

Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment



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Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment

4th Edition

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Prepared by
AWS D14 Committee on Machinery and Equipment

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

Requirements are presented for the design and fabrication of constructional steel weldments that are used in industrial and mill cranes, lifting devices and other material handling equipment. Requirements are also included for modification, weld repair, and postweld treatments of new and existing weldments. Filler metal and welding procedure guidelines are recommended for the applicable base metals, which are limited to carbon and low-alloy steels. Allowable unit stresses are provided for weld metal and base metal for various cyclically loaded joint designs.



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Foreword

(This Foreword is not a part of AWS D14.1/D14.1M:2005, *Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment*, but is included for informational purposes only.)

This specification was prepared for the overhead crane and material handling industries to continue the advancement of welding and to increase product reliability. This 4th edition provides revisions to ANSI/AWS D14.1-97, *Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment*, under the direction of the AWS Machinery and Equipment Committee.

The participating committee, representing manufacturers, users, and government, joined in the preparation of this document. It will provide all concerned, including the general public, with high quality, reliable products and an economical approach to production, consistent with the industry's capabilities.

This specification will be reviewed periodically to assure its success in serving all parties concerned with its provisions. Revisions will be issued when warranted.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D14 Committee on Machinery and Equipment, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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Amendment

The following Amendment has been identified and is incorporated in this reprint.

AWS Standard: D14.1/D14.1M:2005, *Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment*

Amendment Number: 1

Subject: Table 2, Allowable Stress in Weld Metal

Table 2
Allowable Stress in Weld Metal

Type of Weld	Stress in Weld ⁽¹⁾		Allowable Stress	Required Weld Strength Level ⁽²⁾
Complete joint penetration groove welds (Joint Class I, II, III, or IV)	Shear on the effective area		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed <u>0.36</u> times yield strength of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
Partial joint penetration groove welds (Joint Class IV or V)	Compression normal to effective area	Joint not designed to bear	0.45 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.55 times yield strength of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
		Joint designed to bear	Same as base metal	
	Tension or compression parallel to the axis of the weld ⁽³⁾		Same as base metal	
	Shear parallel to axis of metal		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed <u>0.36</u> times yield strength of base metal.	
	Tension normal to effective area		0.27 times nominal tensile strength of weld metal, except tensile stress on base metal shall not exceed <u>0.55</u> times yield strength of base metal.	

NOTE: Underlined values are revised. This is a partial representation of Table 2.

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Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment

1. Scope and General Provisions

1.1 Scope. This specification applies to the welding of all principal structural weldments and all primary welds used in the manufacture of cranes for industrial, mill, power house, and nuclear facilities. Furthermore, the specification applies to other overhead material handling machinery and equipment that support and transport loads within the design rating, vertically or horizontally, during normal operations, and, when agreed upon between the Owner and Manufacturer, to loading caused by abnormal operations or environmental events, such as seismic loading.

Secondary welds that will be subjected to tensile stresses of less than 5000 psi [34.5 MPa] need only meet the requirements of Section 7, Workmanship, and Section 10, Weld Quality and Inspection. The engineering drawings shall specify the joint detail, type, and size of weld. This specification is not intended for application to construction- or crawler-type cranes. For the welding of rails, refer to AWS D15.2, *Recommended Practice for the Welding of Rails and Related Rail Components for Use by Rail Vehicles*.

All provisions of this specification are equally applicable to the strengthening and repairing of existing overhead cranes and material handling equipment as described above.

This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system shall be used independently of the other without combining in any way. The specification with the designation D14.1 uses U.S. Customary Units. The specification D14.1M uses SI Units. The latter are shown in appropriate columns in tables and figures or within brackets []. Detailed dimensions on figures are in inches. A separate tabular form that relates the U.S. Customary Units with SI Units may be used in tables and figures.

Safety and health issues and concerns are beyond the scope of this standard, and therefore are not fully addressed herein. Safety and health information is avail-

able from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* and applicable federal and state regulations. Some other sources of safety and health information can be found in Annex D.

1.2 General Provisions. The Manufacturer's¹ adherence to this specification shall include responsibility for the following:

- (1) Welding, as defined in the Scope, in accordance with this specification;
- (2) Producing the welds designated on the drawings by appropriate welding symbols and notes containing sufficient detail to show joint preparations compatible with the designated welding processes;
- (3) Providing written welding procedures;
- (4) Recording results of all procedure and welder qualification tests;
- (5) Controlling the use of designated base metals and consumables; and
- (6) Inspecting the welds to the requirements of this specification.

1.2.1 Acceptance. Acceptance shall be as agreed upon between the Manufacturer and the Owner (purchaser). The fundamental premise of this specification is to provide general stipulations applicable to most situations. Acceptance criteria for production welds different from those stated in this specification may be used for a particular application, provided they are suitably documented by the proposer and approved by the Engineer. These alternate acceptance criteria can 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.

1. Manufacturer refers to the organization responsible for the performance of the work covered by this specification (see definition in Section 3).

1.2.2 Welding Symbols. Welding symbols used on shop drawings shall be those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special requirements shall be fully explained by added notes or details.

1.2.3 Mechanical Testing of Welds. Methods used in the mechanical testing of welds shall be those described in AWS B4.0 or B4.0M, *Standard Methods for Mechanical Testing of Welds*. When there is a conflict between this specification and AWS B4.0 or B4.0M, the provisions of this specification shall govern.

1.2.4 Filler Metal Specifications. All welding consumables shall meet the requirements of the applicable AWS filler metal specifications, except for specific requirements of this specification.

2. Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 American Welding Society (AWS) Standards²

- (1) AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*
- (2) AWS A3.0, *Standard Welding Terms and Definitions*
- (3) AWS A5.01, *Filler Metal Procurement Guidelines*
- (4) AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*
- (5) AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*
- (6) AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*
- (7) AWS A5.18, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*
- (8) AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*
- (9) AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
- (10) AWS A5.25, *Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding*
- (11) AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes for Electrogas Welding*
- (12) AWS A5.28, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*

2. AWS standards are published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

(13) AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*

(14) AWS A5.32, *Specification for Welding Shielding Gases*

(15) AWS B2.1, *Specification for Welding Procedure and Performance Qualification*

(16) AWS B4.0, *Standard Methods for Mechanical Testing of Welds* (U.S. Customary Units only)

(17) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds* (SI Units only)

(18) AWS C4.1, *Oxygen Cutting Surface Roughness Gauge*

(19) AWS QC1, *Standard for AWS Certification of Welding Inspectors*

2.2 American Society of Mechanical Engineers (ASME) Standards³

(1) ASME B 46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*

2.3 American Society for Testing and Materials (ASTM) Standards⁴

- (1) ASTM E 23, *Test Methods for Notched Bar Impact Testing of Metallic Materials*
- (2) ASTM E 94, *Standard Guide for Radiographic Examination*
- (3) ASTM E 164, *Practice for Ultrasonic Contact Examination of Weldments*
- (4) ASTM E 165, *Test Method for Liquid Penetrant Examination*
- (5) ASTM E 317, *Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems without the Use of Electronic Measurement Instruments*
- (6) ASTM A 435, *Specification for Straight-Beam Ultrasonic Examination of Steel Plates*
- (7) ASTM E 709, *Guide for Magnetic Particle Examination*
- (8) ASTM E 1316, *Standard Terminology for Non-destructive Examinations*

2.4 American Society for Nondestructive Testing (ASNT) Standards⁵

(1) SNT-TC-1A, *Recommended Practice No. SNT-TC-1A*

3. ASME standards are published by the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10017.

4. ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

5. ASNT standards are published by the American Society for Nondestructive Testing, Inc., P.O. Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518.

3. Definitions

The terms that follow are defined for the purposes of this specification. Other terms used in this specification are defined in AWS A3.0, *Standard Welding Terms and Definitions*.

Engineer. The responsible technical authority.

Manufacturer. The organization responsible for the performance of the work covered by this specification.

Owner. The person, company, or agency that purchases the equipment.

principal structural weldments. Those weldments that carry the main working loads during normal operations.

primary welds. Welds, the failure of which would result in (1) a carried load being dropped in excess of 4 in. [100 mm] or (2) an increase of stress beyond the allowable stress limits, as defined in Section 5, Allowable Stresses, in other welds or base metal. Any welds subject to only compressive stresses are not considered primary.

secondary welds. Welds not covered by the requirements of primary welds; secondary welds shall be noted as such on the drawings. Secondary welds only need to meet the requirements of Section 7, Workmanship, and Section 10, Weld Quality and Inspection.

tensile strength of the weld metal. The minimum tensile strength specified for the filler metal classification as published in the applicable filler metal specification.

4. Base Metals

4.1 Specifications. All ferrous and nonferrous metals, structural steel, steel castings, forgings, and any other metals used in the fabrication by welding of all components for overhead material handling machinery and equipment shall be identified by a specification. Common industry-wide specifications from organizations such as the American Society for Testing and Materials (ASTM), the American Iron and Steel Institute (AISI), the American Petroleum Institute (API), and the Society of Automotive Engineers (SAE), or written proprietary specifications developed by an individual equipment manufacturer, may be used.

4.2 Proprietary Base Metals. The weldability of and the procedure for welding (1) base metals covered by a specific equipment manufacturer's proprietary specifica-

tion, (2) steels not listed in Table 1, or (3) base metals not covered by accepted national specifications, shall be established by qualification, except as provided for in 4.4.

4.3 Tensile and Yield Strengths of a Base Metal. The minimum specified tensile and yield strengths for base metals are listed in Table 1. When Table 1 or the base metal specification does not establish the minimum tensile and yield strengths for acceptance, the Manufacturer shall establish the minimum tensile and yield strengths for design purposes. The documentation may be in the form of references to published data or compilations of test data. In the establishment of minimum tensile and yield strengths for design purposes, due regard shall be made for size effects, thermal or mechanical treatments, and the effect of the welding process on the base material in the heat-affected zone (HAZ).

4.4 Weldability. Steel base metals listed in Table 1 (including combinations thereof) shall be considered weldable without separate qualification, except base metals with a minimum yield strength of 90 ksi [620 MPa] or higher (see 9.1.1). The steels listed in Table 1 are classified into groups according to the degree of difficulty encountered during welding related to chemical composition, rolling condition, or heat treatment. Steels in the higher classifications require greater precautions during welding, such as preheat, limited heat input, or other precautions to ensure sound weldments. When welding combinations of these steels, precautions related to the steel with the higher classification number should be observed.

4.5 Quenched and Tempered Steels. Quenched and tempered steels may be used where design and other factors permit or require them. Their use shall be compatible with their mechanical properties and the design requirements as documented by the equipment manufacturer. Documentation may be in either of two forms:

- (1) An acceptable service history proving reliability, or
- (2) Welding procedure development and qualification data establishing the expected service life of the steel according to accepted engineering criteria for the application.

4.6 Nonferrous Metals. Nonferrous metals that meet the requirements of an accepted specification, as described in 4.1, may be used in the fabrication of components by welding. Proper documentation in the form of qualified welding procedures and other experimental data shall be provided by the Manufacturer using such metals.

