

Machinery and Equipment Welding Specification



Documents

Document Sharing Hub

AWS D14.0/D14.0M:2024
An American National Standard

Approved by the
American National Standards Institute
October 3, 2023

Machinery and Equipment

Welding Specification

1st Edition

Revises AWS D14.1/D14.1M:2005
AWS D14.3/D14.3M:2019
AWS D14.4/D14.4M:2019
AWS D14.5/D14.5M:2009

Prepared by the
American Welding Society (AWS) D14 Committee on Machinery and Equipment

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification establishes design, manufacture, quality, inspection, and repair requirements for carbon, low-alloy, and alloy steel welded connections in machinery and equipment. It addresses topics including weld joint design, workmanship, quality acceptance criteria, nondestructive examination methods (visual, radiographic, ultrasonic, magnetic particle, and liquid penetrant), repair of weld defects, and postweld heat treatment.



ISBN Print: 978-1-64322-291-2

ISBN PDF: 978-1-64322-292-9

© 2023 by American Welding Society

All rights reserved

Printed in the United States of America

Photocopy Rights. No portion of this standard may be reproduced, stored in a retrieval system, or transmitted in any form, including mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

Authorization to photocopy items for internal, personal, or educational classroom use only or the internal, personal, or educational classroom use only of specific clients is granted by the American Welding Society provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, tel: (978) 750-8400; Internet: www.copyright.com.

Statement on the Use of American Welding Society Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS American National Standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is neither undertaking to render professional or other services for or on behalf of any person or entity, nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. It is assumed that the use of this standard and its provisions is entrusted to appropriately qualified and competent personnel.

This standard may be revised, corrected through publication of amendments or errata, or supplemented by publication of addenda. Information on the latest editions of AWS standards including amendments, errata, and addenda is posted on the AWS web page (www.aws.org). Users should ensure that they have the latest edition, amendments, errata, and addenda.

Publication of this standard does not authorize infringement of any patent or trade name. Users of this standard accept any and all liabilities for infringement of any patent or trade name items. AWS disclaims liability for the infringement of any patent or product trade name resulting from the use of this standard.

AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Standards Development, 8669 NW 36 St, # 130, Miami, FL 33166 (see Annex L). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS D14 Committee on Machinery and Equipment. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D14 Committee on Machinery and Equipment and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D14 Committee on Machinery and Equipment to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

This page is intentionally blank.

Personnel

AWS D14 Committee on Machinery and Equipment

J. S. Bailey, Chair	<i>Vermeer Corporation</i>
B. K. Banzhaf, 1 st Vice Chair	<i>CNH Industrial America LLC</i>
D. L. Jones, 2 nd Vice Chair	<i>Flowserve</i>
K. R. Bulger, Secretary	<i>American Welding Society</i>
R. L. Arn	<i>Trinity Industries Incorporated</i>
F. D. Borns	<i>Consultant</i>
T. J. Bruno	<i>Link-Belt Construction Equipment Co</i>
J. E. Campbell	<i>Machinery & Welder Corp</i>
B. S. Daines	<i>SpaceX</i>
C. L. Decker	<i>The Lincoln Electric Company</i>
W. E. DePorter	<i>Komatsu Mining Corp Group</i>
T. F. Gary	<i>G & W Products Incorporated</i>
R. K. Goyal	<i>John Deere and Co.</i>
S. A. Harris	<i>Altec Industries Incorporated</i>
R. L. Larsen	<i>John Deere Des Moines Works</i>
R. Leemans	<i>Consultant</i>
J. T. McMurtrey	<i>Atlas Materials Testing & Inspection</i>
D. K. Miller	<i>The Lincoln Electric Company</i>
D. W. Moers	<i>CRC-Evans</i>
C. L. Rasmussen	<i>Brigham Young University—Idaho</i>
D. B. Rizor	<i>Werk-Brau Co. Inc.</i>
M. K. Shriver	<i>Crown Equipment Corporation</i>
J. D. Slipke	<i>Rosenboom Machine & Tool Incorporated</i>
P. T. Snyder	<i>Consultant</i>
M. A. Stevenson	<i>Stevenson Fabrication Services Inc</i>
K. M. Wald	<i>Felling Trailers</i>
D. R. Wisner	<i>M and M Engineering</i>
R. R. Wyers	<i>Komatsu Mining Corp Group</i>

Advisors to the AWS D14 Committee on Machinery and Equipment

S. L. Blankman	<i>Matheson Trigas East Region</i>
D. D. Jones	<i>Texas Hydraulics</i>
L. L. Schweinegruber	<i>Consultant</i>

AWS D14.0/D14.0M Task Group on General Requirements

J. E. Campbell, Chair	<i>Machinery & Welder Corp</i>
J. S. Bailey	<i>Vermeer Corporation</i>
B. K. Banzhaf	<i>CNH Industrial America LLC</i>
D. K. Miller	<i>The Lincoln Electric Company</i>

AWS D14.0/D14.0M Task Group on Materials

D. L. Jones, Chair	<i>Flowserve</i>
B. K. Banzhaf	<i>CNH Industrial America LLC</i>

B. S. Daines	<i>SpaceX</i>
D. D. Jones	<i>Texas Hydraulics</i>
R. R. Wyers	<i>Komatsu Mining Corp Group</i>

AWS D14.0/D14.0M Task Group on Design

J. S. Bailey, Chair	<i>Vermeer Corporation</i>
B. K. Banzhaf	<i>CNH Industrial America LLC</i>
C. L. Decker	<i>The Lincoln Electric Company</i>
W. E. De Porter	<i>Komatsu Mining Corp Group</i>
R. K. Goyal	<i>John Deere and Co.</i>
R. Leemans	<i>Consultant</i>
D. K. Miller	<i>The Lincoln Electric Company</i>
K. M. Wald	<i>Felling Trailers</i>

AWS D14.0/D14.0M Task Group on Qualification

J. E. Campbell, Chair	<i>Machinery & Welder Corp</i>
S. A. Harris	<i>Altec Industries Incorporated</i>
D. D. Jones	<i>Texas Hydraulics</i>
M. S. Pratt	<i>Vermeer Corporation</i>
C. L. Rasmussen	<i>Brigham Young University—Idaho</i>
D. B. Rizor	<i>Werk-Brau Co. Inc.</i>
M. A. Stevenson	<i>Stevenson Fabrication Services Inc</i>
R. R. Wyers	<i>Komatsu Mining Corp Group</i>

AWS D14.0/D14.0M Task Group on Fabrication

T. F. Gary, Chair	<i>G & W Products Incorporated</i>
J. A. McMullen	<i>Fronius USA LLC</i>
D. W. Moers	<i>CRC-Evans</i>
C. L. Rasmussen	<i>Brigham Young University—Idaho</i>
M. K. Shriver	<i>Crown Equipment Corporation</i>
M. A. Stevenson	<i>Stevenson Fabrication Services Inc</i>
A. White	<i>Glendale Manufacturing U-Haul</i>

AWS D14.0/D14.0M Task Group on Inspection

J. T. McMurtrey, Chair	<i>Atlas Materials Testing & Inspection</i>
F. D. Borns	<i>Consultant</i>
R. L. Larsen	<i>John Deere Des Moines Works</i>
J. D. Slipke	<i>Rosenboom Machine & Tool Incorporated</i>
A. White	<i>Glendale Manufacturing U-Haul</i>

Foreword

This foreword is not part of this standard but is included for informational purposes only.

In 1967, the Technical Activities Committee of the American Welding Society established a technical committee to provide standards and recommended practices for the welding and fabrication of industrial equipment and machinery. The scope of that technical committee, identified as D14 committee, was to collect, review, and promulgate minimum requirements considered necessary for the control of welding in the fabrication of industrial machinery and equipment. At that time, the committee determined that a single universal standard and guide covering all machinery and equipment was impractical due to differences in utilization and operational requirements, and over the next 13 years released D14.1-70, *Specification for Welding Industrial and Mill Cranes*; D14.3-77, *Specification for Welding Earthmoving and Construction Equipment*; D14.4-77, *Classification and Application of Welded Joints for Machinery and Equipment*; and D14.5-80, *Specification for Welding of Presses and Press Components*.

Since that time, these standards have undergone continued revision. AWS D14.1/D14.1M was revised in 1985, 1997, and 2005. AWS D14.3/D14.3M was revised in 1982, 1994, 2000, 2005, 2010, and 2019. AWS D14.4/D14.4M was revised in 1997, 2005, 2012, and 2019. AWS D14.5/D14.5M was revised in 1997 and 2009.

50 years later, the D14 Committee has identified a need to harmonize and eliminate overlap between D14 documents relating to machinery and equipment. This document combines and replaces AWS D14.1/D14.1M, *Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment*, AWS D14.3/D14.3M, *Specification for Welding Earthmoving, Construction, Agricultural, and Ground-Based Material Handling Equipment*, AWS D14.4/D14.4M, *Specification for the Design of Welded Joints in Machinery and Equipment*, and AWS D14.5/D14.5M, *Specification for Welding of Presses and Press Components*.

This document establishes design, manufacture, quality, inspection, and repair requirements for carbon, low-alloy, and alloy steel welded connections in machinery and equipment. It addresses topics including weld joint design, fabrication, quality acceptance criteria, nondestructive examination methods (visual, radiographic, ultrasonic, magnetic particle, and liquid penetrant), repair of weld defects, and postweld heat treatment.

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 36th St #130, Miami, FL 33166.

All errata to a standard shall be published in the *Welding Journal* and posted on the AWS website.

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

This page is intentionally blank.

Dedication

The AWS D14 Committee on Machinery and Equipment dedicates this edition of the D14.0/D14.0M, *Machinery and Equipment Welding Specification*, to David Landon for his significant contribution to welding.

Dave was a 1981 graduate from LeTourneau University with a Bachelor of Science degree in Engineering with a Welding emphasis. He was the manager of Welding Engineering at Vermeer Corporation, a manufacturer of construction, industrial and agricultural equipment located in Pella, Iowa. He worked for Vermeer for over 25 years where he had responsibility for welding engineering, metallurgy, and welder training. In 2012 Dave was awarded with the Bob Vermeer Spirit of Caring Award, honoring his commitment to trustworthiness, respect, responsibility, fairness, caring and citizenship.

Dave served on the board of directors for the American Welding Society (AWS) from 2007–2017. In 2009, Dave was inducted as a member of AWS Counselors and in 2015 served as AWS President. He also served as a trustee of the AWS Foundation 2014–2015. He had recently been appointed as the 2020–2023 President of the International Institute of Welding, an international consortium of the welding associations of over 53 member countries.

Dave was a tremendous contributor to AWS's technical activities since 1994 serving in many chair and officer roles on many committees including the Technical Activities Committee, D14 Committee on Machinery and Equipment, and the AWS Certification Exam Bank Subcommittee.

Most importantly, Dave was a friend and mentor to many on the D14 Committee and in the welding community.

This page is intentionally blank.

