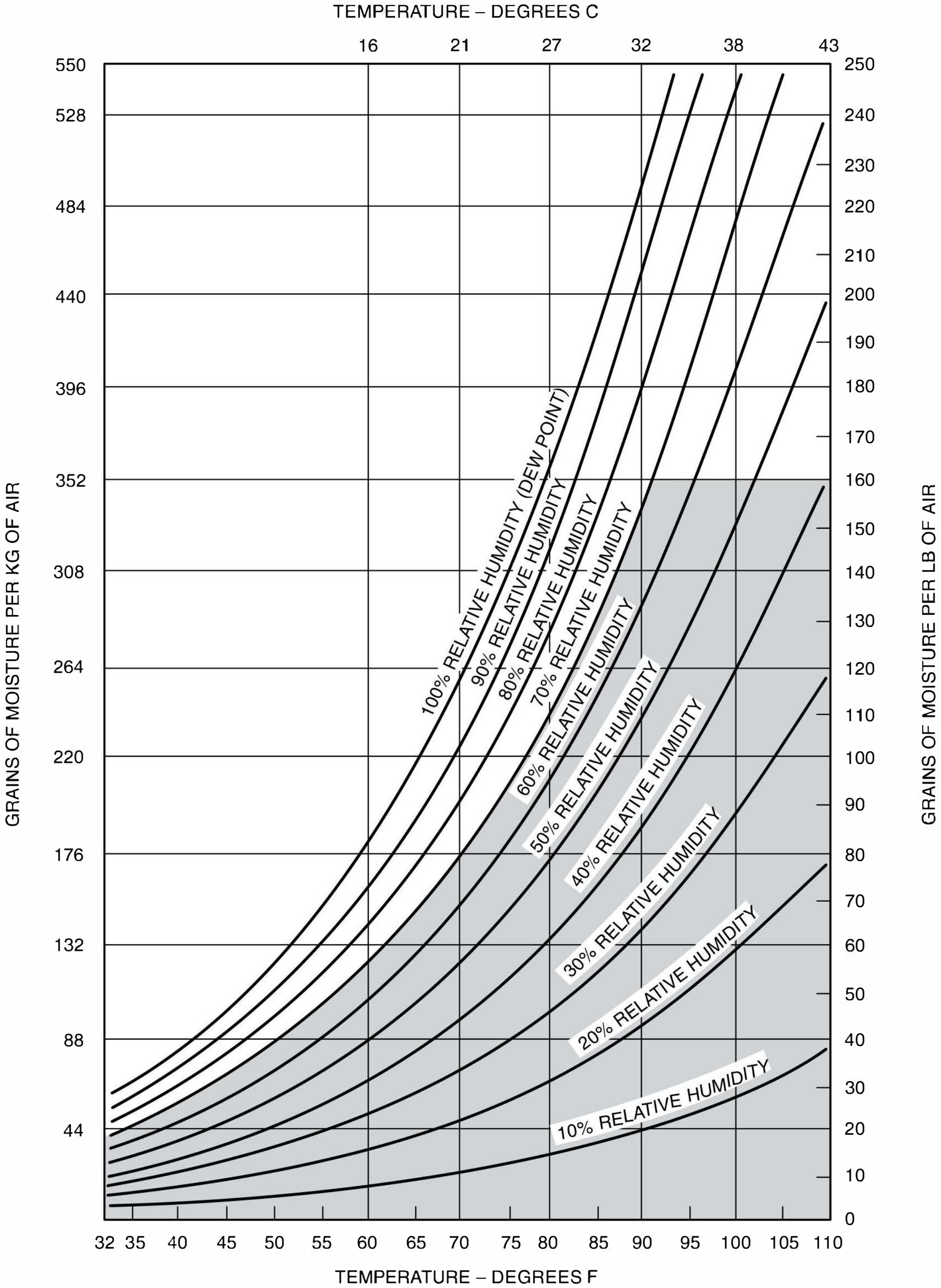
Annex D (Normative)
Temperature-Moisture Content Charts

This annex is part of this standard and includes mandatory elements for use with this standard.