Table 1
Weldability Classification of Steels

Material Class ⁽¹⁾	Steel Specification and Grade			Minimum or Range of Tensile Strength ksi [MPa]	Minimum Yield Strength ksi [MPa]
I	AISI/SAE			See Notes (2), (3), & (4)	See Notes (2) & (4)
	1005	Sheet, Plate	Hot Rolled	42 [290]	23.5 [162]
	1006	Bar or Casting	Hot Rolled	43 [295]	24 [165]
	1008	(Usually specified by composition only—without mechanical properties)	Hot Rolled	44 [305]	24.5 [170]
	1010		Hot Rolled	47 [325]	26 [180]
	1012		Hot Rolled	48 [330]	26.5 [183]
	1013		Hot Rolled	49 [338]	27 [186]
	1015		Hot Rolled	50 [345]	27.5 [190]
	1016		Hot Rolled	55 [380]	30 [205]
	1017		Hot Rolled	53 [365]	29 [200]
	1018		Hot Rolled	58 [400]	32 [220]
	1020		Hot Rolled	55 [380]	30 [205]
	1021		Hot Rolled	61 [420]	33 [230]
	1025		Hot Rolled	58 [400]	32 [220]
II	ASTM			See Note (5)	See Note (5)
	A27	Grade N-1 Castings Chemistry Only		Not Specified—See 4.3	Not Specified—See 4.3
		Grade 60-30		60 [415]	30 [205]
		Grade 65-35		65 [450]	35 [240]
	A36	Shapes, Plate, Bar		58–80 [400–550]	36 [250]
	A53	Grade B Pipe		60 [415]	35 [240]
	A106	Grade B Pipe		60 [415]	35 [240]
	A131	Grade A, B, D, CS, DS		58–75 [400–520]	34 [235]
		Ship Building Shapes, Plate, Bars			
	A139	Grade A Pipe		48 [330]	30 [205]
		Grade B		60 [415]	35 [240]
		Grade C		60 [415]	42 [290]
		Grade D		60 [415]	46 [315]
		Grade E		66 [455]	52 [360]
	A283	Grade C, ≤ 2 in. [50 mm] Plate		55–75 [380–515]	30 [205]
		Grade D, ≤ 1 in. [25 mm]		60–80 [415–550]	33 [230]
	A381	Grade Y35 Pipe		60 [415]	35 [240]
	A500	Grade A Tubing		45 [310]	33 [288]
		Grade B		58 [400]	42 [290]
	A501	Tubing		58 [400]	36 [250]
	A515	Grade 55, ≤ 8 in. [200 mm] Plate <i>Grade no longer listed in A515-2003</i>		55–75 [380–515]	30 [205]
	A516	Grade 55, ≤ 8 in. [200 mm] Plate		55–75 [380–515]	30 [205]
		Grade 60, ≤ 8 in. [200 mm] Plate		60–80 [415–550]	32 [220]
	A524	Grade I, ≤ 0.375 in. [10 mm] Pipe		60–85 [414–586]	35 [240]
		Grade II, > 0.375 in. [10 mm] Pipe		55–80 [380–550]	30 [205]
	A570— <i>Withdrawn in 2000</i>	Grade 36 Sheet, ≤ 0.229 in. [6 mm]		53 [365]	36 [250]
	A573	Grade 58 Plate, ≤ 1.5 in. [40 mm]		58–71 [400–490]	32 [220]
		Grade 65 Plate, ≤ 1.5 in. [40 mm]		65–77 [450–530]	35 [240]
	A662	Grade A Plate, ≤ 1.5 in. [40 mm]		58–78 [400–540]	40 [275]
		Grade B Plate, ≤ 1.5 in. [40 mm]		65–85 [450–585]	40 [275]
	A709	Grade 36 Shapes, Plate, Bar		58–80 [400–550]	36 [250]
	API ⁽⁶⁾				
	5L	Grade B Pipe		60 [410]	35 [240]

(continued)

Table 1 (Continued)
Weldability Classification of Steels

Material Class ⁽¹⁾	Steel Specification and Grade		Minimum or Range of Tensile Strength ksi [MPa]	Minimum Yield Strength ksi [MPa]
III	AISI/SAE 1030	Sheet, Plate, Bar, or Casting (Usually specified by composition only—without mechanical properties)	See Notes (2) & (7) 68 [470]	See Notes (2) & (4) 37.5 [260]
	ASTM A27	Grade N-2 Castings Heat Treated	See Note (5) Not Specified—See 4.3	See Note (5) Not Specified—See 4.3
		Grade 70-36	70 [485]	36 [250]
		Grade 70-40	70 [485]	40 [275]
	A106	Grade C Pipe	70 [485]	40 [275]
	A131	Grade AH32, DH32, EH32	64–85 [440–590]	46 [315]
		AH36, DH36, EH36	71–90 [490–620]	51 [355]
		Ship Building Shapes, Plate, Bars		
	A283	Grade C, > 2 in. [50 mm] to ≤ 4 in. [100 mm] Plate	55–75 [380–515]	30 [205]
		Grade D, > 2 in. [50 mm] to ≤ 4 in. [100 mm] Plate	60–80 [415–550]	33 [230]
	A500	Grade C Round Tubing	62 [427]	46 [317]
		Grade C Shaped Tubing	62 [427]	50 [345]
	A515	Grade 60, ≤ 2 in. [50 mm] Plate	60–80 [415–550]	32 [220]
		Grade 65, ≤ 2 in. [50 mm] Plate	65–85 [450–585]	35 [240]
	A516	Grade 60, ≤ 2 in. [50 mm] Plate	60–80 [415–550]	32 [220]
		Grade 65, ≤ 2 in. [50 mm] Plate	65–85 [450–585]	35 [240]
	A537	Class 1, ≤ 2.5 in. [65 mm] Plate	70–90 [485–620]	50 [345]
	A572	Shapes, Plate, Sheet, & Bar HSLA Cb-V Steels		
		Grade 42, ≤ 2 in. [50 mm]	60 [415]	42 [290]
		Grade 50, ≤ 0.5 in. [13 mm]	65 [450]	50 [345]
		Grade 50, > 0.5 [13 mm] to ≤ 2 in. [50 mm]		
		Type 1 or 2 Killed Steel	65 [450]	50 [345]
	A588	Grades A, B, C, & K Shapes, Plate, & Bar ≤ 4 in. [100 mm]	70 [480]	50 [340]
	A606	Type 2 & 4 Sheet ≤ 0.180 in. [5 mm] Weathering Steel—As Rolled Cut Lengths All Other Coils & Cut Lengths	70 [480] 65 [450]	50 [340] 45 [310]
	A607— <i>Withdrawn in 2000</i>	Type 1 Class 2 Sheet ≤ 0.180 in. [5 mm] HSLA Non-Weathering	Grade 45 Grade 50 60 [410] 65 [450]	45 [310] 50 [340]
	A618	HSLA Structural Tubing Wall ≤ 3/4 in. [19 mm] Wall > 3/4 in. [19 mm] to ≤ 1.5 in. [38 mm]	Grade II Grade II Grade III 70 [485] 67 [460] 65 [450]	50 [345] 46 [315] 50 [345]
	A633	HSLA Normalized Structural Plate, ≤ 4 in. [100 mm] Plate, ≤ 2.5 in. [65 mm] Plate, > 2.5 in. [65 mm] to ≤ 4 in. [100 mm]	Grade A Grades C & D Grades C & D 63–83 [430–570] 70–90 [485–620] 65–85 [450–590]	42 [290] 50 [345] 46 [315]
	A662	Grade B PV Plate Moderate & Low Temp. Applications	65–85 [450–585]	40 [275]

(continued)

Table 1 (Continued)
Weldability Classification of Steels

Material Class ⁽¹⁾	Steel Specification and Grade			Minimum or Range of Tensile Strength ksi [MPa]	Minimum Yield Strength ksi [MPa]
III (Cont'd)	A709	Structural Shapes, Plate, Bars—Bridges	Grade 50 Grade 50W		
		Non-Weathering		65 [450]	50 [345]
	API ⁽⁶⁾ 5LX	Weathering Grade 42 High-Strength Pipe		70 [485] 60 [410]	50 [345] 42 [290]
IV	ASTM A283	Grade C, > 4 in. [100 mm] to ≤ 12 in. [300 mm] Plate		See Note (5) 55–75 [380–515]	See Note (5) 30 [205]
		Grade D, > 4 in. [100 mm] to ≤ 8 in. [200 mm] Plate		60–80 [415–550]	33 [230]
	A515	Grade 60, > 2 in. [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65, > 2 in. [50 mm] Plate		65–85 [450–585]	35 [240]
	A516	Grade 60, > 2 in. [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65, > 2 in. [50 mm] Plate		65–85 [450–585]	35 [240]
	A537 ⁽⁸⁾	Class 2, ≤ 2.5 in. [65 mm] Plate		80–100 [550–690]	60 [415]
	A572	Shapes, Plate, Sheet & Bar			
		Grade 60, ≤ 1.25 in. [32 mm]		75 [520]	60 [415]
		Grade 65, ≤ 1.25 in. [32 mm]		80 [550]	65 [450]
	A607— <i>Withdrawn in 2000</i>	HSLA Non-Weathering	Grade 60 Grade 65	75 [520] 80 [550]	60 [410] 65 [450]
	A633 ⁽⁸⁾	HSLA Normalized Structural Plate	Grade E Grade E		
		≤ 4 in. [100 mm] > 4 in. [100 mm] to ≤ 6 in. [150 mm]		80–100 [550–690] 80–100 [550–690]	60 [415] 55 [380]
V ⁽⁸⁾	ASTM			See Note (5)	See Note (5)
	A514	HSLA Q&T Plate, ≤ 2.5 in. [65 mm]		110–130 [760–895]	100 [690]
		> 2.5 in. [65 mm] to ≤ 6 in. [150 mm]		100–130 [690–895]	90 [620]
	A517	HSLA Q&T PV Plate, ≤ 2.5 in. [65 mm]		115–135 [795–930]	100 [690]
		> 2.5 in. [65 mm] to ≤ 6 in. [150 mm]		105–135 [725–930]	90 [620]
	A709	HSLA Q&T Plate, ≤ 2.5 in. [65 mm]		110–130 [760–895]	100 [690]
		Grades 100 & 100 W, > 2.5 in. [65 mm] to ≤ 4 in. [100 mm]		100–130 [690–895]	90 [620]

Notes:

- (1) Material Class I steels are the most weldable, and Material Class V steel the most difficult to weld of the steels listed.
- (2) All tensile and yield strength values for AISI/SAE steels are *estimated minimum values*.
- (3) Hardness is not to exceed 160 Brinell for the AISI/SAE steels listed under Weldability Class I. These same AISI/SAE steels should be placed in a higher Weldability Class when hardness exceeds 160 Brinell (ultimate strength greater than 80 ksi [550 MPa]).
- (4) See 4.3 for tensile-yield property determination for AISI/SAE steels.
- (5) All tensile and yield strength values listed for ASTM steels are specified by the ASTM Standard.
- (6) API = American Petroleum Institute.
- (7) Hardness is not to exceed 180 Brinell for the AISI/SAE steel listed under Weldability Class III. This same AISI/SAE steel should be placed in a high Weldability Class when hardness exceeds 180 Brinell (ultimate strength greater than 90 ksi [620 MPa]).
- (8) Qualification is required due to the upper limit of the tensile strength range or the entire range exceeding 90 ksi [620 MPa].

5. Allowable Stresses

5.1 General. The allowable stresses for base metal and weld metal and the type of fatigue analysis to be used shall conform to the requirements of the design specifications from organizations such as the American Institute of Steel Construction (AISC), the American Society of Mechanical Engineers (ASME), the Crane Manufacturers Association of America (CMAA), or the Monorail Manufacturers Association (MMA). In the absence of other requirements, the allowable stresses in the base metal and the weld metal shall conform to the following requirements.