Table of Contents

	Page No.
<i>Personnel</i>	v
<i>Foreword</i>	vii
<i>Dedication</i>	ix
<i>List of Tables</i>	xiii
<i>List of Figures</i>	xiv
1. General Requirements	1
1.1 Scope	1
1.2 Limitations	1
1.3 Responsibilities	1
1.4 Qualifications	2
1.5 Units of Measure	3
1.6 Safety	3
1.7 Symbols	3
1.8 International Usage	3
2. Normative References	5
3. Terms and Definitions	7
4. Base Metals	10
4.1 Base Metal Specifications	10
4.2 Properties	10
4.3 Weldability and Welding Procedure Qualification	10
5. Welding Processes and Consumables	10
5.1 Processes	10
5.2 Consumables	10
6. General Design Requirements	11
6.1 Weldment Classifications	11
6.2 Weld Classifications	11
6.3 Loading Classifications	11
6.4 Combined Unit Stresses	11
6.5 Low Temperature Service	11
6.6 High Temperature Service	12
6.7 Corrosion	12
6.8 Filler Metals	12
6.9 Visual Inspection and Nondestructive Testing	12
6.10 Base Metal Selection	12
6.11 Special Joint Considerations	12
7. Welded Connection Design	13
7.1 Joint Details	13
7.2 Details of Welds	14
7.3 Tubular Connections	19
7.4 Welds in Combination with Rivets and Bolts	19
7.5 Cyclic Loading	19
7.6 Prohibited Joints	22

8. Welding Procedure Qualification	57
8.1 Scope	57
8.2 General Requirements	61
8.3 Method I—Prototype Testing	63
8.4 Method II—Welding Procedure Qualification by Standard Testing Methods	64
8.5 Method III—Prequalified Welding Procedures	65
9. Welding Personnel Qualification	85
9.1 Scope	85
9.2 General	85
9.3 Welder Performance Qualification	85
9.4 Welding Operator Qualification	86
9.5 Operators of Automatic Welding Equipment	87
9.6 Qualification of Tack Welders	87
10. Fabrication	91
10.1 Scope	91
10.2 General Requirements	91
10.3 Equipment	92
10.4 Preparation of Materials	92
10.5 Preparation Method	92
10.6 Dimensional Tolerances	92
10.7 Assembly	93
10.8 Repair	95
10.9 Distortion Control	97
10.10 Stress Relief (PWHT)	98
10.11 Peening	98
10.12 Vibratory Weld Conditioning	98
11. Inspection and Acceptance Criteria	101
11.1 Scope	101
11.2 Qualification of Inspection Personnel	101
11.3 Quality of Welds	101
11.4 Visual Inspection	101
11.5 Radiographic Testing	103
11.6 Ultrasonic Testing	107
11.7 Magnetic Particle Testing	113
11.8 Liquid Penetrant Testing	113
Annexes	133
Annex A (Normative)—Welding of Industrial and Mill Cranes and Other Material Handling Equipment	135
Annex B (Normative)—Weld Joint Detail	139
Annex D (Normative)—Illustrative Examples of Prohibited Joints and Welds	183
Annex E (Informative)—Groove Face Width for Flare-Bevel-Groove and Flare-V-Groove Welds	187
Annex F (Informative)—Roadmap for Welding Procedure Specification (WPS) Development	189
Annex G (Informative)—Suggested Welding Procedure Specification and Qualification Test Record Forms	191
Annex H (Informative)—Recommended Practices for Storage and Treatment of Electrodes and Fluxes	193
Annex I (Informative)—Suggested Format for Demonstration of OEM WPS	197
Annex J (Informative)—Weld Break Test Samples	199
Annex K (Informative)—Qualification and Calibration of UT Units with Other Approved Reference Blocks	203
Annex L (Informative)—Requesting an Official Interpretation on an AWS Standard	207
Annex M (Informative)—Informative References	209
Commentary	211
List of AWS Documents on Machinery and Equipment	220

List of Tables

Table	Page No.
7.1 Allowable Stresses	24
7.2 Z-Loss Dimensions (Nontubular)	25
7.3 Z-Loss Dimensions for Calculating PFP T-, Y, and K-Tubular Connection Minimum Weld Sized	25
7.4 Effective Size of Flare-Groove Welds [Butt Welds] Filled Flush	25
7.5 Minimum Weld Size for Partial Joint Penetration Groove Welds [Butt Welds]	26
7.6 Minimum Single Pass Fillet Weld Size for Heat Input	26
7.7 Minimum Size Double Fillet Welds to Develop Full Static Strength	26
7.8 Arc Stud Welding, Stud Diameter Recommendations	27
7.9 Fatigue Stress Design Parameters	28
7.10 Allowable Fatigue Stress Range	45
8.1 Weldability Classification—Steel Products for Prequalified Welding Procedure Specifications	70
8.2 Base Metal/Filler Metal Strength Relationships for Prequalified Welding Procedure Specifications	76
8.3 Weldability Classifications	77
8.4 Minimum Preheat and Interpass Temperatures	78
8.5 Filler Metal Requirements for Prequalified Complete-Joint-Penetration Groove Welds	79
8.5M Filler Metal Requirements for Prequalified Complete-Joint-Penetration Groove Welds	80
8.6 Prequalified Joint Dimensions and Ground Angles for CJP Groove Welds in Tubular T-, Y-, and K-Connections made by SMAW, GMAW-S, and FCAW	81
8.7 Prequalified WPS Requirements	82
8.8 Prequalified WPS Variables	83
9.1 Welding Personnel Qualification—Type and Position Limitations	88
10.1 Tolerances for Groove Weld Joint Preparation for Arc Welding	99
10.2 Limits on Acceptability and Repair of Cut Edge Discontinuities of Plate	99
11.1 NDE and Visual Inspection Requirements	114
11.2 Visual Acceptance Criteria	115
11.3 Standard Hole-Type and Wire Image Quality Indicator Requirements	117
11.4 Examples of Acceptable Indications	117
E.1 Face Width Dimension Tolerances	188
F.1 Roadmap for Development of Welding Procedure Specifications (WPSs)	189
H.1 Electrodes Covered by AWS A5.1/A5.1M, <i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>	194
H.2 Electrodes Covered by AWS A5.5/A5.5M, <i>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</i>	194

List of Figures

Figure	Page No.
3.1 Reentrant Angles at Fillet Weld Toes	8
3.2 Reentrant Angle at Weld Bead Toe	9
3.3 Reentrant Angles at Groove Weld Face and Root Surface	9
3.4 Reentrant Angles at Groove Weld Face.	9
3.5 Fillet Weld with Acute and Obtuse Reentrant Angles.	10
6.1 Illustration of an Eccentric Connections.	13
7.1 Transition of Thickness at Butt Joints of Parts Having Unequal Thickness	46
7.2 Transition of Width at Butt Joints of Parts Having Unequal Width	47
7.3 Skewed T-Joints.	47
7.4 Minimum Overlap Distance	48
7.5 Transverse Lines of Plug or Slot Welds	48
7.6 Longitudinal Fillet Welds in Holes	48
7.7 Minimum Length of Longitudinal Fillet Welds at the End of a Plate or Flat Bar Members.	49
7.8 Distance to the Edge for Fillet Welds in Slots or Holes	49
7.9 Effective Length of a Diagonal Groove Weld.	50
7.10 Details for Fillet Welds	50
7.11 Concave Fillet Weld Profiles.	51
7.12 Convex Fillet Weld Profiles	51
7.13 Slot and Tab Detail	52
7.14 Combination of Bevel Groove and Fillet Weld Profiles	52
7.15 Allowable Stress Ranges for Cyclically Applied Load (Fatigue)—US Customary Units	53
7.16 Allowable Stress Ranges for Cyclically Applied Load (Fatigue)—SI Units	53
7.17 Examples of Unacceptable Reentrant Corners	54
7.18 Examples of Acceptable Reentrant Corners	55
7.19 Runout Weld Example.	56
7.20 Wrap Weld at Flexible Connections	57
8.1 Typical Microhardness Locations	84
8.2 Weld Bead in which Depth and Width Exceed the Width of the Weld Face.	84
9.1 Examples of Workmanship Samples.	89
9.2 Fillet Weld Break Specimen—Tack Welder Qualification	90
9.3 Groove Weld Break Specimen—Tack Welder	90
9.4 Method for Rupturing Specimen—Tack Welder Qualification.	91
9.5 Method of Evaluating Tack Welder Qualification for Grooves	91
10.1 Workmanship Tolerances in Assembly of Groove [Butt] Welded Joints	100
10.2 Edge Discontinuities in Cut Material	100
11.1 Cracks in Welded Joints	118
11.2 Acceptable and Unacceptable Weld Profiles.	119
11.3 Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length	120
11.4 Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 10 in [250 mm] in Length	120
11.5 Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length	121
11.6 Radiographic Identification and Hole-Type IQI Locations on Transition Joints Less Than 10 in [250 mm] in Length	121
11.7 Examples of Aligned Rounded Indications.	122
11.8 Examples of Groups of Aligned Rounded Indications	122
11.9 Charts for Thickness Equal to 1/8 in [3 mm] to 1/4 in [6 mm], Inclusive	122
11.10 Charts for Thickness Over 1/4 in [6 mm] to 3/8 in [10 mm], Inclusive	123
11.11 Charts for Thickness Over 3/8 in [10 mm] to 3/4 in [20 mm], Inclusive	123

11.12	Charts for Thickness Over 3/4 in [20 mm] to 2 in [50 mm], Inclusive	124
11.13	Charts for Thickness Over 2 in [50 mm] to 4 in [100 mm], Inclusive	125
11.14	Charts for Thickness Over 4 in [100 mm].	126
11.15	Transducer Positions (Typical)	127
11.16	Test Procedure—CJP Groove Weld in Butt Joints	128
11.17	Method of Detecting Longitudinal Discontinuities in CJP Groove Welds in Butt Joints Not Ground Flush	128
11.18	Method of Detecting Longitudinal Discontinuities in CJP Groove Welds in Butt Joints Ground Flush . .	129
11.19	Method of Detecting Longitudinal Discontinuities in CJP Groove Welds [Butt Welds] in Corner Joints Not Ground Flush	129
11.20	Procedure for Testing CJP Groove Welds [Butt Welds] in T-Joints	130
11.21	Method of Using Procedure for Testing CJP Groove Welds [Butt Welds] in T-Joints	130
11.22	Plan View of UT Scanning Patterns	131
A.1	Splices or Connections with Fillers Less than 1/4 in [6 mm] Thick	137
A.2	Splices or Connections with Fillers 1/4 in [6 mm] or Thicker	137
B.1	Typical Complete Joint Penetration Groove Welded [Butt Welded] Joints	141
B.2	Typical Partial Joint Penetration Groove Welded [Butt Welded] Joints	163
B.3	Details for Prequalified Fillet Welds of Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Submerged Arc Welding (SAW), and Flux Cored Arc Welding (FCAW)	174
B.4	Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections	175
B.5	Fillet Welded Prequalified Tubular Joints Connections Made by SMAW, GMAW, and FCAW	176
B.6	Prequalified Joint Details for CJP T-, Y-, and K-Tubular Connections.	177
B.7	Definitions and Detailed Selections for Prequalified CJP T-, Y-, and K-Tubular Connections	178
B.8	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Standard Flat Profiles for Limited Thickness.	179
B.9	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Profile with Toe Fillet for Intermediate Thickness	180
B.10	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections—Concave Improved Profile for Heavy Sections or Fatigue	181
B.11	Prequalified Skewed T-Joint Details (Nontubular)	182
D.1	Prohibited Joints and Welds on Principal Structural Weldments	183
D.2	Prohibited Joints and Welds—Cyclically Loaded—on Principal Structural Weldments	184
D.3	Prohibited Joints and Welds—Cyclically Loaded—on Principal Structural Weldments	185
E.1	Flare-Bevel-Groove and Flare-V-Groove Welds.	187
J.1	Fillet Weld Break Test Specimen	199
J.2	PJP Flare Groove Weld Break Test Specimen.	200
J.3	Weld Break Test Specimen Welding Steps	200
J.4	Weld Break Test Specimen Macro-Section.	200
J.5	Method for Testing Fillet Weld Break Test Specimen.	200
J.6	Method for Testing Flare Groove Weld Break Test Specimen	201
J.7	Method for Testing Flare Bevel Weld Break Test Specimen	201
K.1	Other Approved Blocks and Typical Transducer Position	205

This page is intentionally blank.