Notes:
1. Any standard psychrometric chart may be used in lieu of this chart.
2. See Figure D.2 for an example of the application of this chart in establishing electrode exposure conditions.

Figure D.1—Temperature-Moisture Content Chart to be Used in Conjunction with Testing Program to Determine Extended Atmospheric Exposure Time of Low-Hydrogen SMAW Electrodes (see 7.3.2.3)



EXAMPLE: AN ELECTRODE TESTED AT 90°F [32°C] AND 70% RELATIVE HUMIDITY (RH) MAY BE USED UNDER THE CONDITIONS SHOWN BY THE SHADED AREAS. USE UNDER OTHER CONDITIONS REQUIRES ADDITIONAL TESTING.

Figure D.2—Application of Temperature-Moisture Content Chart in Determining Atmospheric Exposure Time of Low-Hydrogen SMAW Electrodes (see 7.3.2.3)

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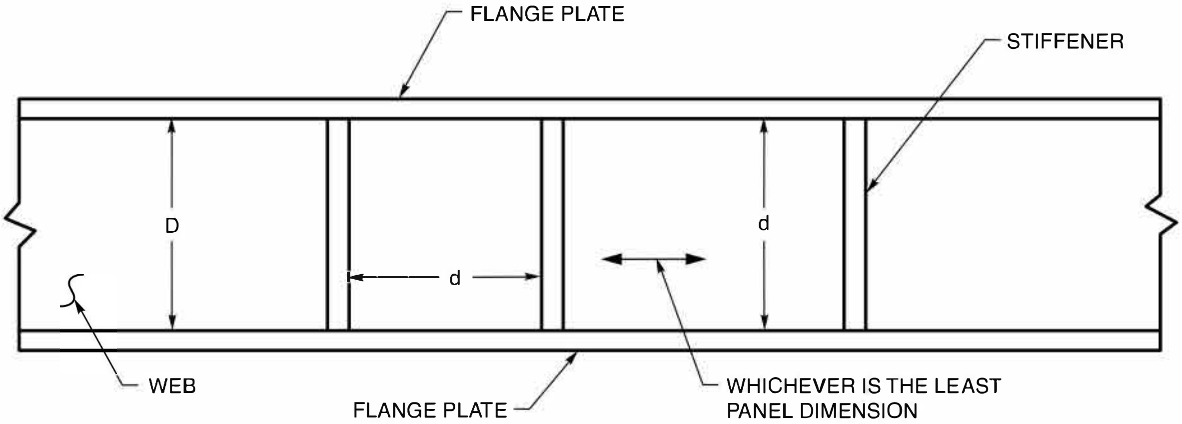
Annex E (Normative)
Flatness of Girder Webs—Statically Loaded Structures

This annex is part of this standard and includes mandatory elements for use with this standard.



Notes:
1. D = Depth of web.
2. d = Least panel dimension.

Table E.1
Intermediate Stiffeners on Both Sides of Web

Thickness of Web, in	Depth of Web, in	Least Panel Dimension, in													
5/16	Less than 47	25	31	38	44	50									
	47 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
3/8	Less than 56	25	31	38	44	50	56	63							
	56 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
7/16	Less than 66	25	31	38	44	50	56	63	69						
	66 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
1/2	Less than 75	25	31	38	44	50	56	63	69	75	81				
	75 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
9/16	Less than 84	25	31	38	44	50	56	63	69	75	81	88			
	84 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
5/8	Less than 94	25	31	38	44	50	56	63	69	75	81	88	94		
	94 and over	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		Maximum Allowable Variation, in													
		1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1–1/16