5.1.1 Base Metal. Unless otherwise specified by the design specifications in 5.1, the allowable tensile or compressive stress in the base metal shall be 50% of the yield strength, and the allowable shear stress in the base metal shall be 40% of the yield strength for members not controlled by buckling.

5.1.2 Weld Metal. Allowable stresses in the weld metal shall conform to Table 2.

5.2 Fatigue. The maximum stress in welded joints subject to repeated stress fluctuations or reversals shall not exceed:

- (1) The allowable tensile or compressive stress in 5.1; or
- (2) The allowable fatigue stress as defined in the design specifications indicated in 5.1.

In the absence of other requirements, fatigue loading shall be addressed as follows:

5.2.1 Members subject to repeated loading shall be designed so that the maximum stress does not exceed that allowed by 5.1 and the stress range does not exceed the value given in Table 3 for the applicable stress category and nominal number of loading cycles. Stress categories for weld joint configurations are described in Table 4 and illustrated in Figure 1.

5.2.2 The stress range is the maximum stress minus the minimum stress. The minimum stress is considered negative if it is opposite in direction to the maximum stress. The nominal number of loading cycles shall be the number defined in the design specification for the duty cycle class or determined by the Engineer for the duty cycle and life specified in the purchase contract.

6. Weld Joint Design

6.1 General Requirements. Complete information regarding location, type, size, and extent of all welds and welded joints shall be shown on the drawings. Any special inspection requirements shall be noted on the draw-

ings or other appropriate documents. In general, design details should minimize restraint, avoid undue concentration of welding, and afford ample access for depositing the weld metal.

6.2 Groove Welds

6.2.1 The effective area of a weld shall be the effective weld length multiplied by the effective throat.

6.2.2 The effective length of any groove weld is the length throughout which the correctly proportioned weld cross section exists.

6.2.3 The effective throat is the minimum distance from the root of a weld to its face, less any reinforcement. For a complete joint penetration weld, this shall be the nominal thickness of the thinner part joined.

6.2.4 The effective throat of a partial penetration weld is joint penetration below the surface of the member (see Table 5 for the minimum effective throat required).

Shop or working drawings shall specify the groove depths (S) applicable for the weld size (E) required for the welding process and position of welding to be used.

6.2.5 Groove welds made from one side only, except in secondary members, are prohibited unless they are completely fused to a backing strip, or qualified in accordance with the requirements of this specification (see 6.9).

6.2.6 A complete joint penetration groove weld is one that has been welded from both sides, or from one side, in which the weld metal completely fills the groove and is fused to the base metal throughout its total thickness (see 6.9).

6.3 Intermittent Groove Welds. Intermittent groove welds are prohibited, except in secondary members.

6.4 Fillet Welds (See Figures 2 and 3)

6.4.1 The minimum fillet weld size shall be as shown in Table 6, except where fillet welds are used to reinforce groove welds (see Figure 3).

6.4.2 The maximum fillet weld size permitted along the edges of members shall be:

- (1) The thickness of the base metal when the metal is less than 1/4 in. [6 mm] thick; or
- (2) The thickness of the base metal less 1/16 in. [2 mm] when the metal is 1/4 in. [6 mm] or more in thickness, unless the weld is designated on the drawing to be built out to obtain full throat thickness.

6.4.3 The effective weld area shall be the effective weld length multiplied by the effective throat. The shear stress in a fillet weld shall be considered as applied to this effective area regardless of the direction of applied

Table 2
Allowable Stress in Weld Metal

Type of Weld	Stress in Weld ⁽¹⁾		Allowable Stress	Required Weld Strength Level ⁽²⁾
Complete joint penetration groove welds (Joint Class I, II, III, or IV)	Tension normal to the effective area		Same as base metal	Matching weld metal shall be used.
	Compression normal to the effective area		Same as base metal	Weld metal with a strength level equal to or one classification (10 ksi [69 MPa]) less than matching weld metal may be used.
	Tension or compression parallel to the axis of the weld		Same as base metal	Weld metal with a strength level equal to or less than matching weld metal may be used.
	Shear on the effective area		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.36 times yield strength of base metal.	
Partial joint penetration groove welds (Joint Class IV or V)	Compression normal to effective area	Joint not designed to bear	0.45 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.55 times yield strength of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
		Joint designed to bear	Same as base metal	
	Tension or compression parallel to the axis of the weld ⁽³⁾		Same as base metal	
	Shear parallel to axis of metal		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.36 times yield strength of base metal.	
	Tension normal to effective area		0.27 times nominal tensile strength of weld metal, except tensile stress on base metal shall not exceed 0.55 times yield strength of base metal.	
Fillet welds (Joint Class IV, V, or VI)	Shear on effective area		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.36 times yield strength of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
	Tension or compression parallel to axis of weld ⁽³⁾		Same as base metal	
Plug and slot welds (Joint Class V or VI)	Shear parallel to faying surfaces (on effective area)		0.27 times nominal tensile strength of weld metal, except shear stress on base metal shall not exceed 0.36 times yield strength of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.

Notes:

(1) For definitions of effective area, see 6.2, 6.4, and 6.7.

(2) For matching weld metal, see Table 9.

(3) Fillet welds and partial joint penetration groove welds joining the component elements of built-up members, such as flange-to-web connections, may be designed without regard to the tensile or compressive stress in these elements parallel to the axis of the welds.

Table 3
Allowable Stress Range⁽¹⁾

Stress Category (From Table 4)	Allowable Stress Range, ksi [MPa] per Nominal Number of Loading Cycles			
	20 000 to 100 000 ⁽²⁾	100 000 to 500 000	500 000 to 2 000 000	Over 2 000 000
A	63 [435]	37 [255]	24 [165]	24 [165]
B	49 [340]	29 [200]	18 [125]	16 [110]
B'	39 [270]	23 [160]	15 [100]	12 [80]
C	35 [240]	21 [145]	13 [90]	10 [70] ⁽³⁾
D	28 [190]	16 [110]	10 [70]	7 [50]
E	22 [150]	13 [90]	8 [55]	5 [34]
E'	16 [110]	9 [60]	6 [40]	3 [20]
F	15 [100]	12 [80]	9 [60]	8 [55]

Notes:

- (1) Stress range is defined as the algebraic difference between the maximum stress and the minimum stress. Tension stress is considered to have the opposite algebraic sign from the compression stress.
 (2) For less than 20 000 loading cycles, use the allowable stress for static loading in accordance with 5.1.1.
 (3) Flexural stress range of 12 ksi [80 MPa] permitted at toe of stiffener welds or flanges.

load. The effective length of a fillet weld shall be the overall length of the full size fillet, including boxing (end returns).

6.4.4 Fillet welds terminated at ends or sides of parts or members shall, wherever practicable, be returned continuously around the corners for a distance at least twice the nominal size of the weld where such return can be made in the same plane. Fillet welds deposited on the opposite sides of a common plane of contact between two parts shall be interrupted at a corner common to both welds.

Unless otherwise specified in the contract documents, fillet welds connecting attachments shall start or terminate a distance approximately equal to the weld size from the end of the joint. For girder stiffeners, the welds joining the stiffeners to the web shall start or terminate a distance approximately equal to two times the weld size from the end of the joint.

6.4.5 Fillet welds in holes or slots may be used to transmit shear in lap joints to prevent the buckling or separation of lapped parts, or to join components of built up members. Fillet welds in holes or slots are not to be considered plug or slot welds.

6.4.6 Fillet welds shall not be used in skewed T-joints that have an included angle of less than 60° or more than 135°. The edge of the abutting member shall be beveled, when necessary, to limit the root opening to 1/8 in. [3 mm] maximum.

6.5 Intermittent Fillet Welds

6.5.1 The length of any segment of intermittent fillet welds shall not be less than four times the weld size, with a minimum of 2 in. [50 mm]. Welds shall be made on both sides of the joint for at least 25% of its length. Maximum spacing permitted between welds shall be 12 in. [300 mm].

6.5.2 Intermittent fillet welds may be used to carry calculated loads except as prohibited in 6.5.4.

6.5.3 Intermittent fillet welds shall be no less than 2 in. [50 mm] in length at each end of the joint. (Note restriction in 6.4.4.)

6.5.4 Intermittent fillet welds on primary tension members are prohibited.

6.6 Staggered Intermittent Fillet Welds (See Figure 4)

6.6.1 When staggered intermittent fillet welds are used, the clear spacing shall be considered the distance between two consecutive welds on the same side of the plate.

6.6.2 When the total aggregate length of the staggered intermittent fillet weld is 90% or more of the joint length, any odd number of weld segments may be used provided:

- (1) Welds are placed at each end of the joint on one side, and
- (2) Clear spacing does not exceed 6 in. [150 mm].

6.6.3 Intermittent staggered fillet welds on primary tension members are prohibited.

Table 4
Stress Categories to Determine Allowable Stress Range

General Condition	Situation	Kind of Stress ⁽¹⁾	Stress Category (see Table 3)	Illustrative Example Numbers (See Figure 1) ⁽²⁾
Plain Material	Base metal with rolled or cleaned surface. Flame-cut edges with ANSI smoothness of 1000 or less.	T or Rev.	A	1, 2
Built-up Members	Base metal and weld metal in members without attachments, built-up plates, or shapes connected by continuous fillet welds parallel to the direction of applied stress.	T or Rev.	B	3, 4, 5, 6
	Base metal and weld metal in members without attachments, built-up plates, or shapes connected by complete joint penetration groove welds with backing bars not removed, or by partial joint penetration groove welds parallel to the direction of applied stress.	T or Rev.	B'	3, 4, 5, 6
	Base metal at toe of welds on girder webs or flanges adjacent to welded transverse stiffeners.	T or Rev.	C	7
	Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends or wider than flange with welds across the ends. Flange thickness ≤ 0.8 in. [20 mm] Flange thickness > 0.8 in. [20 mm]	T or Rev. T or Rev.	E E'	5 5
	Base metal at end of partial length welded cover plates wider than the flange without welds across the ends.		E'	5
Groove Welds	Base metal and weld metal at complete joint penetration groove welded splices of parts of similar cross section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of Section 10.	T or Rev.	B	10, 11
	Base metal and weld metal at complete joint penetration groove welded splices at transitions in width or thickness, with welds ground to provide slopes no steeper than 1 to 2-1/2 with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection in accordance with the requirements of Section 10. A514 base metal Other base metals	T or Rev. T or Rev.	B' B	12, 13 12, 13
	Base metal and weld metal at complete joint penetration groove welded splices, with or without transitions having slopes no greater than 1 to 2-1/2 when reinforcement is not removed but weld soundness is established by radiographic or ultrasonic inspection in accordance with the requirements of Section 10.	T or Rev.	C	10, 11, 12, 13
Partial Joint Penetration Groove Welds	Weld metal of partial joint penetration transverse groove welds, based on effective throat area of the weld or welds	T or Rev.	F ⁽³⁾	16

(continued)