Machinery and Equipment Welding Specification

1. General Requirements

1.1 Scope. This specification establishes design, manufacture, quality, inspection, modification, strengthening and repair requirements for welded connections in machinery and equipment. It addresses topics including weld joint design, workmanship, quality acceptance criteria, nondestructive examination methods (visual, radiographic, ultrasonic, magnetic particle, and liquid penetrant), repair of weld defects, and postweld heat treatment. It reflects the welding practices employed by manufacturers within the industry and incorporates various methods which have been proven successful by individual manufacturers. No restrictions are placed on the use of any welding process or procedure, provided the welding procedure is qualified in accordance with this specification. No attempt is made to limit or restrict the progression of welding technology for the manufacturing and repair of machinery and equipment, nor should any such limitation be inferred.

For the purpose of this document, machinery and equipment includes:

(1) Cranes for Industrial, Mill, Powerhouse, and Nuclear Facilities. This specification is also applicable for other overhead material handling machinery and equipment that support and transport loads vertically or horizontally within the design rating during normal operations; and, to loading caused by abnormal operations or environmental events (e.g., seismic loading) when agreed upon between the Owner and Manufacturing Authority. See Commentary C-1.1 (1).

(2) Earthmoving, Construction, Agricultural, and Ground-Based Material Handling Equipment. These are described as on- and off-highway machinery and associated implements, as well as support equipment such as conveyors. Products that this specification cover include, but are not limited to, crawlers, tractors, graders, loaders, off-highway trucks, power shovels, backhoes, mobile cranes, draglines, forklifts, power trucks, skid steers, and similar equipment.

(3) Presses and Press Components. Products include, but are not limited to, stamping presses, brake presses, and arbor presses. See Commentary C-1.1 (3).

(4) Other Machinery and Equipment. This document may be used for other machinery and equipment when agreed upon between the Owner and Manufacturing Authority.

1.2 Limitations. The specification was specifically developed for welded machinery and equipment that utilize carbon, low-alloy, and alloy steels.¹ The specification may be suitable to govern design, manufacture, and inspection of machinery or equipment outside the scope of the intended purpose. However, the Design Authority should evaluate such suitability, and based upon such evaluations, incorporate into contract documents any necessary changes to the requirements to address the specific requirements of the application that is outside the scope of the specification. The D14 Committee encourages the Design Authority to consider the applicability of other AWS documents for applications involving aluminum (AWS D1.2), sheet steel equal to or less than 3/16 in [5 mm] thick (AWS D1.3), stainless steel (AWS D1.6), strengthening and repair of existing structures (AWS D1.7), and titanium (AWS D1.9).

1.3 Responsibilities. As demonstrated in Table 1.1, the Design, Manufacturing, and Inspection Authority may all reside with one company or separate companies. The division of responsibilities and/or deviations from this practice shall be specified in contract documents. The following entities shall be responsible, at a minimum, for the listed activities:

1.3.1 The Design Authority shall specify the following on design documents:

- (1) Full details of the required welds, including the type, size, and length.
- (2) The base metals to be used.

¹ See ASTM A941 for definitions of carbon, low-alloy, and alloy steels.

- (3) Base metal properties for those material specifications that do not specify mechanical properties (see 6.10.1).
- (4) Inspection classifications Class I, II, and III, when applicable (see 6.9).

1.3.2 The Design Authority shall specify the following in Contract Documents, when applicable:

- (1) Provisions for low temperature operations (see 6.5).
- (2) Provisions for high temperature operations (see 6.6).
- (3) Provisions for corrosive environments (see 6.7).
- (4) NDE requirements not addressed by this specification (see 6.9).
- (5) Special fillet weld hold back and end return requirements (see 7.2.3.10).
- (6) When testing is required to verify the effective weld size (see 7.2.2.3(3) and 7.2.3.12).
- (7) All requirements that add to, subtract from, or otherwise modify the requirements of this specification.

1.3.3 The Manufacturing Authority shall:

(1) Have a quality system in place that addresses welding. The requirements of AWS B5.17, *Specification for the Qualification of Welding Fabricators*, or ISO 3834, *Quality requirements for fusion welding of metallic materials*, may be used as a guide in establishing this quality program. Accreditation of quality systems of welding fabricators may be obtained through the AWS Certified Welding Fabricator (CWF) or equivalent programs.

(2) Produce welds meeting the requirements of this specification and as designated on drawings (see Clauses 10 and 11).

(3) Provide and follow written welding procedure specifications (WPSs) (see Clause 8).

(4) Ensure that qualified welders and welding operators are used to make welds (see Clause 9).

(5) Record and maintain the results of all welding procedure qualification and welder performance qualification tests (see Clauses 8 and 9).

(6) Control the use of designated base metals and consumables (see Clauses 4 and 5).

1.3.4 The Inspection Authority shall:

(1) Ensure inspection personnel are qualified in accordance with 1.4.3.

(2) Ensure inspection requirements are met in accordance with this specification and contract documents.

(3) Ensure Visual Inspection is conducted in accordance with 11.4.

(4) Ensure NDE Technicians are qualified and that data is interpreted by a qualified person in accordance with Clause 11.

(5) Ensure welds are made in accordance with the proper welding procedure (Clause 8) and by a welder qualified for that procedure (Clause 9).

1.3.5 The Inspection Authority shall be responsible for NDE not addressed by this specification per 1.3.2 (4), when applicable.

1.4 Qualifications

1.4.1 The Design Authority shall have the technical design expertise necessary to interpret and comply with this specification. The individual(s) may be on staff or contracted, and shall possess one or more of the following qualifications:

- (1) Professional or Chartered Engineer—Mechanical, Welding, Civil, Structural, Agricultural.
- (2) An individual who by degree, training, or experience is qualified in design of welded connections.

1.4.2 The Manufacturing Authority shall have the technical welding expertise necessary to interpret and comply with this specification. The individual(s) may be on staff or contracted, and shall possess one of the following qualifications:

(1) An AWS Certified Welding Engineer in conformance with the provisions of AWS B5.16, *Specification for the Qualification of Welding Engineers*,

(2) IIW International Welding Engineer (IWE),

(3) Professional Engineer (PE) with expertise in welding,

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

(5) An individual who by degree, training, or experience is qualified in welding engineering disciplines.

1.4.3 The Inspection Authority shall have the technical inspection expertise necessary to interpret and comply with this specification. The individual(s) may be on staff or contracted, and shall possess one of the following qualifications:

(1) Current 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 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*,

(3) Current 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*,

(4) Current 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 Testing 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.

1.5 Units of Measure. This standard makes use of both the U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements might not be exact equivalents; therefore, each system shall be used independently.

1.6 Safety. Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein. Safety and health information is available from the following sources:

American Welding Society:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS Safety and Health Fact Sheets

(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

1.7 Symbols. Welding symbols shown on drawings shall be compatible with those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination* or ISO 2553, *Welding and allied processes—Symbolic representation on drawings—Welded joints*. Special conditions or deviations shall be fully explained by added notes, details, or definitions on the drawings.

1.8 International Usage. This specification includes terms and symbols that are more commonly used outside of the North American market. These terms are shown in brackets [] when used in the specification.

Table 1.1
Examples of Typical Division of Responsibilities

#	Title	Description	Design Authority	Manufacturing Authority	Inspection Authority
1	Typical OEM (Default)	Original Equipment Manufacturer that designs and manufactures standard equipment models for sale in the public market. Examples: tractor, dozer, forklift, jib crane	OEM	OEM	OEM
2	Stock Component Supplier	Supplier designs and manufactures standard product or sub-components. Example: off-the-shelf welded wheels, axles, suspension components, hoist, control box	Supplier	Supplier	Supplier, with OEM verification as needed
3	Collaborative Design	Collaborative design between the owner and the manufacturer who produces the part.	Shared responsibility as agreed upon between Owner and Manufacturer	Manufacturer	Specified in contract documents
4	Subcontractor	Subcontractor manufactures parts to the design specifications of an original equipment manufacturer. Examples: loader boom, bucket, frame, drive shaft	OEM	Subcontractor	Subcontractor, with OEM verification as needed
5	Contract Manufacturing	Owner provides a customized design to a manufacturer for production. Examples: mill crane, customized press	Owner	Manufacturer	Owner
6	Owner Inspection	Owner oversees inspection of equipment produced by an original equipment manufacturer. Examples: customized track crane, overhead crane	OEM	OEM	Owner
7	Custom	Any situation that deviates from the examples cited above	Specified in contract documents	Specified in contract documents	Specified in contract documents

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) standards:

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*

AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

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

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

AWS A5.23/A5.23M, *Specification for Low-Alloy and High Manganese Steel Electrodes and Fluxes for Submerged Arc Welding*

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

AWS A5.29/A5.29M, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*

AWS A5.32M/A5.32 (ISO 14175 MOD) *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

AWS B5.1, *Specification for the Qualification of Welding Inspectors*

AWS B5.16, *Specification for the Qualification of Welding Engineers*

AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*

AWS C4.6M (ISO 9013), *Thermal Cutting—Classification of Thermal Cuts—Geometric Product Specification and Quality Tolerances*

AWS D1.1/D1.1M, *Structural Welding Code—Steel*

AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*

AWS QC1, *Specification for AWS Certification of Welding Inspectors*

AWS QC15, *Specification for the Certification of Radiographic Interpreters*

American Society for Nondestructive Testing (ASNT) standards:

ANSI/ASNT CP-189, *ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel*

SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

American Society of Mechanical Engineers (ASME) standards:

ASME Section V, *ASME Boiler and Pressure Vessel Code, Section V, Nondestructive Testing*

ASME Section VIII-Div 1, *ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels*

American Society for Testing and Materials (ASTM) standards:

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*

ASTM A435/A435M, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*
 ASTM A941, *Standard Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys*
 ASTM E94, *Standard Guide for Radiographic Examination*
 ASTM E140, *Standard Hardness Conversion Tables for Metals*
 ASTM E164, *Standard Practice for Contact Ultrasonic Testing of Weldments*
 ASTM E165/E165M, *Standard Practice for Liquid Penetrant Testing for General Industry*
 ASTM E384, *Standard Test Method for Knoop and Vickers Hardness of Materials*
 ASTM E587, *Standard Practice for Ultrasonic Angle Beam Contact Testing*
 ASTM E747, *Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*
 ASTM E1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole Type Image Quality Indicators (IQI) Used for Radiology*
 ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*
 ASTM E3024/E3024M, *Standard Practice for Magnetic Particle Testing for General Industry*

CSA Group standard:

CSA W178.2, *Welding Inspector Certification*

International Organization for Standardization (ISO) standards:

ISO 2553, *Welding and allied processes—Symbolic representation on drawings—Welded joints*
 ISO 3452-1, *Non-destructive testing—Penetrant testing—Part 1: General principles*
 ISO 3471, *Earth-moving machinery—Roll-over protective structures—Laboratory tests and performance requirements*
 ISO 9015-1, *Destructive tests on welds in metallic materials—Hardness testing—Part 1: Hardness test on arc welded joints*
 ISO 9712, *Non-destructive testing—Qualification and certification of NDT personnel*
 ISO 14175, *Welding consumables—Gases and gas mixtures for fusion welding and allied processes*
 ISO 14346, *Static design procedure for welded hollow-section joints—Recommendations*
 ISO 14347, *Fatigue—Design procedure for welded hollow section joints—Recommendations*
 ISO 14373, *Resistance welding—Procedure for spot welding of uncoated and coated low carbon steels*
 ISO 14555, *Welding—Arc stud welding of metallic materials*
 ISO 15607, *Specification and qualification of welding procedures for metallic materials—General rules*
 ISO 15609-1, *Specification and qualification of welding procedures for metallic materials—Welding procedure specification—Part 1: Arc welding*
 ISO 15614-1, *Specification and qualification of welding procedures for metallic materials—Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*
 ISO 17638, *Non-destructive testing of welds—Magnetic particle testing*
 ISO 17640, *Non-destructive testing of welds—Ultrasonic testing—Techniques, testing levels, and assessments*
 ISO 19232-5, *Non-destructive testing—Image quality of radiographs—Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators*

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

backup weld (tubular structures). The initial closing pass in a CJP groove weld, made from one side only, which serves as a backing for subsequent welding, but is not considered as a part of the theoretical weld (Figures B.8 through B.10, Details C and D).

bead reentrant angle. The reentrant angle between adjacent weld beads. In a multipass weld, this angle can be present at the weld bead toe or at the end of a weld bead. See also toe reentrant angle. See Figure 3.2.

consumables. Filler metals, fluxes, and shielding gases used in the welding process.

contract documents. Any written contractual requirements between two parties (e.g., between the owner and manufacturer or between a manufacturer and a subcontractor). Contract documents may include items such as, but not limited to: purchase orders, drawings, and specifications.

data variable (D). A welding variable that is required to be listed on a WPS whose change beyond the tolerance listed on the WPS requires a revision in the WPS but not requalification of the PQR (Formerly known as nonessential variable).