Thickness of Web, mm	Depth of Web, m	Least Panel Dimension, meters													
8.0	Less than 1.19	0.63	0.79	0.97	1.12	1.27									
	1.19 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
9.5	Less than 1.42	0.63	0.79	0.97	1.12	1.27	1.42	1.60							
	1.42 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
11.1	Less than 1.68	0.63	0.79	0.97	1.12	1.27	1.42	1.60	1.75						
	1.68 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
12.7	Less than 1.90	0.63	0.79	0.97	1.12	1.27	1.42	1.60	1.75	1.90	2.05				
	1.90 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
14.3	Less than 2.13	0.63	0.79	0.97	1.12	1.27	1.42	1.60	1.75	1.90	2.05	2.24			
	2.13 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
15.9	Less than 2.39	0.63	0.79	0.97	1.12	1.27	1.42	1.60	1.75	1.90	2.05	2.24	2.39		
	2.39 and over	0.51	0.63	0.76	0.89	1.02	1.14	1.27	1.40	1.52	1.65	1.78	1.90	2.03	2.16
		Maximum Allowable Variation, millimeters													
		6	8	10	11	12	14	16	18	20	21	22	24	25	27

Note: For actual dimensions not shown, use the next higher figure.

Table E.2
No Intermediate Stiffeners

Thickness of Web, in	Depth of Web, in																
Any	38	47	56	66	75	84	94	103	113	122	131	141	150	159	169	178	188
	Maximum Allowable Variation, in																
	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1–1/16	1–1/18	1–3/16	1–1/4

Thickness of Web, mm	Depth of Web, meters																
Any	0.97	1.19	1.42	1.68	1.90	2.13	2.39	2.62	2.87	3.10	3.33	3.58	3.81	4.04	4.29	4.52	4.77
	Maximum Allowable Variation, millimeters																
	6	8	10	11	12	14	16	18	20	21	22	24	25	27	29	30	32

Note: For actual dimensions not shown, use the next higher figure.

Table E.3
Intermediate Stiffeners on One Side Only of Web

Thickness of Web, in	Depth of Web, in	Least Panel Dimension, in													
5/16	Less than 31	25	31												
	31 and over	17	21	25	29	34	38	42	46	50	54	59	63	67	71
3/8	Less than 38	25	31	38											
	38 and over	17	21	25	29	34	38	42	46	50	54	59	63	67	71
7/16	Less than 44	25	31	38	44										
	44 and over	17	21	25	29	34	38	42	46	50	54	59	63	67	71
1/2	Less than 50	25	31	38	44	50									
	50 and over	17	21	25	29	34	38	42	46	50	54	59	63	67	71
9/16	Less than 56	25	31	38	44	50	56								
	56 and over	17	21	25	29	34	38	42	46	50	54	59	63	67	71
5/8	Less than 63	25	31	38	44	50	56	63							
	63 and over	17	210	25	29	34	38	42	46	50	54	59	63	67	71
		Maximum Allowable Variation, in													
		1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1–1/16

Thickness of Web, mm	Depth of Web, m	Least Panel Dimension, meters													
8.0	Less than 0.78	0.63	0.79												
	0.78 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
9.5	Less than 0.97	0.63	0.79	0.97											
	0.97 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
11.1	Less than 1.12	0.63	0.79	0.97	1.12										
	1.12 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
12.7	Less than 1.27	0.63	0.79	0.97	1.12	1.27									
	1.27 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
14.3	Less than 1.42	0.63	0.79	0.97	1.12	1.27	1.42								
	1.42 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
15.9	Less than 1.60	0.63	0.79	0.97	1.12	1.27	1.42	1.60							
	1.60 and over	0.43	0.53	0.63	0.74	0.86	0.97	1.07	1.17	1.27	1.37	1.50	1.60	1.70	1.80
		Maximum Allowable Variation, millimeters													
		6	8	10	11	12	14	16	18	20	21	22	24	25	27

Note: For actual dimensions not shown, use the next higher figure.