Table 4 (Continued)
Stress Categories to Determine Allowable Stress Range

General Condition	Situation	Kind of Stress ⁽¹⁾	Stress Category (see Table 3)	Illustrative Example Numbers (See Figure 1) ⁽²⁾
Fillet-Welded Connections	Base metal at intermittent fillet welds	T or Rev.	E	
	Base metal at junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the member so as to balance weld stresses. b ≤ 1 in. [25 mm] b > 1 in. [25 mm]	T or Rev. T or Rev.	E E'	17, 18 17, 18
	Base metal at members connected with transverse fillet welds. b ≤ 1 in. [25 mm] b > 1 in. [25 mm]	T or Rev.	C ⁽³⁾	20, 21
Fillet Welds	Weld metal of continuous or intermittent longitudinal or transverse fillet welds.	S	F ⁽³⁾	15, 17, 18, 20, 21
Plug or Slot Welds	Base metal at plug or slot welds.	T or Rev.	E	27
	Shear on plug or slot welds.	S	F	27
Mechanically Fastened Connections	Base metal at cross section of high-strength bolted slip-critical connections, except axially loaded joints which induce out-of-plane bending in connected material.	T or Rev.	B	8
	Base metal at net section of other mechanically fastened joints.	T or Rev.	D	8, 9
	Base metal at net section of fully tensioned high-strength, bolted bearing connections.	T or Rev.	B	8, 9
Attachments	Base metal at details attached by complete joint penetration groove welds subject to longitudinal and/or transverse loading when the detail embodies a transition radius R with the weld termination ground smooth and for transverse loading, the weld soundness established by radiographic or ultrasonic inspection in accordance with Section 10.			
	Longitudinal Loading R > 24 in. [600 mm]	T or Rev.	B	14
	24 in. [600 mm] ≥ R > 6 in. [150 mm]	T or Rev.	C	14
	6 in. [150 mm] ≥ R > 2 in. [50 mm]	T or Rev.	D	14
	R ≤ 2 in. [50 mm]	T or Rev.	E	14
	Detail base metal for transverse loading: equal thickness and reinforcement removed. R > 24 in. [600 mm]	T or Rev.	B	14
	24 in. [600 mm] ≥ R > 6 in. [150 mm]	T or Rev.	C	14
	6 in. [150 mm] ≥ R > 2 in. [50 mm]	T or Rev.	D	14
	R ≤ 2 in. [50 mm]	T or Rev.	E	14, 15
	Detail base metal for transverse loading: equal thickness and reinforcement not removed. R > 24 in. [600 mm]	T or Rev.	C	14
	24 in. [600 mm] ≥ R > 6 in. [150 mm]	T or Rev.	C	14
	6 in. [150 mm] ≥ R > 2 in. [50 mm]	T or Rev.	D	14
	R ≤ 2 in. [50 mm]	T or Rev.	E	14, 15

(continued)

Table 4 (Continued)
Stress Categories to Determine Allowable Stress Range

General Condition	Situation	Kind of Stress ⁽¹⁾	Stress Category (see Table 3)	Illustrative Example Numbers (See Figure 1) ⁽²⁾
Attachments (Cont'd)	Detail base metal for transverse loading: unequal thickness and reinforcement removed. R > 2 in. [50 mm] R ≤ 2 in. [50 mm]	T or Rev. T or Rev.	D E	14 14, 15
	Detail base metal for transverse loading: unequal thickness and reinforcement not removed. All R	T or Rev.	E	14, 15
	Detail base metal for transverse loading. R > 24 in. [600 mm] 6 in. [150 mm] ≥ R > 2 in. [50 mm] R ≤ 2 in. [50 mm]	T or Rev. T or Rev. T or Rev.	C D E	19 19 19
	Base metal at detail attached by complete joint penetration groove welds subject to longitudinal loading. 2 in. [50 mm] < a ≤ 12b or 4 in. [100 mm] a > 12b or 4 in. [100 mm] when b ≤ 1 in. [25 mm] a > 12b or 4 in. [100 mm] when b > 1 in. [25 mm]	T or Rev. T or Rev. T or Rev.	D E E'	15 15 15
	Base metal at detail attached by fillet welds or partial joint penetration groove welds subject to longitudinal loading. a ≤ 2 in. [50 mm] 2 in. [50 mm] < a ≤ 12b or 4 in. [100 mm] a > 12b or 4 in. [100 mm] when b ≤ 1 in. [25 mm] a > 12b or 4 in. [100 mm] when b > 1 in. [25 mm]	T or Rev. T or Rev. T or Rev. T or Rev.	C D E E'	15, 23, 24, 25, 26 15, 23, 24, 26 15, 23, 24, 26 15, 23, 24, 26
	Base metal attached by fillet welds or partial joint penetration groove welds subjected to longitudinal loading when the weld termination embodies a transition radius with the weld termination ground smooth. R > 2 in. [50 mm] R ≤ 2 in. [50 mm]	T or Rev. T or Rev.	D E	19 19
	Fillet-welded attachments where the weld termination embodies a transition radius, weld termination ground smooth, and main material subject to longitudinal loading. R > 2 in. [50 mm] R ≤ 2 in. [50 mm]	T or Rev. T or Rev.	D E	19 19
	Base metal at stud-type shear connector attached by fillet weld or automatic end weld.	T or Rev.	C	22
	Shear stress on nominal area of stud-type shear connectors.	S	F	—

Notes:

- (1) "T" signifies range in tensile stress only; "Rev." signifies a range involving reversal of tensile or compressive stress; "S" signifies range in shear, including shear stress reversal.
- (2) These examples are provided as guidelines and are not intended to exclude other reasonably similar situations.
- (3) Allowable fatigue stress range for transverse partial joint penetration groove welds and transverse fillet welds is a function of the effective throat, depth of penetration, and plate thickness. See Frank and Fisher, *Journal of the Structural Division*, Vol. 105, N. ST9, Sept. 1979.

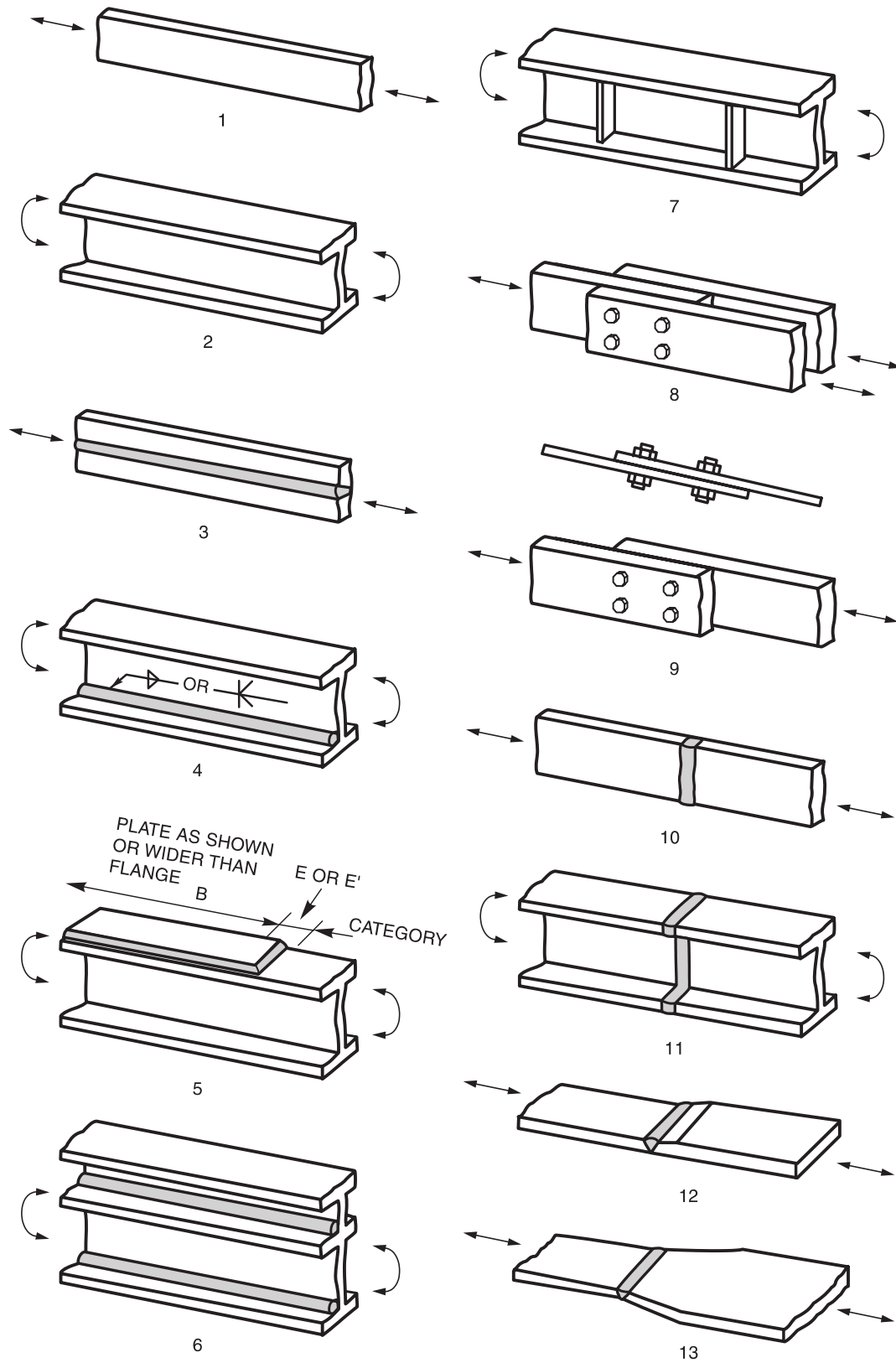


Figure 1—Illustrative Examples for Table 4

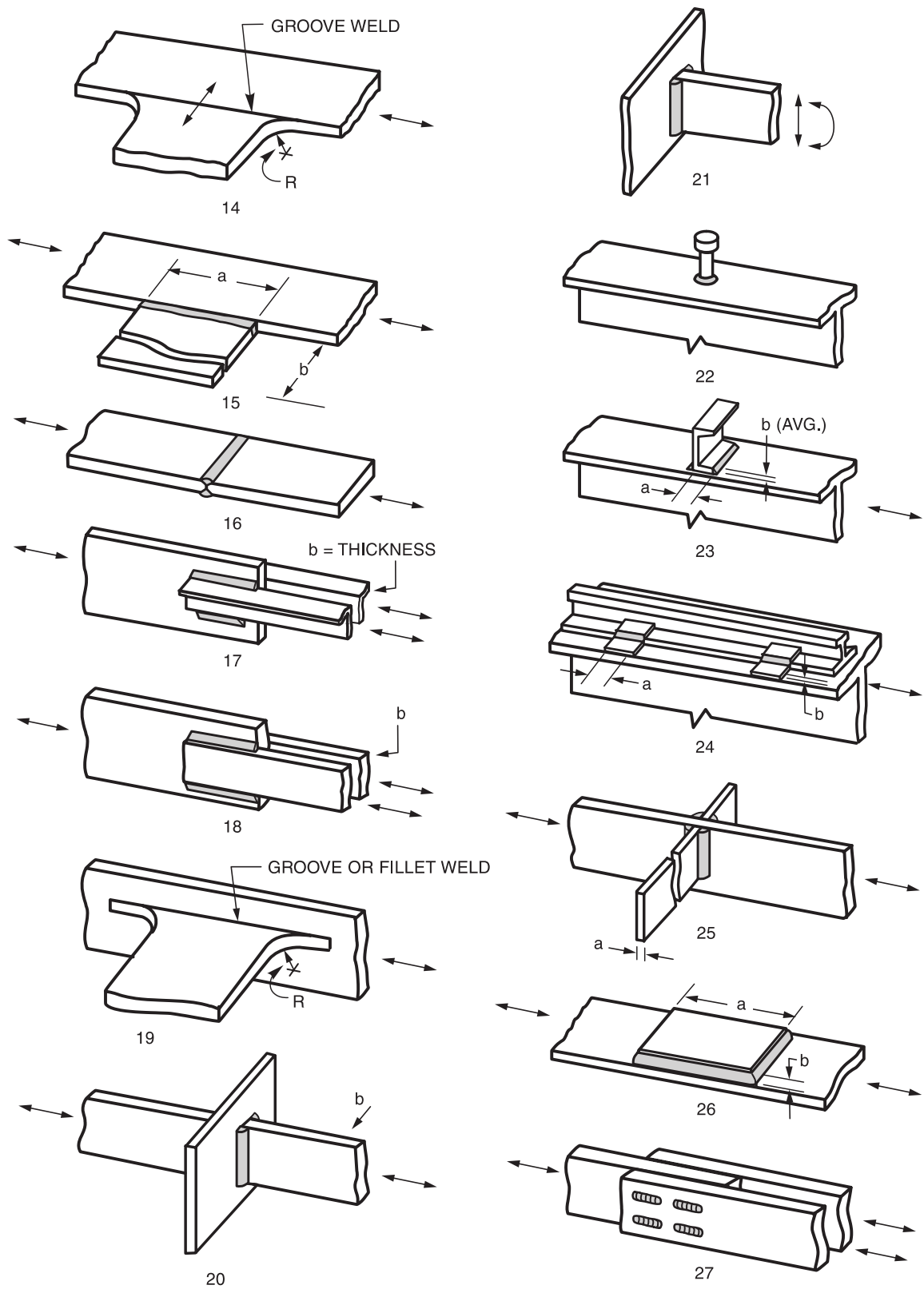
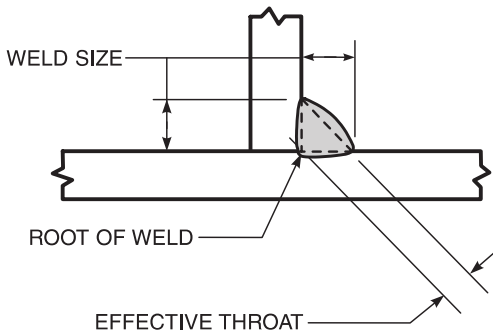