Design Authority. The individual or organization responsible for all decisions and specifications with respect to the design of the equipment and/or subcomponents.

dihedral angle (Ψ). The angle between two adjoining members on the side of the joint to which the weld is applied.

drawing. Engineering prints or drawings created by the Design Authority which convey detailed information and specifications about the parts, weldments, and/or assemblies to be manufactured.

equipment modification. An alteration to machinery or equipment constructed in accordance with these specifications that changes the original design.

falling object protection structure (FOPS). System of structural members arranged in such a way as to provide operators with reasonable protection from falling objects (e.g., trees, rocks, small concrete blocks, tools).

fracture toughness. The ability of a material to resist fracture when a flaw is present. It may be measured by Charpy V-notch, dynamic tear, plane-strain fracture toughness, or drop-weight nil-ductility transition temperature tests.

fracture toughness variable (T). A qualification variable that is required when fracture toughness is specified by the Design Authority.

hold-back. The unwelded portion of a joint where a fillet weld is intentionally started or stopped away from the end of the joint.

Inspection Authority. The individual or organization responsible for all decisions and requirements with respect to the inspection requirements of the equipment and/or subcomponents.

Manufacturing Authority. The individual or organization responsible for all decisions and requirements with respect to the manufacturing of the equipment and/or subcomponents.

operator of automatic welding equipment. Welding personnel who operate equipment that requires only occasional or no observation and no manual adjustment of the controls.

Original Equipment Manufacturer (OEM). A single manufacturer that assumes all of the responsibilities assigned by this specification.

Owner. The person, company, or agency purchasing the end product.

primary weld. Any weld on a principal structural weldment directly transferring the main working load(s).

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

qualification variable (Q). See **performance qualification variable** and **procedure qualification variable** (Formerly known as Essential Variable).

qualified person. A person who, by possession of a recognized degree or certificate of professional standing, or who, by extensive knowledge, training, and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work.

reentrant angle. The angle between lines tangent to weld profile surfaces at the junction of those surfaces. See also **bead reentrant angle** and **toe reentrant angle**. See Figures 3.1–3.5.

reentrant corner. Any corner cut within a member that forms an angle of 135 degrees or less, creating a high stress concentration. See examples in Figures 7.17 and 7.18.

repair. The restoration of machinery or equipment to meet its intended performance without changing the original design.

roll over protection structure (ROPS). System of structural members whose primary purpose is to reduce the possibility of a seat-belted operator being crushed in the event of a machine roll-over.

runout weld. A weld that is continued beyond the end of a joint as a surfacing weld. See 7.2.8.4, and Figure 7.19.

secondary member. Any component not carrying the main working loads during normal operations.

secondary weld. Any weld that does not directly transfer the main working loads through components that make up the principal structural weldment. All welds on secondary weldments are secondary welds. Welds that join attachments to principal structural weldments are secondary welds. A secondary weld can fail through the throat and not affect the normal operation of the equipment.

secondary weldment. A welded secondary member.

stress range. The algebraic difference between the maximum stress and minimum stress.

structural welds. Welds which carry the primary working loads during normal operations.

toe reentrant angle. The reentrant angle between the base metal and weld face at the weld toe or root surface at the weld root. See also bead reentrant angle. See Figures 3.1, 3.3–3.5.

welding variable. Any controllable detail of a welding procedure which is required to be addressed on the Welding Procedure Specification (WPS).

wrap. The continuation of a fillet weld around a corner of a member as an extension of the principal weld.

Z-Loss. The portion of an acute angle weld joint, in the root area, that is not included as a portion of the effective throat. See Figure B.11(D).

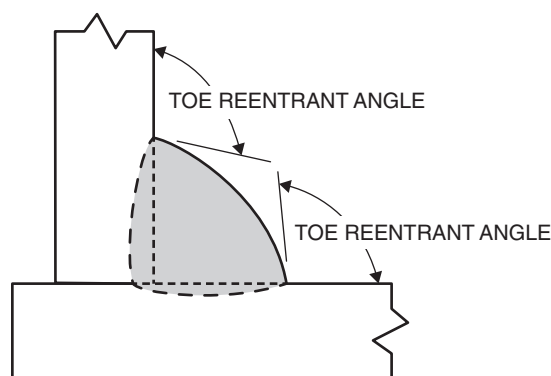


Figure 3.1—Reentrant Angles at Fillet Weld Toes

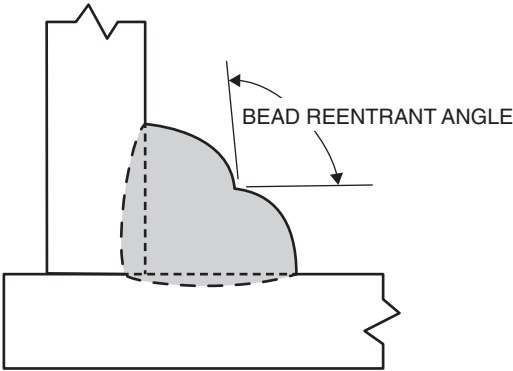


Figure 3.2—Reentrant Angle at Weld Bead Toe

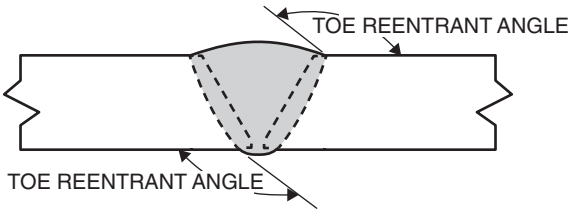


Figure 3.3—Reentrant Angles at Groove Weld Face and Root Surface

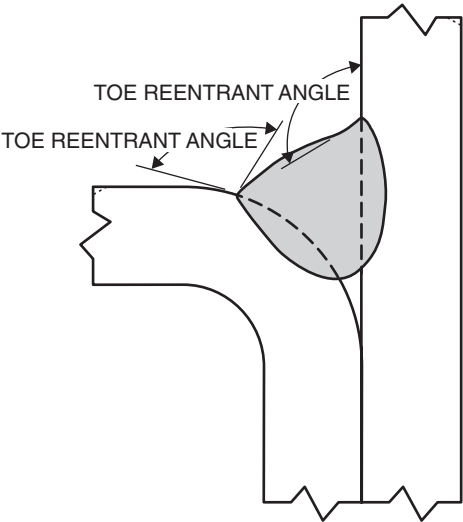


Figure 3.4—Reentrant Angles at Groove Weld Face

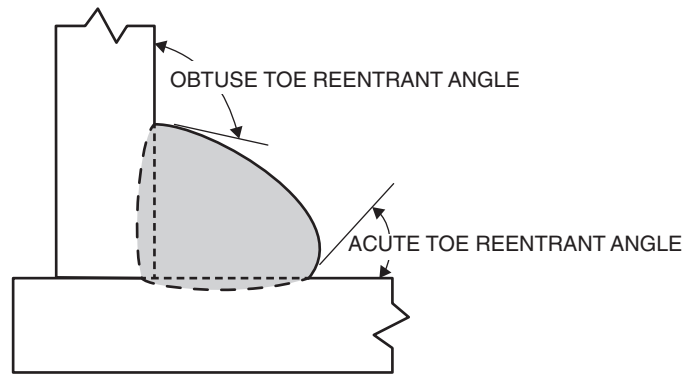


Figure 3.5—Fillet Weld with Acute and Obtuse Reentrant Angles

4. Base Metals

4.1 Base Metal Specifications. Steel, steel castings and forgings, and nonferrous metals used in the weldments of machinery and equipment shall be identified by a specification. Specifications developed by the OEM or commonly used industry-wide specifications developed by organizations such as the International Organization for Standardization (ISO), ASTM International (ASTM), SAE International (SAE), regional organizations such as the European Committee for Standardization (CEN/EN), and national organizations such as the Japanese Industrial Standards Committee (JISC/JIS), China National Standards Committee (GB/T), and the Bureau of Indian Standards Committee (BIS/IS) may be used. A list of commonly used steels, steel castings and forgings, and nonferrous metals can be found in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, and AWS B2.1/B2.1M-BMG, *Base Metal Grouping for Welding Procedure and Performance Qualification*. If a base metal has the same UNS number designation as a base metal listed in AWS B2.1/B2.1M, that base metal is also assigned that M-number or M-number plus Group Number.

4.2 Properties. Base metal specifications shall designate the chemical composition of the material to be used and when required for proper identification shall include the mechanical properties, heat treatment, or other properties of the material as specified by the Design Authority. Base metals are expected to be compatible with the welding process and consumables recommended in this specification.

4.3 Weldability and Welding Procedure Qualification. The weldability and procedure for welding base metals shall be established by qualification in accordance with the requirements of Clause 8. See Commentary C-4.3.

5. Welding Processes and Consumables

5.1 Processes

5.1.1 All welding processes and methods recognized by AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying* may be used within the scope of this document.

5.1.2 Processes which are not classified or recognized by AWS may be used, and shall be qualified according to the requirements of Clause 8.

5.2 Consumables

5.2.1 Consumables which are not classified in accordance with AWS A5 requirements may be used, provided the Manufacturer qualifies the WPS using the proposed consumables according to the requirements of Clause 8.

5.2.2 Consumables shall be protected and stored so that their characteristics or welding properties are not adversely affected. Consumable manufacturer's recommendations shall be applied. Annex H contains general practices for storage and the use of SMAW, FCAW, GMAW, and SAW consumables.

5.2.3 When a gas or gas mixture is used for shielding in any gas-shielded process, it shall meet the requirements of AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes* or ISO 14175, *Welding consumables—Gases and gas mixtures for fusion welding and allied processes*.

6. General Design Requirements

6.1 Weldment Classifications

6.1.1 Principal Structural Weldments. The Design Authority shall determine which weldment(s) carry the main working load(s) during normal operations, and are therefore principal structural weldment(s). Weldments that do not carry main working load(s) during normal operations may be considered secondary weldments.