Figure 1 (Continued)—Illustrative Examples for Table 4

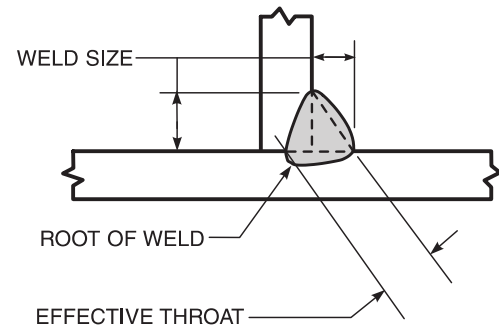
Table 5
Minimum Effective Throat for Partial Joint Penetration Groove Welds

Metal Thickness of Thicker Part Jointed		Minimum Effective Throat	
in.	mm	in.	mm
$\leq 1/4$	≤ 6	$1/8$	3
$> 1/4$ to $\leq 1/2$	> 6 to ≤ 13	$3/16$	5
$> 1/2$ to $\leq 3/4$	> 13 to ≤ 20	$1/4$	6
$> 3/4$ to $\leq 1-1/2$	> 20 to ≤ 40	$5/16$	8
$> 1-1/2$ to $\leq 2-1/4$	> 40 to ≤ 55	$3/8$	10
$> 2-1/4$ to ≤ 6	> 55 to ≤ 150	$1/2$	13
> 6	> 150	$5/8$	16

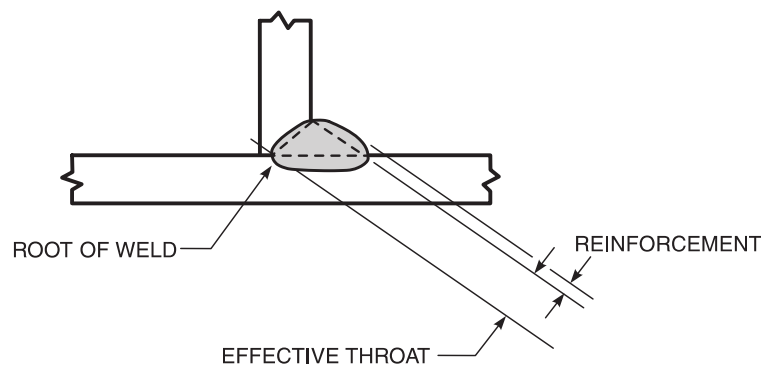
General Note: The effective throat does not need to exceed the thickness of the thinner part joined.



(A) STANDARD FILLET WELD

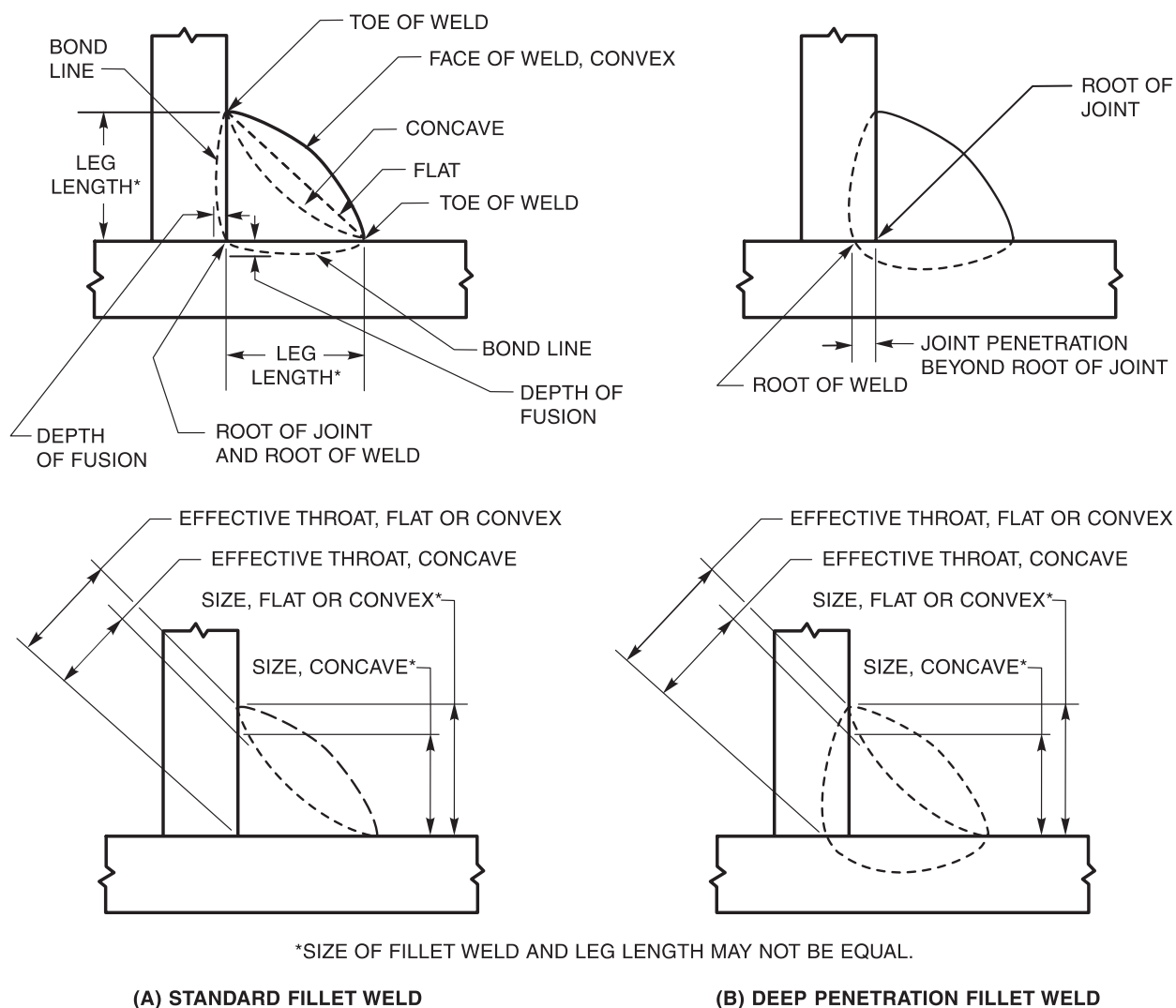


(B) DEEP PENETRATION FILLET WELD

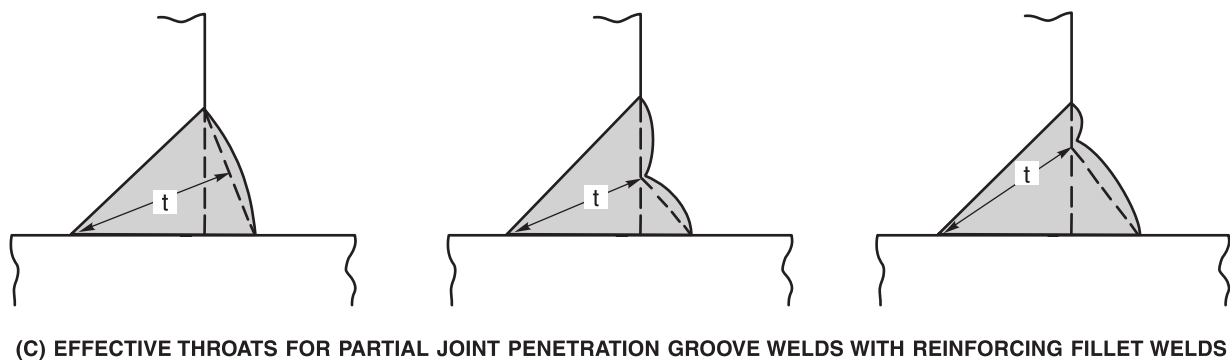


(C) ACTUAL THROAT OF A BEVEL GROOVE WELD REINFORCED WITH A FILLET WELD

Figure 2—Fillet and Combined Weld Dimension



Source: Figures 3(A) and 3(B) from AWS D14.5-97, Figures 2(A) and 2(B).



Source: Figure 3(C) from AWS A3.0:2001, Figure 25(I).

Figure 3—Size and Effective Throat Measurements for Fillet and Partial Penetration Groove Welds with Reinforcing Fillet Welds

Table 6
Minimum Fillet Weld Size

Metal Thickness of Thicker Part Joined		Weld Size ⁽¹⁾			
		Shielded Metal Arc Welding		Deep Penetration Process ⁽²⁾ for Single Pass Welds ⁽³⁾ Flat or Horizontal Positions	
in.	mm	in.	mm	in.	mm
≤ 1/4	≤ 6	1/8	3	1/8	3
> 1/4 to ≤ 1/2	> 6 to ≤ 13	3/16	5	1/8	3
> 1/2 to ≤ 3/4	> 13 to ≤ 20	1/4	6	3/16	5
> 3/4	> 20	5/16	8	1/4	6

Notes:

- (1) Weld size need not exceed thickness of thinner member. Minimum weld size for cyclically loaded structures is 3/16 in. [5 mm].
 (2) The intent of this table is not to establish the arc welding processes that provide deep penetration, but rather, to establish the typical allowable decrease of fillet weld size, provided the Manufacturer can demonstrate that the required effective throat can be obtained by the qualified welding procedure in accordance with Section 9.
 (3) Also applies to the root pass of a multiple pass weld.

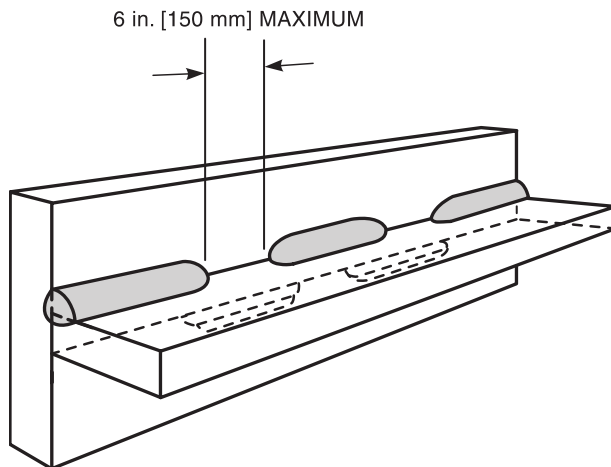


Figure 4—Staggered Intermittent Fillet Weld

6.7 Plug and Slot Welds

6.7.1 Plug or slot welds may be used to transmit shear loading in a lap joint to prevent buckling or separation of lapped parts, or to join component parts of built up members, except with quenched and tempered steels.

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

6.7.3 The minimum diameter of the hole for a plug weld shall be no less than the thickness of the part con-

taining it plus 5/16 in. [8 mm], preferably rounded to the next greater odd 1/16 in. [2 mm]. The maximum diameter shall equal the minimum diameter plus 1/8 in. [3 mm] or 2 1/4 times the thickness of the member, whichever is greater. The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

6.7.4 The length of the slot for a slot weld shall not exceed 10 times the thickness of the weld. The width of the slot shall not be less than the thickness of the part containing it plus 5/16 in. [8 mm], preferably rounded to the next greater odd 1/16 in. [2 mm]. The maximum width shall equal the minimum width plus 1/8 in. [3 mm] or 2 1/4 times the thickness of the member, whichever is greater. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

6.7.5 The depth of filling of plug or slot welds in metal 5/8 in. [16 mm] thick or less shall be equal to the thickness of the metal. In metal over 5/8 in. [16 mm] thick, it shall be at least one-half the thickness of the metal but no less than 5/8 in. [16 mm].

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

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

6.7.8 Plug and slot welds on primary tension members are prohibited.

6.8 Suggested Classification of Welded Joints

6.8.1 The classifications of welded joints for use in the design and manufacture of overhead material handling machinery and equipment are listed in 6.9 and illustrated in Figure 5.

6.8.2 These classifications can be used for qualification and examination of welded joints used in fabrication of equipment covered by this specification.

6.8.3 It is not the intent of these classifications to restrict the use of other proven methods and procedures that have achieved acceptable results, when agreed to in writing by the Manufacturer and Owner.

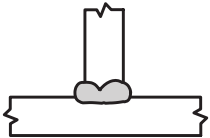
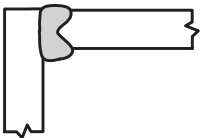
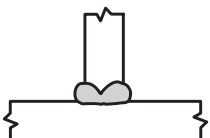
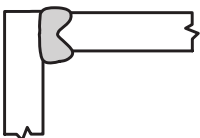
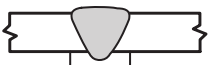
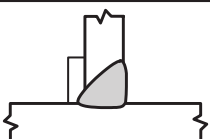
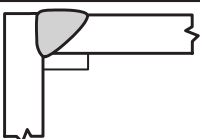
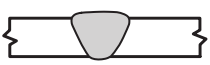
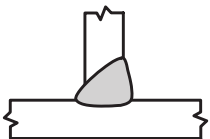
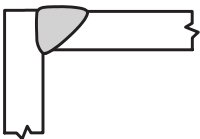
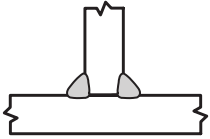
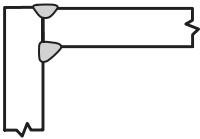
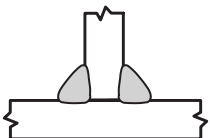
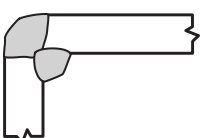
JOINT CLASS	CONFIGURATION OF WELDED JOINTS		
I			
II			
III			
			
IV			
			
			

Figure 5—Classification of Welded Joints

JOINT CLASS	CONFIGURATION OF WELDED JOINTS		
V			
VI			

General Note: Avoid loading the joint in the arrow direction.

Figure 5 (Continued)—Classification of Welded Joints

6.9 Weld Joint Classes

6.9.1 Joint Class I. Joints in this class are double-welded butt joints with complete joint penetration. The root of the first weld is chipped, gouged, or ground to sound metal before making the second weld, and the weld faces are ground or machined flush with the direction of metal removal parallel to the principle stress. Welded joints that are made using backing tape, fusible flux backing material, or a nonfusible backing bar, and are back welded to obtain a completely fused root, shall be qualified in accordance with Section 9, Qualification. Finished joints shall be nondestructively examined according to Section 10, Weld Quality and Inspection, and the results recorded.

6.9.2 Joint Class II. Joints in this class are double-welded butt, T-, and corner joints with complete joint penetration. The root of the first weld is chipped, gouged, or ground to sound metal before making the second weld. Welded joints that are made using backing tape, fusible flux backing material, or a nonfusible backing bar, and are back welded to obtain a completely fused root, shall be qualified in accordance with Section 9, Qualification. Finished joints shall be nondestructively examined according to Section 10, Weld Quality and Inspection, and the results recorded.

6.9.3 Joint Class III. Joints in this class are complete joint penetration butt, T-, and corner joints welded from both sides, or from one side using a backing strip that is not removed after welding.

6.9.4 Joint Class IV. Joints in this class are complete joint penetration butt, T-, and corner joints welded from one side without the use of backing; partial joint penetration butt, T-, and corner joints welded on both sides; and fillet welded lap, T-, and corner joints welded on both sides.

6.9.5 Joint Class V. Joints in this class are partial joint penetration butt, T-, and corner joints welded on one side; and fillet, plug, or slot welded lap, T-, and corner joints welded on one side only.

6.9.6 Joint Class VI. Joints in this class are joints which do not require special weld groove preparation, such as butt, T-, corner, lap, or edge joints; plug welds; welds of secondary importance in strength; and structural welded joints of secondary importance not subject to dynamic loading.

6.10 Joint Qualification

6.10.1 Joints meeting the following requirements are designated as prequalified:

(1) Conformance with the details of 6.2 through 6.7, and Figures I.1 or I.2 in Annex I; and

(2) Welded with one of the following processes in accordance with the requirements of Section 8, Processes and Filler Metals, as applicable: shielded metal arc, submerged arc, flux cored arc, and gas metal arc with other than short-circuiting transfer.

6.10.2 Other joint configurations may be used with proper qualification in accordance with Section 9, Qualification.

6.11 Transition of Thicknesses or Widths at Butt Joints

6.11.1 Butt joints between parts of unequal thicknesses and also subject to tensile stress shall have a smooth transition between the offset surfaces at a maximum slope of 1 in 2-1/2 with the adjacent surface of either part. The transition may be accomplished by sloping the weld face(s), by chamfering the thicker part, or by a combination of the two methods (see Figure 6).

6.11.2 Transition of thickness in butt joints between parts of unequal thickness, that are subject only to shear or compressive stress, shall be accomplished as specified in 6.11.1 when the offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected. When the offset does not exceed the thickness of the thinner part connected, the face of the weld shall be sloped (1) no more than 1 in 2-1/2 from the surface of the thinner part or (2) to the surface of the thicker part if this requires a lesser slope. The exception is that truss member joints and beam and girder flange joints shall be made with a smooth transition of the type specified in 6.11.1.

6.11.3 Butt joints between parts of unequal width that are subject to tensile stress shall have either (1) a smooth slope between offset edges of no more than 1 in 2-1/2 with the edge of either part or (2) a 2.0 ft [600 mm] minimum radius tangent to the narrower part at the center of the butt joint, as shown in Figure 7. A radius transition is required for steels having yield strength greater than or equal to 90 ksi [620 MPa].

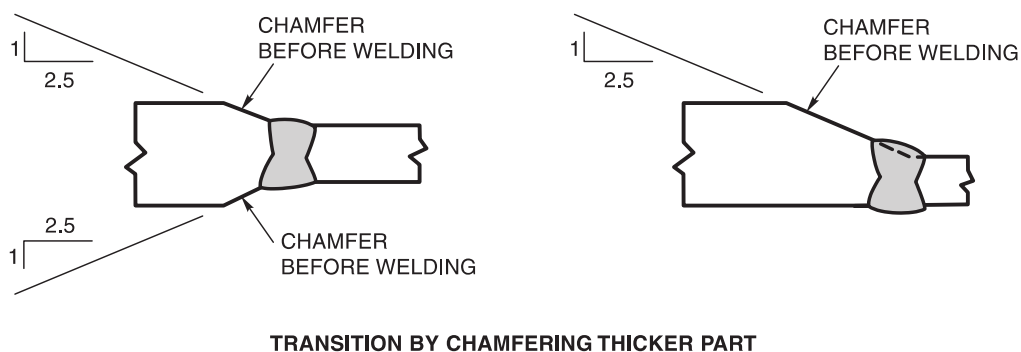
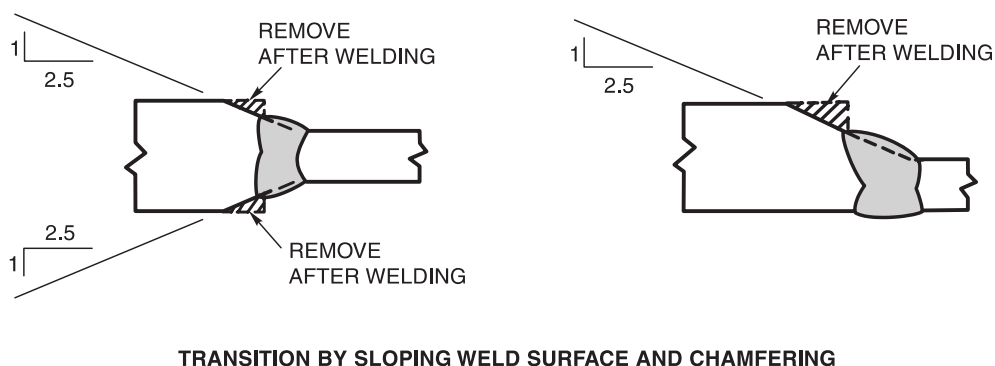
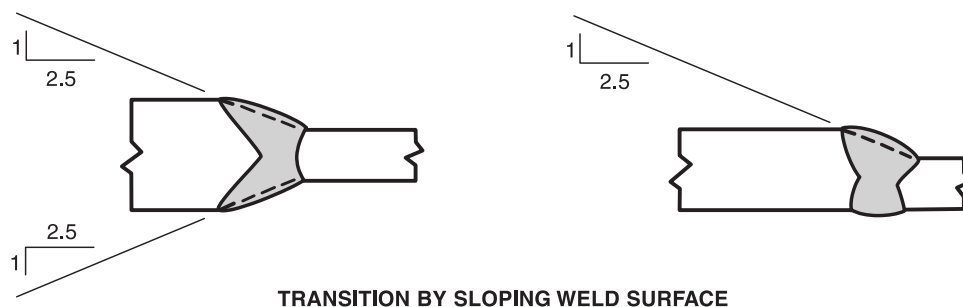
6.12 Material for Joint Extensions, Backing, and Spacers

6.12.1 Material for joint extensions and backing used in welding shall conform to the following requirements:

(1) When used for welding any prequalified steel listed in 4.4, they may be of any of the steels in the same list.

(2) When used for welding with a steel qualified in accordance with this specification, they shall be of the steel qualified.

(3) Use 100 ksi [690 MPa] minimum yield strength steel when and only when welding 100 ksi [690 MPa] minimum yield strength steels.