6.1.1.1 Roll Over Protective System/Falling Object Protective System (ROPS/FOPS). All weldments that are part of the ROPS or FOPS shall be considered as principal structural weldments.

6.1.1.2 Highway Transportation Weldments. Weldments through which normal highway transportation loads are carried shall be considered as principal structural weldments. The following are not considered normal highway transportation loads: (a) loads associated with the initial shipping of the product; and (b) loads associated with off-road transportation.

6.1.1.3 Assembly and Lifting Points. Lifting points and devices associated with assembly, shipping, and erection shall be considered as principal structural weldments.

6.1.2 Welded Attachments. Attachments to principal structural weldments that are connected with welds that are 4 in [100 mm] or longer in length in the direction of principal stress shall be considered to be part of the principal structural weldment. Attachments that are welded to principal structural weldments that are connected with welds that are less than 4 in [100 mm] in length in the direction of principal stress may be considered secondary weldments.

6.1.3 Mechanically Fastened Attachments. Welded attachments that are mechanically fastened to principal structural weldments may be considered secondary members.

6.2 Weld Classifications

6.2.1 Primary Welds. The Design Authority shall determine which welds are primary welds. Primary welds shall include all welds on principal structural weldments that directly transfer main working loads through the weldment. Primary welds shall be subject to the restrictions of 7.6.

6.2.2 Secondary Welds. The Design Authority shall determine which welds are secondary welds. Welds that are less than 4 in [100 mm] in length that connect attachments to principal structural weldments are not primary welds.

6.3 Loading Classifications

6.3.1 Static Versus Cyclic Loading. The Design Authority shall determine which principal structural weldments are subject to cyclic loading under normal operating conditions. Weldments subject to fewer than 20,000 cycles of live load during the normal service life shall be considered to be statically loaded, provided the restrictions of 7.5.3.6 are met. See Commentary C-6.3.1.

6.3.2 Statically loaded principal structural weldments shall be subject to the requirements of 7.2 and 7.6.1.

6.3.3 Cyclically loaded principal structural weldments shall be subject to the requirements of 7.2, 7.5, and 7.6.2.

6.4 Combined Unit Stresses. In the case of simultaneous multi-directional stresses on weldments, all combinations of resultant stresses shall be considered.

6.5 Low Temperature Service

6.5.1 Fracture Toughness Requirements. Design criteria of welded joints in machinery and equipment could necessitate a minimum level of fracture toughness. Design criteria requiring fracture toughness shall be specified as follows:

6.5.1.1 The Owner specifies requirements for fracture toughness in the contract documents.

6.5.1.2 The Design Authority specifies requirements for fracture toughness in the design drawings.

6.5.2 When fracture toughness is required, the Design Authority shall specify the materials and portions of the structure requiring testing, the method of fracture toughness testing, testing temperatures, acceptance criteria, when heat-affected zone testing is required, and other circumstances associated with the required testing. When minimum fracture toughness for welded joints is required, the welding procedure specification(s) for the applicable joints shall be qualified by test; qualification by prototype testing or prequalified welding procedures is not permitted. Welding procedure qualification testing shall include fracture toughness testing of the weld metal and, if required, the heat-affected zone.

6.6 High Temperature Service. Design criteria of welded joints in machinery and equipment might require special consideration when the operating temperature of the equipment is above 300 °F [150 °C]. Considerations may include reduced material strength, stiffness, creep, thermal expansion, fatigue resistance, or other factors. The Design Authority shall be responsible for determining what factors need to be considered and how to address them. See Commentary C-6.6.

6.7 Corrosion. Design criteria of welded joints in machinery and equipment might require special consideration when the weldment is subject to corrosive conditions. Considerations may include the required coatings, fatigue resistance, or other factors. The Design Authority shall be responsible for determining what factors need to be considered and how to address them. See Commentary C-6.7.

6.8 Filler Metals. The Design Authority shall specify when the weld filler metal tensile strength is required to, or permitted to, undermatch the base metal tensile strength. When no strength level is specified, the filler metals shall match the base metal strength. See Commentary C-6.8.

6.9 Visual Inspection and Nondestructive Testing

6.9.1 Visual Inspection. All welds shall be subject to Visual Inspection per Inspection Class IV of Table 11.1 with the Acceptance Criteria given in Table 11.2

6.9.2 NDE. The Design Authority shall designate in the contract documents the required Inspection Class per 7.5.4.4 and 7.5.4.5. The default Inspection Classification is IV. See Tables 11.1 and 11.2 for Inspection Class Requirements and Acceptance Criteria, respectively.

6.10 Base Metal Selection. See Clause 4 for information on specifying base metals. When selecting base materials, the weldability of the materials to be joined shall be considered. See Commentary C-6.10 for more information.

6.10.1 Mechanical Properties of Base Metal. When the base metal specification does not establish the minimum mechanical properties (e.g., tensile strength, yield strength, percent elongation) required for welding procedure qualification or other processes, the Design Authority shall establish the required minimum mechanical properties. The documentation may be in the form of references to published data or compilations of test data. In the establishment of minimum mechanical properties for design purposes, size effects, thermal or mechanical treatments, and the effect of the welding process on the base material heat-affected zone shall be considered.

6.11 Special Joint Considerations

6.11.1 Eccentricity of Connections

6.11.1.1 Moments caused by significant deviation from concentric or axially aligned connections shall be provided for in analysis and design (see Figure 6.1 for an illustration of an eccentric connection).

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

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

6.11.2 Connections and Splices in Compression Members

6.11.2.1 For connections of compression members bearing on bearing plates, there shall be sufficient weld to hold all parts in place.

6.11.2.2 Where compression members are finished to bear at splices or connections, welds shall be designed to hold all parts in alignment and shall be proportioned to carry 50% of the computed stress in the member.

6.11.2.3 Welds joining splices in compression members which are not finished to bear, shall be designed to transmit the force in the members.

6.11.2.4 In all cases, if there is repeated application of the load, the maximum stress range in such connections or splices shall not exceed the fatigue stresses allowed by this specification.

6.11.3 Connections of Components of Built-Up Members. When a member is built up of two or more pieces, the pieces shall be connected along their longitudinal joints by sufficient weld to make the pieces act in unison.

6.11.4 Beam Copes and Weld Access Holes. Radii of beam copes and weld access holes shall provide a smooth transition free of notches or cutting past the points of tangency between adjacent surfaces and shall meet the surface requirements of 10.4 and 10.5.

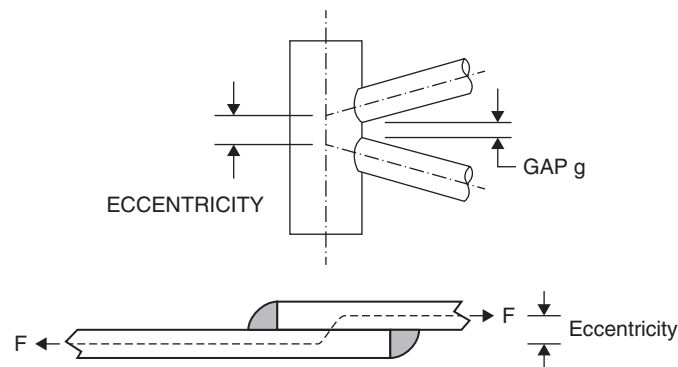


Figure 6.1—Illustration of Eccentric Connections

7. Welded Connection Design

7.1 Joint Details. Typical joint details can be found in Annex B. The standard welding symbols used to describe joint details shall comply with 1.6. See Annex B for alternative details of partially filled flare groove welds.

7.1.1 Butt Joint Width and Thickness Transitions

7.1.1.1 Butt joints in principal structural weldments between parts having unequal thicknesses and subject to tensile stress shall have a smooth transition between the offset surfaces at a slope of no more than 1 in 2.5 with the surface of either part. The transition may be accomplished by sloping weld surfaces, by chamfering the thicker part, or by a combination of the two methods (see Figure 7.1).

7.1.1.2 In butt joints in principal structural weldments between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished, as specified in Figure 7.1, when the offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected. When the offset is equal to or less than the thickness of the thinner part connected, the face of the weld shall be sloped no more than 1 in 2.5 from the surface of the thinner part or shall be sloped to the surface of the thicker part if this requires a lesser slope with the following exception: truss member joints and beam and girder flange joints shall be made with smooth transitions of the type specified in 7.1.1.1.

7.1.1.3 Butt joints in principal structural weldments between parts having unequal width and subject to tensile stress shall have a smooth transition between offset edges at a slope of no more than 1 in 2.5 with the edge of either part or shall be transitioned with a 2.0 ft [0.6 m] minimum radius tangent to the narrower part of the center of the butt joints (see Figure 7.2).

7.1.2 T-Joints

7.1.2.1 Skewed T-Joints. In skewed T-joints, the upright member may be chamfered or left square (see Figure 7.3). See Figure B.11 for detailing of welds in skewed T-joints.

7.1.3 Corner Joints. For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting.

7.1.4 Lap Joints

7.1.4.1 In principal structural weldments, the minimum overlap of parts in lap joints shall be five times the thickness of the thinner part, but not less than 1 in [25 mm] (see Figure 7.4).

7.1.4.2 Unless lateral deflection of the lapped parts is prevented, the lapped parts shall be welded on both sides of the joint by one of the following methods:

- (1) Transverse fillet welds on the end of each lapped member (Figure 7.4).
- (2) At least two transverse lines of plug or slot welds (Figure 7.5 (a) and (b)).
- (3) Two or more longitudinal fillet welds in holes or slots (Figure 7.6).

7.1.4.3 Longitudinal fillet welds may be either at the edges of the member or in slots or holes. The following provisions for fillet weld lengths and the perpendicular spacing between longitudinal fillet welds apply:

(1) 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 them (Figure 7.7).

(2) The transverse spacing of longitudinal fillet welds used in end connections 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 welds may be either at the edges of the member or in slots.

7.1.4.4 When fillet welds in holes or slots are used, the clear distance from the edge of the hole or slot to the adjacent edge of the part containing it, measured perpendicular to the direction of stress, shall be no less than five times the thickness of the part, nor less than two times the width of the hole or slot (Figure 7.8). The strength of the part shall be determined from the critical net section of the base metal.

7.1.5 Parallel Joints. Parallel joints (formerly known as edge joints) shall be designed in such a way to prevent prying about the root of the weld. See prohibition in 7.6.1.5.

7.2 Details of Welds

7.2.1 Complete Joint Penetration (CJP) Groove Welds

7.2.1.1 Effective Area. The effective area of a complete joint penetration groove weld shall be the effective length multiplied by the effective weld size.

7.2.1.2 Effective Length. The effective length of a complete joint penetration groove weld shall be the width of the part joined, perpendicular to the direction of tensile or compressive stress. For groove welds transmitting shear, the effective length is the length specified. See Figure 7.9.

7.2.1.3 Effective Weld Size. The effective size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

7.2.1.4 Minimum Length. Intermittent or partial length complete joint penetration groove welds shall be prohibited except that members built-up of elements connected by fillet welds may have groove welds of limited length at points of localized load. The groove weld shall extend at uniform size for at least the length required to transfer the load. Beyond this length, the groove should be made with a transition in depth to zero over a distance not less than four times its depth.

7.2.1.5 Prequalified Details. When prequalified welding procedures are used in accordance with 8.5, only the prequalified CJP groove details in Annex B, Figure B.1 may be used. If other details are used, the detail shall be qualified in accordance with Clause 8.

7.2.1.6 Dimensional Tolerances. Dimensions of groove welds specified in 7.2.1.5 may vary on design or detailed drawings within the limits or tolerances shown in the "As Detailed" column in Figure B.1. J- and U-grooves may be prepared before or after assembly.