CENTERLINE ALIGNMENT
(PARTICULARLY APPLICABLE TO WEB PLATES)

OFFSET ALIGNMENT
(PARTICULARLY APPLICABLE TO FLANGE PLATES)

General Notes:

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

Figure 6—Transition of Butt Joints in Parts Having Unequal Thickness

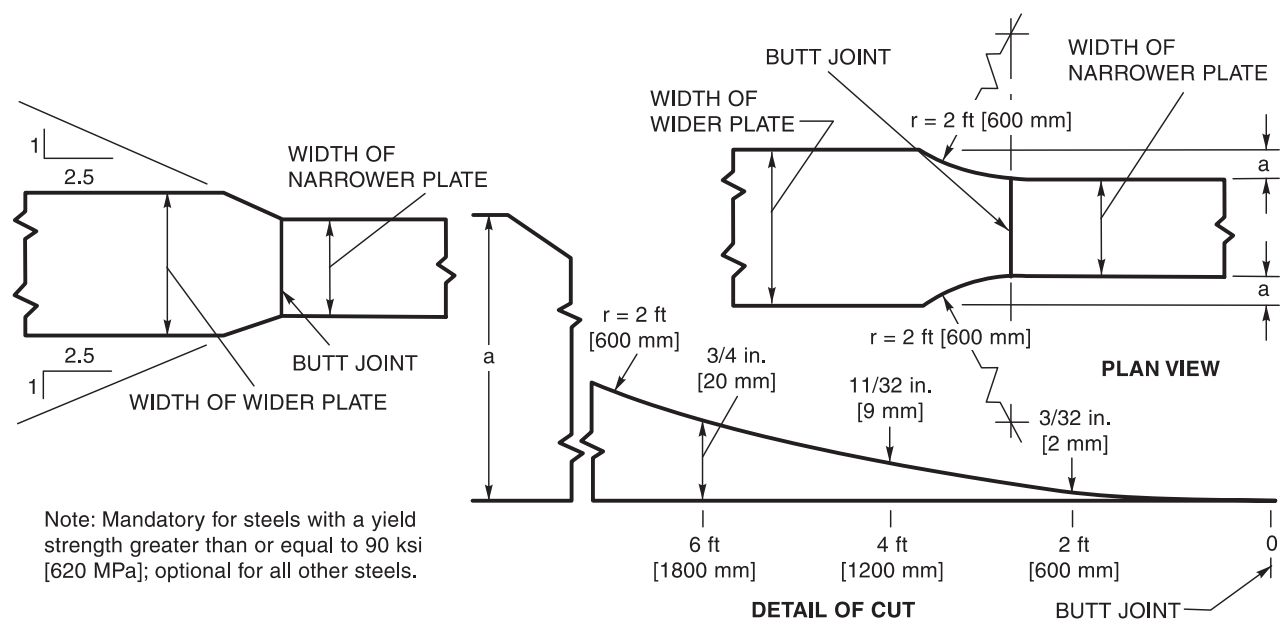


Figure 7—Transition of Width at Butt Joints of Parts Having Unequal Width (see 6.11.3)

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

6.13 Dimensional Tolerances. Dimensions of groove welds specified on design or detailed drawings may vary from the dimensions shown in Figures I.1 and I.2 only within the following limits:

6.13.1 The specified thickness of base metal or weld effective throat is the maximum nominal thickness that may be used.

6.13.2 The stated groove angle is the minimum; it may be detailed to exceed the dimensions shown by no more than 10° .

6.13.3 The stated radius of J and U grooves is the minimum. U grooves may be prepared before or after fit up.

6.13.4 Double groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than $1/4$ of the thickness of the thinner part joined, unless otherwise designated in Figures I.1 and I.2.

6.13.5 The root face of the joint shall be as shown in Figures I.1 and I.2 with the following variations permitted:

(1) For shielded metal arc, gas metal arc, and flux cored arc welding, it may not be detailed less than the specified dimension.

(2) For complete joint penetration submerged arc welding, the specified root face of the joint is the maximum.

6.13.6 The stated root opening of the joints is the minimum. It may be detailed to exceed the specified dimensions by no more than $1/16$ in. [2 mm], except that the root opening of joints for submerged arc welding shall be detailed as zero (no variation) when so specified.

6.14 Lap Joints

6.14.1 The minimum overlap of parts in stress carrying lap joints shall be five times the thickness of the thinner part. Unless lateral deflection of the parts is prevented, they shall be connected by at least two transverse lines of fillet, plug, or slot welds or by two or more longitudinal fillet or slot welds.

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

6.14.3 When fillet welds in holes or slots are used, the clear distance from the edge of the hole or slot to the adjacent edge of the part containing it, measured perpen-

dicular to the direction of stress, shall be no less than five times the thickness of the part nor less than two times the width of the hole or slot. The strength of the part shall be determined from the critical net section of the base metal.

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

6.16 Welds in Combination with Rivets and Bolts. Rivets or bolts used in bearing-type connections shall not be considered as sharing the load in combination with welds. Welds, if used, shall be provided to carry the entire load in the connection. High-strength bolts properly installed as a slip-critical-type connection prior to welding may be considered as sharing the load with the welds. Bolts or rivets used in assembly may be left in place if their removal is not specified. If bolts are to be removed, the plans should indicate whether holes should be filled and in what manner.

6.17 Eccentricity of Connections

6.17.1 Eccentricity between intersecting parts and members shall be avoided insofar as practicable.

6.17.2 In designing welded joints, adequate provision shall be made for bending stresses due to eccentricity, if any, in the disposition and section of base-metal parts and in the location and types of welded joints.

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

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

7. Workmanship

7.1 General

7.1.1 All requirements of this section shall be observed in the production and inspection of welded assemblies produced by any of the processes acceptable under this specification.

7.1.2 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 specification.

7.1.3 Welding shall not be done when the ambient temperature is lower than 0°F [−18°C], when surfaces are wet or exposed to rain, snow, or high wind velocities, or when welding personnel are exposed to inclement conditions. The maximum permissible wind velocity will vary with the welding process and procedure. Heating, local protection from the elements, or both, shall be used as necessary.

7.1.4 The size and length of welds shall not be less than those specified by design requirements and detail drawings, except as permitted by 10.6(6), nor shall they exceed those requirements by more than 25% without prior approval of the design change by the responsible Engineer. Also, the location of welds shall not be changed without prior approval of the Design Engineer.

7.2 Preparation of the Base Metal

7.2.1 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other visual defects that would adversely affect the quality of the weld. Surfaces to be welded and surfaces adjacent to a weld shall be free from loose or thick mill scale, slag, rust, paint, moisture, and other foreign material, or contaminants that will prevent proper welding or produce hazardous fumes. Thin mill scale (that can withstand vigorous wire brushing), thin rust-inhibitive coating, or anti-spatter compound (that will not cause problems with welding) need not be removed.

7.2.2 When oxyfuel gas cutting is employed, the cutting torch shall be adjusted and manipulated to avoid cutting beyond (inside) the prescribed lines. The roughness of cut surfaces shall not be greater than Sample No. 2 of AWS C4.1, *Surface Roughness Gauge*, for material thicknesses up to 2 in. [50 mm], and Sample No. 1 for material 2 in. [50 mm] to 8 in. [200 mm] thick. Surfaces exceeding the above roughness values and occasional notches or gouges not exceeding 3/16 in. [5 mm] deep shall be corrected by machining or grinding. Notches or other sharp discontinuities exceeding 3/16 in. [5 mm] may be repaired by welding only with the approval of the Design Engineer. Approved weld repairs shall be made only by following a documented repair welding procedure that shall contain the following:

- (1) Discontinuity removal and joint preparation.
- (2) Welding process and filler metal to be used.
- (3) Preheat and welding variables and also any post-heat requirements necessary to comply with this specification.
- (4) Procedures for grinding the completed weld smooth and flush to within the surface roughness accep-

tance criteria of 7.2.2. Weld repaired surfaces and edges that will not be subsequently incorporated into a welding joint shall be stress relieved by any approved method when determined necessary by the Design Engineer.

7.2.3 Machining, plasma arc cutting, air carbon arc cutting, oxyfuel gas cutting, oxygen gouging, chipping, or grinding may be used for joint preparation, back gouging, and the removal of unacceptable work or metal. One exception is that oxygen gouging shall not be used on quenched and tempered steel. Thermally cut surfaces should be ground as needed to proper contour. Preparation of nonferrous base metals by nontraditional methods shall be a matter of agreement between the Manufacturer and Owner.

7.2.4 Edges of built up beam and girder webs shall be cut to the prescribed camber with empirically developed manufacturing allowance for shrinkage due to cutting and welding. However, deviation from the specified camber tolerances may be corrected by carefully supervised application of a limited amount of localized heat or other suitable means of obtaining the specified camber.

The use of flame straightening of distorted members and camber correction by localized heating shall have the approval of the Design Engineer and follow an approved written procedure (see 12.4). When flame straightening is used, the temperature of the heated areas shall be accurately measured. The temperature shall not exceed 1100°F [590°C] for quenched and tempered steels or normalized and tempered steels, and 1200°F [650°C] for other steels.

7.2.5 Dimensional Tolerances. Dimensions of built up beams and girders shall be within the tolerance of the general specification governing the work, and also within the following special tolerances. All measurements shall be taken at the Manufacturer's plant prior to shipment, unless otherwise specified.

7.2.5.1 Maximum deviation from straightness, D_s , (referenced to the neutral axis) of welded beams or girders, where there is no specified sweep:

$$D_s, \text{ in.} = 0.0125 \times \text{total length, ft}$$

$$D_s, \text{ mm} = 1.04 \times \text{total length, m}$$

7.2.5.2 Maximum deviation from specified camber (in the service position), D_c , of welded beam or girders:

$D_c, \text{ in.} = \pm 0.003 \times \text{total length, ft, or } \pm 1/4 \text{ in, whichever is greater}$

$D_c, \text{ mm} = \pm 0.25 \times \text{total length, m, or } \pm 6 \text{ mm, whichever is greater}$

7.2.5.3 Lateral deviation between the centerline of the web and the centerline of the flange of buildup H or I members at the contact surface (referenced to neutral axis) shall be 1/4 in. [6 mm] maximum.

7.2.5.4 The maximum deviation from the specified depth for welded built up beams and girders, measured at the web centerline, shall be $\pm 1/2$ in. [13 mm] for depths up to 72 in. [1800 mm]. For depths over 72 in. [1800 mm], the maximum deviation shall be $+3/4$ in. [20 mm] to $-1/2$ in. [13 mm].

7.2.6 Re-entrant corners, except for the corners of weld-access cope holes adjacent to a flange, shall be filleted to a radius of no less than 3/4 in. [20 mm]. The fillet and its adjacent cuts shall meet without offset or cutting past the point of tangency.

7.3 Visual Inspection and Repair of Plate and Wrought Steel Products

7.3.1 In the repair and the determination of the limits of visible internal discontinuities on rolled, sheared, or oxygen cut edges, the amount of metal removed shall be the minimum necessary to remove the discontinuity, but not to exceed the permissible limit given in Table 7. Material cut edges may exist at any angle with respect to the rolling direction. All repairs of discontinuities by welding shall conform to the applicable provisions of this specification.

7.3.2 The limits of acceptability and the repair of visually observed edge discontinuities shall be in accordance with Table 7. The length of discontinuity is the visible length dimension on the material edge, and the depth is the distance that the discontinuity extends into the material from the edge.