7.2.1.7 Joint Root Openings. Joint root openings may vary as noted in Annex B and 10.7.2. However, for automatic or machine welding using the FCAW, GMAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) should not exceed 1/8 in [3 mm]. Variations greater than 1/8 in [3 mm] should be locally corrected prior to automatic or machine welding.

7.2.1.8 Backing. Requirements for welds for attaching steel backing and whether the backing shall be removed or left in place shall be determined as described in (1), (2), and (3) below, and the stress range categories of Table 7.9.

(1) T- and Corner Joints Made from One Side. Welds for attaching backing may be made inside or outside the joint groove. Backing for joints subject to cyclic transverse tension (fatigue) loading shall be removed and the back side of the joint finished in accordance with the finish and roughness criteria of Table 11.2 and inspected in accordance with Table 11.1.

(2) Butt Splices. Welds for attaching backing may be inside or outside the groove unless restricted in the stress category description. Tack welds located outside the joint groove shall terminate not closer than 1/2 in [12 mm] from the edge of the connected part. Backing may remain in place or be removed unless restricted in the stress category used in design.

(3) Longitudinal Groove Welds and Corner Joints. Steel backing, if used, shall be continuous for the full length of the joint. If splicing of steel backing is required for long joints, the splice shall be made with a complete joint penetration groove weld. Welds for attaching backing may be inside or outside the groove.

7.2.1.9 Filler Metal Strength. Filler metal strengths shall be as specified in Table 7.1.

7.2.1.10 Allowable Stress. The calculated stresses on the effective area of welded joints shall not exceed the allowable stresses given in Table 7.1.

7.2.1.11 Finishing Techniques. Groove welds may be finished by grinding, chipping, machining, or other method approved by the Design Authority. Reasons for finishing groove welds include improved fatigue life, cosmetics, or fit. If not specified, groove welds shall be left in the as welded condition provided they meet the quality acceptance criteria of 11.4.6.

7.2.1.12 Prohibited Details. The restrictions of 7.6 shall apply to all primary welds on principal structural weldments.

7.2.2 Partial Joint Penetration (PJP) Groove Welds

7.2.2.1 Effective Area. The effective area of a partial joint penetration groove weld shall be the effective length multiplied by the effective weld size.

7.2.2.2 Effective Length. The effective length for a partial joint penetration groove weld shall be the width of the part joined (see Figure 7.9). In the case of intermittent partial joint penetration groove welds, the cumulative full length of each weld segment shall be taken as the effective length.

7.2.2.3 Effective Weld Size. The effective size of a partial joint penetration groove weld is dependent on the groove joint geometry and welding variables. Effective weld size for specific joint preparation geometries is specified in the prequalified joint details in Annex B. Common examples include:

(1) When the included groove angle is 60° or greater the weld size shall be equal to the depth of bevel for the following welding processes: SMAW, SAW, GMAW, FCAW.

(2) When the included groove angle is less than 60°, refer to Figure 7.3, Table 7.2, Table 7.3, or an appropriate joint detail in Annex B. Note the Z-Loss dimensions for determining effective throat.

(3) The effective weld size for flare groove welds, when filled flush to the radiused member surface—such as a round bar or 90° bend in a formed section, or the corner of a rectangular tube—shall be as shown in Table 7.4. Alternatively, when required by the Design Authority, validation test sections shall be used to verify that the effective weld size is consistently obtained. Validation required shall consist of sectioning the radiused member normal to its axis, at mid-length, and at the ends of the weld. The section shall be no closer than 1 in [25 mm] from each weld end. Such sectioning shall be made on a number of combinations of material sizes representative of the range used in construction, or as required by the Design Authority.

7.2.2.4 Minimum Effective Length. The minimum effective length of a PJP groove weld shall be at least four times the nominal weld size.

7.2.2.5 Minimum Size. The minimum weld size of partial joint penetration groove welds required to provide adequate heat input shall be as shown in Table 7.5. The use of minimum weld sizes is not intended to preclude the use of appropriate preheat which may be required because of joint restraint or base metal composition.

7.2.2.6 Prequalified Details. When prequalified welding procedures are used in accordance with 8.5, only the prequalified PJP groove details in Annex B, Figure B.2 shall be used. If other details are used, the detail shall be qualified in accordance with Clause 8.

7.2.2.7 Skewed T-Joints. Welds in skewed T-joints, with angles smaller than 60°, are considered partial joint penetration groove welds (see Figure 7.3).

7.2.2.8 Dimensional Tolerances. Dimensions of groove welds specified in 7.2.2.6 may vary on design or detailed drawings within the limits or tolerances shown in the “As Detailed” column in Figure B.2. J- and U-grooves may be prepared before or after assembly.

7.2.2.9 Filler Metal Strength. Filler metal strengths shall be as specified in Table 7.1.

7.2.2.10 Allowable Weld Metal Stress. The calculated stresses on the effective area of welded joints shall not exceed the allowable stresses given in Table 7.1.

7.2.2.11 Finishing Techniques. Groove welds may be finished by grinding, chipping, machining, or other method approved by the Design Authority. Reasons for finishing groove welds include improved fatigue life, cosmetics, or fit. If not specified, groove welds may be left in the as welded condition provided they meet the quality acceptance criteria of 11.4.6.

7.2.2.12 Prohibited Details. The restrictions of 7.6 shall apply to all primary welds on principal structural weldments.

7.2.3 Fillet Welds

7.2.3.1 Effective Area. The effective area shall be the effective length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load. Stress on the effective throat area of fillet welds (see 7.2.3.4) is considered as shear stress regardless of the direction of load application.

7.2.3.2 Effective Length. The effective length of a fillet weld shall be the overall length of the full-size fillet, including any weld wrap. No reduction in effective length shall be made for either the start or crater of the weld if the weld is full size throughout its length. The effective length of a curved fillet weld shall be measured along the center line of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area found from 7.2.4.1, then this latter area shall be used as the effective area of the fillet weld.

7.2.3.3 Effective Throat. The effective throat shall be the minimum distance, minus any convexity, between the weld root and the face of a fillet weld. See 7.2.3.8 for skewed T-joints. See Figures 7.11 and 7.12.

7.2.3.4 Minimum Length. The minimum effective length of a fillet weld shall be at least four times the nominal size, or the effective size of the weld shall not exceed one fourth its effective length.

7.2.3.5 Intermittent Welds. The minimum length of an intermittent fillet weld shall be in accordance with 7.2.3.4, and the clear space between intermittent fillet weld segments shall not exceed 12 times the thickness of the thinner part, but not more than 6 in [150 mm].

7.2.3.6 Minimum Size

(1) The minimum single pass fillet weld size shall be as shown in Table 7.6. The weld sizes shown in Table 7.6 are required to provide adequate heat input for quality welds. Smaller weld sizes may be used when the WPS is qualified by test in accordance with Clause 8.

(2) The minimum fillet weld size to develop the full static strength of the thinner member joined is given in Table 7.7. These values are only applicable when the filler metal is properly matched with the base metal; the welds are loaded statically, and the thinner plate or leg is fillet welded continuously on both sides (double fillet weld).

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

- (1) The thickness of the base metal, for metal less than 1/4 in [6 mm] thick as detailed in Figure 7.10(A), or
- (2) 1/16 in [2 mm] less than the thickness of base metal, for metal 1/4 in [6 mm] or more in thickness, as detailed in Figure 7.10(B), unless the weld is designated on the drawing to be built out to obtain full throat thickness. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld may be less than 1/16 in [2 mm], provided the weld size is clearly verifiable.

7.2.3.8 Fillet Welds in Skewed T-Joints. Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60° nor greater than 135° (see Figure 7.3).

7.2.3.9 Fillet Welds in Holes or Slots. Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. The minimum diameters of a hole or radius of a slot shall be a function of the thickness of the material (t) with the hole or slot. Fillet welds in holes or slots shall not be considered as plug or slot welds.

- (1) The minimum diameter of a hole shall be the greater of 4t or 2 in [50 mm].
- (2) Except for those ends which extend to the edge of the part, the ends of the slot shall be semicircular. The minimum radius of a slot shall be the greater of the thickness of the plate or 1/2 in [12 mm]. The straight portion of the slot should have a minimum length of 4t. Slots with straight portions less than 4t shall have a minimum radius the greater of 2t or 1 in [25 mm].

7.2.3.10 Fillet Weld Terminations. Fillet welds shall terminate at the end of the joint unless otherwise specified on the drawing. The Design Authority may establish and document a different default fillet weld termination practice. See Commentary C-7.2.3.10.

7.2.3.11 Prequalified Details. Fillet welds sized in accordance with Annex B, Figure B.3 are considered prequalified and may be used with prequalified welding procedures.

7.2.3.12 Deep Penetrating Fillet Welds. Deep penetrating fillet welding procedure specifications shall be qualified in accordance with 8.4.3 prior to utilization in design.

7.2.3.13 Filler Metal Strength. Filler metal strengths shall be as specified in Table 7.1.

7.2.3.14 Allowable Stress. The calculated stresses on the effective area of welded joints shall not exceed the allowable stresses given in Table 7.1.

7.2.3.15 Finishing Techniques. Unless otherwise specified, fillet welds may be left in the as welded condition provided they meet the quality acceptance criteria of 11.4.6. If toe grinding, toe peening, GTAW dressing, or other finishing methods are required by the Design Authority, they shall be specified in contract documents. Toe treatments of fillet welds are typically performed to improve fatigue life.

7.2.3.16 Prohibited Details. The restrictions of 7.6 shall apply to all primary welds on principal structural weldments.

7.2.4 Plug and Slot Welds

7.2.4.1 Effective Area. The effective area of a plug or slot weld shall be the nominal area of the hole or slot in the plane of the faying surface.

7.2.4.2 Maximum Length. The length of the slot for a slot weld shall not exceed ten times the thickness of the part containing it.

7.2.4.3 Minimum Diameter or Width. The minimum diameter of the hole for a plug weld or width of a slot for a slot weld shall be as follows:

- (1) For material 1/4 in [6 mm] or greater in thickness, no less than the thickness of the part containing it plus 5/16 in [8 mm];
- (2) For material less than 1/4 in [6 mm] in thickness, no less than the thickness of the part containing it plus 1/4 in [6 mm].

7.2.4.4 Maximum Diameter or Width. 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.

7.2.4.5 Spacing of Plug and Slots. The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole. 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 of any line shall be two times the length of the slot.

7.2.4.6 Prequalified Details. Plug and slot welds properly detailed in accordance with the requirements of 7.2.4 shall be considered prequalified. If other details are used, the detail shall be qualified in accordance with 8.4.4.

7.2.4.7 Depth of Fill. 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 material. In metal over 5/8 in [16 mm] thick, it shall be at least one-half the thickness of the material, but no less than 5/8 in [16 mm].

7.2.4.8 Filler Metal Strength. Filler metal strengths shall be as specified in Table 7.1.

7.2.4.9 Allowable Stress. The calculated stresses on the effective area of welded joints shall not exceed the allowable stresses given in Table 7.1.

7.2.4.10 Finishing Techniques. Plug and slot welds may be left in the as welded condition. Excess reinforcement may be removed by grinding, machining or other method approved by the Design Authority.

7.2.4.11 Prohibitions

(1) The effective area of plug and slot welds is considered to resist shear stresses only.

(2) Plug and slot welds shall not be used on quenched and tempered steels unless consideration is made by the Design Authority for the potential of a reduction in strength and hardness of the heat-affected zone. See Commentary C-7.2.4.11.

7.2.4.12 Tab and Slot Construction. When a slot or plug weld is used to secure or seal a tab, the tab height should be sized to approximately 1/2 of the material thickness (see Figure 7.13). In cases of cyclic loading, fatigue life should be evaluated. See Commentary C-7.2.4.12.

7.2.5 Edge Welds. Edge welds shall be detailed as partial joint penetration groove welds (see requirements in 7.2.2). Alternatively, parallel joints may be changed to lap joints to allow the use of fillet welds (see requirements in 7.2.3).

7.2.6 Resistance Spot Welds. Resistance spot welding shall be performed in accordance with AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low Alloy Steels* or ISO 14373, *Resistance welding — Procedure for spot welding of uncoated and coated low carbon steels*.

7.2.7 Stud Welding

7.2.7.1 Effective Area. The effective area shall be the nominal area of the stud at its smallest diameter. In the case of studs attached by circumferential fillet welds, refer to 7.2.3.2.

7.2.7.2 Minimum Diameter. The stud diameter shall be large enough to ensure adequate heat input and fusion. Minimum diameter for a given material thickness shall be qualified in accordance with AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* or ISO 14555, *Welding — Arc stud welding of metallic materials*.

7.2.7.3 Maximum Diameter. Refer to the recommendations for maximum stud diameter relative to material thickness in Table 7.8.

7.2.7.4 Allowable Stress. The allowable stress on studs shall be based on the minimum strength of the stud as listed in the stud's material and product specification(s). For studs with a diameter larger than the base material thickness, shear strength of base metal shall also be checked.

7.2.7.5 Prohibitions. Stud welds shall not be used on quenched and tempered steels unless consideration is made by the Design Authority for the potential of a reduction in strength and hardness of the heat-affected zone and a qualified welding procedure is used. See Commentary C-7.2.7.5.

7.2.8 Combinations of Welds. If two or more of the general types of welds (groove, fillet, plug, or slot) are combined in a single joint, their allowable capacity shall be computed with reference to the axis of the group in order to determine

the allowable capacity of the combination. However, such methods of adding individual capacities of welds do not apply to fillet welds reinforcing groove welds (see 7.2.8.2).

7.2.8.1 Effective Area. The effective area shall be the effective length multiplied by the effective throat.

7.2.8.2 Effective Throat. The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the minimum distance from the joint root to the weld face of the fillet weld with appropriate allowances for the difference between the D and S dimensions based on the groove angle (see Figure 7.14 and 7.2.2.3).

7.2.8.3 Effective Length. The effective length of a combination weld shall be the overall length of the full-size weld. No reduction in effective length shall be made for either the start or crater of the weld if the weld is full size throughout its length. The effective length of a curved combination weld shall be measured along the center line of the effective throat.

7.2.8.4 Runout Welds. When required by the Design Authority, runout welds shall be specified on design drawings as indicated in Figure 7.19. See Commentary C-7.2.8.4.

7.2.9 Tack Weld Terminations. Where the tack weld termination locations are required, they shall be specified on the drawing.

7.3 Tubular Connections. Refer to the “design of tubular connections” clauses of AWS D1.1/D1.1M or ISO 14346, *Static design procedure for welded hollow-section joints — Recommendations* and ISO 14347, *Fatigue — Design procedure for welded hollow section joints — Recommendations*.

7.4 Welds in Combination with Rivets and Bolts. Rivets and bolts in combination with welds shall not be considered as sharing the stress, and the welds shall be provided to carry the entire stress for which the connection is designed. Bolts or rivets used in assembly may be left in place if their removal is not specified. If bolts are to be removed, the Design Authority shall indicate whether holes are to be filled, and in what manner.

7.5 Cyclic Loading

7.5.1 General

7.5.1.1 The provisions of this section shall apply to welds subject to fatigue with the number of loading cycles greater than 20,000. See 7.5.3.6.

7.5.2 High Cycle Models

7.5.2.1 A high cycle weld fatigue life evaluation method is presented for machinery and equipment designers in 7.5.3 and following. It is based on the weld fatigue stress life methodology specified in AISC 360.

7.5.2.2 Alternatively, the Design Authority may choose to follow one of the methodologies developed by the International Institute of Welding and published in *Recommendations for Fatigue Design of Welded Joints and Components*. The IIW methods are particularly relevant when finite element analysis is used to determine stress ranges and/or when a cumulative damage model is needed.

7.5.2.3 The Design Authority may approve other fatigue life evaluation methods. All the constraints and rules of the selected method shall be followed. The results of different evaluation methodologies may be compared, but in no case shall two distinct methods be combined.

7.5.3 General Considerations

7.5.3.1 Loading Cycles

- (1) The expected number of loading cycles experienced at a given stress range shall be computed.
- (2) For cyclic loading of less than 20,000 cycles, see 7.5.3.6.
- (3) In cases where components might accumulate very high numbers of loading cycles (e.g., over 100 million), special considerations should be made. For example, this can occur with vibrating tools and rotating shafts. In such cases, see 7.5.3.7 and C-7.5.3.7.

7.5.3.2 Stress Range. Stress range shall be computed as the difference between the maximum stress and the minimum stress experienced during loading cycles. In the case of a stress reversal, the stress range is the algebraic difference between the maximum and minimum stress in one reversal.

7.5.3.3 Stress Calculations. Calculated stresses shall be based upon elastic analysis. Stresses shall not be amplified by stress concentration factors for geometrical discontinuities. In the case of axial stress combined with bending, the maximum stresses of each kind shall be those determined for concurrent arrangements of the applied load. The total stresses including those due to eccentricity shall be included in the calculation of the stress range.

7.5.3.4 Stress Category. For cyclically loaded principal structural weldments, the Design Authority shall determine the applicable stress category, consistent with Table 7.9. Such a determination shall be made for every connection with a primary weld and for every welded attachment made to a principal structural weldment. The Design Authority shall calculate the allowable stress range using the equations presented in 7.5.5 or the values presented in Table 7.9.

7.5.3.5 Threshold Allowable Stress Range. When all applied cyclic stress ranges are less than the threshold allowable stress range (F_{TH}), no further evaluation of fatigue resistance is required. See Table 7.9.

7.5.3.6 Number of Cycles. The fatigue resistance of weldments need only be determined when the number of cycles of load application exceeds 20,000.

7.5.3.7 Constant Amplitude Loading. The provisions of this section assume constant amplitude loading. For variable amplitude loading, see 7.5.3.8. Additionally, if there are stress ranges both below and above the threshold values (F_{TH}), the stress ranges below the threshold value (F_{TH}) shall be considered and *Recommendations for Fatigue Design of Welded Joints and Components* is recommended to be used. See 7.5.3.8 for additional guidance.

7.5.3.8 Variable Amplitude Loading. The Design Authority shall evaluate the stress ranges imposed on the connections and their effect on the fatigue life of the component or structure. See C-7.5.3.8.

7.5.3.9 Connection Details

- (1) If fillet welds are used to attach left-in-place longitudinal backing, they shall be continuous. See also 7.2.1.9.
- (2) In transverse CJP groove welded T- and corner-joints, a contouring fillet weld, not less than 1/4 in (6 mm) in size, shall be added.
- (3) The surface roughness of thermally cut edges subject to cyclic stress ranges shall not exceed the requirements in 10.5.2.
- (4) Reentrant corners shall form a radius not less than the prescribed radii in Table 7.9 (see Descriptions 1.3, 1.4, 6.1, 6.2, 6.3, 6.4, and 7.2, as applicable). Radii may be formed by predrilling or sub-punching and reaming a hole, or by thermal cutting to form the radius of the cut. Radii shall be ground as applicable. See examples of acceptable and unacceptable reentrant corners in Figures 7.17 and 7.18.
- (5) For transverse butt joints in regions of tensile stress, weld tabs shall be used to provide for cascading the weld termination outside the finished joint. End dams shall not be used. Weld tabs shall be removed, and the end of the weld finished flush with the edge of the member. See 10.7.4.
- (6) Fillet welds subject to cyclic loading normal to the outstanding legs of angles or on the outer edges of end plates shall wrap around the end of the part for a length not less than two times the weld size; the wrap weld length shall not exceed four times the weld size. See Figure 7.20, 10.7.1.6, and C-10.7.1.6.
- (7) When welded repairs are made to base material, the effect on the fatigue life of the structure shall be evaluated. The Manufacturing Authority shall consult with the Design Authority prior to making any base metal repairs. See 10.8.4 and Commentary C-7.5.3.9 (7).

7.5.4 Constraints of the AISC Stress Life Model

7.5.4.1 Maximum Stress. The provisions of 7.5.3 and 7.5.5 shall apply to stresses calculated on the basis of the applied cyclic load spectrum. The maximum permitted stress due to peak cyclic loads shall be 66% of the material's yield strength.

7.5.4.2 Corrosion Resistance. The cyclic load resistance determined by the provisions of 7.5.3 and 7.5.5 are applicable to members with suitable corrosion protection or subject only to mildly corrosive atmospheres, such as normal atmospheric conditions.

7.5.4.3 Temperature Limits. The cyclic load resistance determined by the provisions of 7.5.3 and 7.5.5 is applicable only to members subject to temperatures not exceeding 300 °F (150 °C).

7.5.4.4 Nondestructive Examination Requirements. The cyclic load resistance determined by the provisions of 7.5.3 and 7.5.5 is applicable only to members with welds that have been inspected in accordance with Table 7.9.

7.5.4.5 Alternative Nondestructive Testing Requirements. In lieu of the requirements of 7.5.4.4, the Design Authority may specify alternative NDE criteria, including increases or reductions in the inspection frequency or elimination of the NDE requirements altogether. Alternative NDE criteria should be based on experience, consistency of manufacturing quality, prototype testing and the field performance of machinery and equipment. Intermittent spot testing of production assemblies should be considered as part of any alternative NDE criteria.

7.5.4.6 Material Limits. The stress categories presented in 7.5.3.4 apply to structural steels with a specified minimum yield stress of 36 to 100 ksi.

7.5.5 Equations. In plain material and welded joints, the range of stress due to the applied cyclic loads shall not exceed the allowable stress range computed as follows.

7.5.5.1 For stress categories A, B, B', C, D, E and E', the allowable stress range, F_{SR} , shall be determined by the following equations:

$$F_{SR} = 1000 \left(\frac{C_f}{n_{SR}} \right)^{0.333} \geq F_{TH} \quad (1)$$

$$F_{SR} = 6900 \left(\frac{C_f}{n_{SR}} \right)^{0.333} \geq F_{TH} \text{ (SI)} \quad (2)$$

where

C_f = constant from Table 7.9 for the fatigue category

F_{SR} = allowable stress range, ksi [MPa]

F_{TH} = threshold allowable stress range, maximum stress range for indefinite design life from Table 7.9, ksi [MPa]

n_{SR} = number of stress range fluctuations in design life

7.5.5.2 For stress category F, the allowable stress range, F_{SR} , shall be determined by the following equations:

$$F_{SR} = 100 \left(\frac{1.5}{n_{SR}} \right)^{0.167} \geq 8 \text{ ksi} \quad (3)$$

$$F_{SR} = 690 \left(\frac{1.5}{n_{SR}} \right)^{0.167} \geq 55 \text{ MPa (SI)} \quad (4)$$

7.5.5.3 For tension-loaded plate elements connected at their end by cruciform, T or corner details with partial-joint-penetration (PJP) groove welds transverse to the direction of stress, with or without reinforcing or contouring fillet welds, or if joined with only fillet welds, the allowable stress range on the cross section of the tension-loaded plate element shall be determined as the lesser of the following:

(1) Based upon crack initiation from the toe of the weld on the tension-loaded plate element, the allowable stress range, F_{SR} , shall be determined by the equations in 7.5.5.1 for stress category C.