7.3.3 Discontinuities over 1 in. [25 mm] in length and in depth, when discovered during either visual inspection of cut surfaces or nondestructive examination of welded joints, shall be evaluated further. The following procedures are recommended:

(1) Where discontinuities, such as W, X, or Y in Figure 8 are observed prior to completing the joint, the size and shape of discontinuity shall be determined by ultrasonic inspection. The area of the discontinuity shall be determined as the area of total loss of back reflection when examined in accordance with the procedure section of ASTM A 435.

(2) For acceptance of W, X, or Y discontinuities, the area of a single 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 width of discontinuity or the aggregate width of discontinuities on any transverse section, as measured perpendicular to the cut material length, exceeds 20% of

Table 7
Limits on Acceptability and Repair of Edge Discontinuities in Cut Surfaces (see 7.3.2)

Size of Discontinuity		Repair Required
Length, in. [mm]	Depth, in. [mm]	
≤ 1 [25]	Unspecified	None; need not be explored.
> 1 [25]	≤ 1/8 [3]	None; depth should be explored per Note (1).
> 1 [25]	> 1/8 [3] to ≤ 1/4 [6]	Remove; repair welding not required.
> 1 [25]	> 1/4 [6] to ≤ 1 [25]	Completely remove and repair weld as limited by Note (2).
> 1 [25]	> 1 [25]	Refer to 7.3.3.

Notes:

- (1) A spot check of 10% of the discontinuities on the edge in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 [3 mm], then all of the discontinuities remaining on that edge shall be explored by grinding to determine depth. If none of the discontinuities explored in the 10% spot check has a depth exceeding 1/8 in. [3 mm], then the remaining of the discontinuities on that edge need not be explored.
- (2) Aggregate length of welding shall not exceed 20% of the length of the plate edge being repaired.

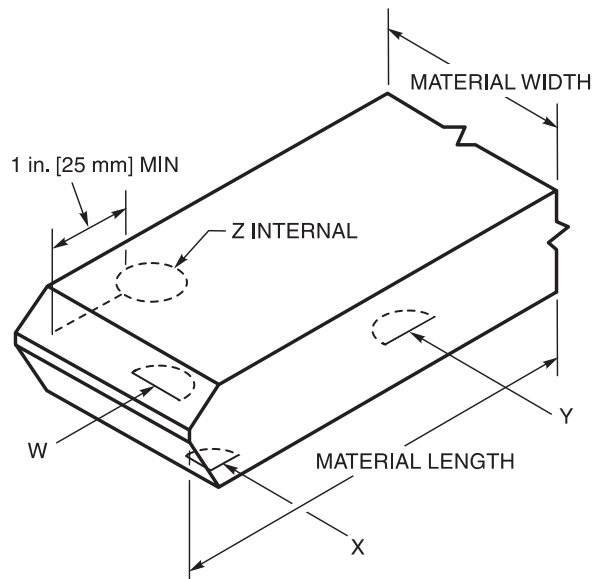


**Figure 8—Edge Discontinuities
in Cut Material (see 7.3.3)**

the cut material width, the maximum allowable 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 percentage area of discontinuity cannot exceed $4 \text{ minus } 4 \times (0.30 - 0.20)$, or 3.6% of the cut material area. The discontinuity on the edge of the plate shall be gouged out to a depth of 1 in. [25 mm] beyond its intersection with the surface by chipping, air carbon arc gouging, or grinding, and then blocked off by

welding in layers not exceeding 1/8 in. [3 mm] in thickness for at least the first four layers.

(3) Repair of an internal discontinuity, Z, in Figure 8 is not required if it does not exceed the allowable area in 7.3.3(2), is discovered after the joint has been completed, and is 1 in. [25 mm] or more from the toe of the weld as measured on the cut material surface. If a Type Z discontinuity is less than 1 in. [25 mm] 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 by welding 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 7.3.3(2), the cut material or sub-component shall be either rejected and replaced or repaired at the discretion of the Design Engineer.

(5) The aggregate length of weld repair shall not exceed 30% of the length of the cut surface without approval of the Design Engineer.

(6) All repairs shall be in accordance with this specification. Gouging of a discontinuity may be done from either the cut material surface or the edge.

7.4 Assembly

7.4.1 Parts to be joined by fillet welds shall be brought as close together as practicable at the joint. Root cracking may occur in a fillet weld if there is no root opening between the parts (e.g., surfaces machined to bear). It may be necessary to provide a small root opening, in such cases, prior to welding. In any case, the root opening between parts shall not exceed 1/8 in. [3 mm] for sections up to 2 in. [50 mm] in thickness. When the root opening between shapes or plates of 2 in. [50 mm] or

more in thickness cannot be closed to meet this tolerance, a maximum root opening of 3/16 in. [5 mm] is acceptable if a sealing weld or suitable backing material⁶ is used. If the root opening is 1/16 in. [2 mm] or greater, the leg of the fillet weld shall be increased by the amount of the separation, or the contractor shall demonstrate that the required effective throat has been obtained.

The separation between the faying surfaces of lap joints and butt joints with a backing shall not exceed 1/16 in. [2 mm]. Deviations from these limits shall be approved by the Design Engineer.

7.4.2 Parts to be joined by partial joint penetration groove welds parallel to the length of the member (bearing joints excepted) shall be brought as close together as practicable. The root opening between parts shall not exceed 1/8 in. [3 mm]. If the root opening between rolled shapes or plates of 2 in. [50 mm] or greater in thickness cannot be closed sufficiently to meet this tolerance, a maximum gap of 3/16 in. [5 mm] is acceptable provided (1) a sealing weld or suitable backing material is used and (2) the final weld meets the requirements for effective throat. Tolerances for bearing joints shall be in accordance with the applicable contract specification or the Manufacturer's standard if no tolerances are included in the contract. Deviations from these limits shall be approved by the Design Engineer.

7.4.3 Parts to be joined at butt joints shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10% of the thickness of the thinner part joined, but in no case more than 0.18 in. [4.5 mm], may be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the slope of the drawn-in parts shall not exceed 1 to 24. Measurement of offset shall be based upon centerline of parts, unless otherwise shown on the drawing. Deviations from these limits shall be approved by the Design Engineer.

7.4.4 Dimensions of the cross section of groove weld joint preparations that vary from those shown on the detail drawings by more than the tolerances given in Table 8 shall be referred to the Design Engineer for acceptance. Exceptions are grooves for electroslag and electrogas welds.

7.4.5 Grooves produced by gouging shall be in accordance with the requirements for processes and filler metals of Section 8.

6. Backing may be flux, glass tape, iron powder, or similar materials. Sealant (root) passes should be made with low-hydrogen covered electrodes or other arc welding processes.

Table 8
Tolerances for Groove Weld Joint
Preparations for Arc Welding (see 7.4.4)

	Root Not Gouged		Root Gouged	
	in.	mm	in.	mm
Root face	±1/16	±2	Not limited	
Root opening with other than steel backing	±1/16	±2	±1/16	±2
Root opening with steel backing	+1/4	+6	Not applicable	
Groove angle	+5°		+10°, -5°	

7.4.6 Groove welds shall be terminated at the ends of a joint in a manner that will ensure sound welds. This should be done by the use of extension bars or run-off plates.

7.4.7 Extension bars and run-off plates shall be removed upon completion of the welding, and the ends of the weld shall be finished smooth and flush with the edges of the abutting parts.

7.4.8 The weld metal of groove welds made with steel backing strips shall be thoroughly fused with the backing. Steel backings shall be removed, where accessible, from welds that are transverse to computed stress, and the joints shall be ground or finished smooth.

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

7.4.10 Steel backing shall be continuous for the full length of a weld. Welded butt joints in a fabricated steel backing shall have complete joint penetration, and the joints shall be welded prior to placement of the backing.

7.4.11 Caulking of welds is not permitted.

7.4.12 Tack Welds

7.4.12.1 Tack welds shall be subject to the same quality requirements as the final welds.

7.4.12.2 Tack welds which are incorporated into the final weld shall be made with electrodes meeting the requirements of the final weld. Multipass tack welds

shall have cascaded ends. Tack welds shall be cleaned prior to depositing additional weld metal.

7.4.12.3 Tack welds not incorporated into final welds shall be removed.

7.4.13 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 examined to ensure soundness (see 12.2.2).

7.5 Control of Distortion and Shrinkage Stresses

7.5.1 The procedure and welding sequence for assembling and joining parts of a structure or of built up members and for welding reinforcing parts to members, shall be designed to minimize distortion and shrinkage.

7.5.2 When practicable, all welds shall be deposited in a sequence that will balance the applied heat while welding progresses.

7.5.3 A program for welding sequence and distortion control shall be provided where shrinkage stresses or distortion are likely to affect the adequacy of the structure.

7.5.4 Joints that are expected to produce large shrinkage should usually be welded with as little restraint as possible before other joints that are expected to cause less shrinkage are welded.

7.5.5 Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking (see 7.8). No peening shall be done on the root pass. Peening of the final weld layer shall be for fatigue enhancement purposes only and shall be done according to an approved written procedure (see 7.8.3).

7.5.6 In making welds under conditions of severe external shrinkage restraint, the welding shall be carried continuously to completion or to a point that will ensure freedom from cracking before the joint is allowed to cool below the minimum specified preheat temperature. Where preheat and interpass temperatures are not specified, welding shall continue to a point where freedom from cracking is assured.

7.6 Stress Relief. Where required by the contract drawings or specifications, welded assemblies shall be stress relieved.

7.6.1 All stress relief operations shall follow an approved written procedure.

7.6.2 Localized stress relieving may be employed, subject to approval by the Design Engineer, when it is impractical to stress relieve the entire weldment. A written procedure shall address the variables given in 7.6.3.

7.6.3 The procedures for furnace stress relief shall address the following:

- (1) Temperature at the start of the thermal cycle.
- (2) Rate of heating to temperature.
- (3) Maximum allowable variation of temperature throughout the portion of the part being heated.
- (4) Maximum temperature tolerance at stress relief temperature.
- (5) Holding time at stress relief temperature.
- (6) Rate of cooling to a temperature suitable for removal of work from the furnace.
- (7) The thermocouples shall have surface contact with the weldment and be shielded from direct impingement of the heat source. The records shall include the location, calibration and thermal chart of each thermocouple, along with traceable weldment documentation. The records and data shall become part of the weldment documentation.
- (8) Support of the weldment to minimize sagging and distortion.
- (9) Spacing of multiple items so all pieces will heat uniformly.
- (10) Use of baffles or insulating material to protect the weldment from direct impingement of the heat source.

7.6.4 Stress relieving of weldments of A514, A517, A709 Grades 100 and 100W, and A710 steels is not recommended. Stress relieving may be necessary for those applications where weldments must retain dimensional stability during machining or where stress corrosion may be involved, neither condition being unique to weldments involving A514, A517, A709 Grades 100 and 100W, and A710 steels. However, the results of notch toughness tests have shown that stress relieving may actually impair weld metal toughness, and intergranular cracking may sometimes occur in the grain-coarsened region of the weld heat affected zone. Such steels should only be stress relieved after consultation with the steel producer and in strict accordance with the producer's recommendations.

Precautionary Note: Consideration must be given to possible distortion due to stress relief.

7.7 Vibratory Conditioning

7.7.1 Vibratory conditioning to obtain dimensional stability of the weldment may be employed with the approval of the Engineer. The conditioning shall be done in accordance with the recommendations of the manufacturer of the vibratory equipment. It shall not be substituted for thermal stress relief.

7.7.2 The conditioning process shall be covered by a written procedure.

7.8 Peening. Shot and mechanical peening provide for improved fatigue life in the weld joint as a result of the