(2) Based upon crack initiation from the root of the weld, the allowable stress range, F_{SR} , on the tension loaded plate element using transverse PJP groove welds, with or without reinforcing or contouring fillet welds, the allowable stress range on the cross section at the root of the weld shall be determined by the equations below, for stress category C':

$$F_{SR} = 1000 \times R_{PJP} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad (5)$$

$$F_{SR} = 6900 \times R_{PJP} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \text{ (SI)} \quad (6)$$

Where R_{PJP} , the reduction factor for reinforced or nonreinforced transverse PJP groove welds, is determined as follows:

$$R_{PJP} = \frac{0.65 - 0.59 \left(\frac{2a}{t_p} \right) + 0.72 \left(\frac{w}{t_p} \right)}{t_p^{0.167}} \leq 1.0 \quad (7)$$

$$R_{PJP} = \frac{1.12 - 1.01 \left(\frac{2a}{t_p} \right) + 1.24 \left(\frac{w}{t_p} \right)}{t_p^{0.167}} \leq 1.0 \text{ (SI)} \quad (8)$$

$2a$ = length of the nonwelded root face in the direction of the thickness of the tension-loaded plate, in [mm]

t_p = thickness of tension loaded plate, in [mm]

w = leg size of the reinforcing or contouring fillet, if any, in the direction of the thickness of the tension-loaded plate, in [mm]

If $R_{PJP} = 1.0$, the stress range will be limited by the weld toe and category C will control.

(3) Based upon crack initiation from the roots of a pair of transverse fillet welds on opposite sides of the tension loaded plate element, the allowable stress range, F_{SR} , on the cross section at the root of the welds shall be determined by the equations below, for stress category C'':

$$F_{SR} = 1000 \times R_{FIL} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad (9)$$

$$F_{SR} = 6900 \times R_{FIL} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \text{ (SI)} \quad (10)$$

Where R_{FIL} , the reduction factor for joints using a pair of transverse fillet welds only, is determined as follows:

$$R_{FIL} = \frac{0.06 + 0.72 \left(\frac{w}{t_p} \right)}{t_p^{0.167}} \leq 1.0 \quad (11)$$

$$R_{FIL} = \frac{0.103 + 1.24 \left(\frac{w}{t_p} \right)}{t_p^{0.167}} \leq 1.0 \text{ (SI)} \quad (12)$$

If $R_{FIL} = 1.0$, the stress range will be limited by the weld toe and category C will control.

User Note: Stress categories C' and C'' are cases where the fatigue crack initiates in the root of the weld. These cases do not have a fatigue threshold and cannot be designed for an infinite life. Infinite life can be approximated by use of a very high cycle life such as 2×10^8 . Alternatively, if the size of the weld is increased such that R_{PJP} or R_{FIL} is equal to 1.0, then the base metal controls, resulting in stress category C, where there is a fatigue threshold and the crack initiates at the toe of the weld.

7.6 Prohibited Joints

7.6.1 Prohibited Joints and Welds in Principal Structural Weldments. The following shall be prohibited for all primary welds on all principal structural weldments, whether subject to static or cyclic loading (see Annex D for illustrative examples):

(1) Butt joints with single sided PJP groove welds, loaded in tension perpendicular to the weld axis, where rotation about the weld root is not restricted.

(2) T-joints with single sided fillet or PJP groove welds, loaded in tension perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

(3) Corner joints with single sided PJP groove or fillet welds, loaded in tension perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

(4) Any CJP groove weld with no particular joint preparation, unless the joint conforms to Annex D.

(5) Any parallel joint where the loading is not parallel to the weld axis.

7.6.2 Prohibited Joints and Welds in Cyclically Loaded Principal Structural Weldments. In addition to the restrictions of 7.6.1, the following shall be prohibited for all primary welds on principal structural weldments subject to cyclic loading (see Annex D for illustrative examples):

(1) Butt joints with single sided PJP groove welds, loaded in compression perpendicular to the weld axis.

(2) T-joints with single sided fillet or PJP groove welds, loaded in compression perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

(3) Corner joints with single sided PJP groove welds, loaded in compression perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

(4) Butt, T-, and corner joints with single sided CJP groove welds made without steel backing where primary bending stresses are imposed on the root of the weld, unless weld root is inspected with MT in accordance with 11.7 or PT in accordance with 11.8.

(5) Butt, T-, and corner joints with single sided CJP groove welds made with removable backing (ceramic, copper, or other) or with no backing, where primary bending stresses are imposed on the root of the weld, unless the WPS is qualified in accordance with this specification, and the weld root is inspected with MT in accordance with 11.7 or PT in accordance with 11.8.

(6) T- and corner joints with single sided CJP groove welds made with left in place steel backing, where primary bending stresses are imposed on the root of the weld.

(7) T- and corner joints with double sided groove welds without reinforcing (contouring) fillet welds.

Table 7.1
Allowable Stresses
(see 7.2.1.9, 7.2.1.10, 7.2.2.9, 7.2.2.10, 7.2.3.13, 7.2.3.14, 7.2.4.8, and 7.2.4.9)

Type of Applied Stress	Allowable Stress	Required Filler Metal Strength Level ^{a,g}
CJP Groove [Butt] Welds		
Tension normal to the effective area ^b	Same as base metal	Matching filler metal shall be used ^c
Compression normal to effective area	Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used
Tension or compression parallel to axis of the weld ^d	Not a welded joint design consideration	Filler metal with a strength level equal to or less than matching filler metal may be used
Shear on effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
PJP Groove [Butt] Welds		
Tension normal to the effective area	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used
Compression normal to effective area of weld in joints designed to bear	0.90 × classification tensile strength of filler metal, but not more than 0.90 × yield strength of the connected base metal	
Compression normal to effective area of weld in joints not designed to bear	0.75 × classification tensile strength of filler metal	
Tension or compression parallel to axis of the weld ^d	Not a welded joint design consideration	
Shear parallel to axis of effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
Fillet Welds		
Shear on effective area of weld	0.30 × classification tensile strength of filler metal except that the base metal net section shear area stress shall not exceed 0.40 × yield strength of the base metal ^e	Filler metal with a strength level equal to or less than matching filler metal may be used
Tension or compression parallel to axis of the weld ^d	Not a welded joint design consideration	
Plug and Slot Welds		
Shear parallel to the faying surface on the effective area ^f	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used

^a Matching and undermatching filler metal relationships with base materials are listed in the applicable referencing application standard (e).

^b For definitions of effective areas, see 7.2.

^c For joining base metals of different strength levels, the lower strength level shall determine the matching filler metal tensile series.

^d Fillet welds and groove welds [butt welds] joining components of built-up members are allowed to be designed without regard to the tension and compression stresses in the connected components parallel to the weld axis although the area of the weld normal to the weld axis may be included in the cross-sectional area of the member.

^e The limitation on stress in the base metal to $0.40 \times$ yield point of base metal does not apply to stress on the diagrammatic weld leg; however, a check shall be made to assure that the strength of the connection is not limited by the thickness of the base metal on the net area around the connection, particularly in the case of double fillet welds on opposite sides of a plate element.

^f The strength of the connection shall also be limited by the tear-out load capacity of the thinner base metal on the perimeter area around the connection.

^g See clause 8.5.3.4 regarding overmatching.

Table 7.2
Z-Loss Dimensions (Nontubular)

Dihedral Angle Ψ	Position of Welding: V [PF/PG] or OH [PD/PE]				Position of Welding: H [PB/PC] or F [PA]			
	Process	ISO Process Designator	Z (in)	Z [mm]	Process	ISO Process Designator	Z (in)	Z [mm]
$60^\circ > \Psi \geq 45^\circ$	SMAW	111	1/8	3	SMAW	111	1/8	3
	FCAW-S	114	1/8	3	FCAW-S	114	0	0
	FCAW-G	136	1/8	3	FCAW-G	136	0	0
	GMAW	13	N/A	N/A	GMAW	13	0	0
$45^\circ > \Psi \geq 30^\circ$	SMAW	111	1/4	6	SMAW	111	1/4	6
	FCAW-S	114	1/4	6	FCAW-S	114	1/8	3
	FCAW-G	136	3/8	10	FCAW-G	136	1/4	6
	GMAW	13	N/A	N/A	GMAW	13	1/4	6

Table 7.3
Z-Loss Dimensions for Calculating PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes

Dihedral Angle Ψ	Position of Welding: V [PF/PG] or OH [PD/PE]				Position of Welding: H [PB/PC] or F [PA]			
	Process	ISO Process Designator	Z (in)	Z[mm]	Process	ISO Process Designator	Z (in)	Z[mm]
$\phi \geq 60^\circ$	SMAW	111	0	0	SMAW	111	0	0
	FCAW-S	114	0	0	FCAW-S	114	0	0
	FCAW-G	136	0	0	FCAW-G	136	0	0
	GMAW	13	N/A	N/A	GMAW	13	0	0
	GMAW-S	13-D	0	0	GMAW-S	13-D	0	0
$60^\circ > \phi \geq 45^\circ$	SMAW	111	1/8	3	SMAW	111	1/8	3
	FCAW-S	114	1/8	3	FCAW-S	114	0	0
	FCAW-G	136	1/8	3	FCAW-G	136	0	0
	GMAW	13	N/A	N/A	GMAW	13	0	0
	GMAW-S	13-D	1/8	3	GMAW-S	13-D	1/8	3
$45^\circ > \phi \geq 30^\circ$	SMAW	111	1/4	6	SMAW	111	1/4	6
	FCAW-S	114	1/4	6	FCAW-S	114	1/8	3
	FCAW-G	136	3/8	10	FCAW-G	136	1/4	6
	GMAW	13	N/A	N/A	GMAW	13	1/4	6
	GMAW-S	13-D	3/8	10	GMAW-S	13-D	1/4	6

Table 7.4
Effective Size of Flare-Groove Welds [Butt Welds] Filled Flush

Welding Process	Flare-Bevel-Groove	Flare-V-Groove
SMAW [111] and FCAW-S [114]	5/16R	5/8R
GMAW ^a [13] and FCAW-G [132, 136]	5/8R	3/4R
SAW [12]	5/16R	1/2R

^a Except GMAW-S [13-D].

Note: R = radius of outside surface. For hollow structural shaped tubing, R shall be taken as two times the nominal wall thickness, unless otherwise specified by the Design Authority.

Table 7.5
Minimum Weld Size for Partial Joint Penetration Groove Welds [Butt Welds]

Base Metal Thickness of Thicker Part Joined in [mm]	Minimum Weld Size ^a in [mm]
1/8 [3] to 3/16 [5] inclusive	1/16 [2]
> 3/16 [5] to 1/4 [6] inclusive	1/8 [3]
> 1/4 [6] to 1/2 [13] inclusive	3/16 [5]
> 1/2 [13] to 3/4 [20] inclusive	1/4 [6]
> 3/4 [20] to 1 1/2 [40] inclusive	5/16 [8]
> 1 1/2 [40] to 2 1/4 [60] inclusive	3/8 [10]
> 2 1/4 [60] to 6 [150] inclusive	1/2 [13]
> 6 [150]	5/8 [16]

^a Except the weld size need not exceed the thickness of the thinner part.

Table 7.6
Minimum Single Pass Fillet Weld Size for Heat Input

Base metal thickness of Thicker part (T) in [mm]	Minimum size ^a of Single pass fillet weld in [mm]
$T \leq 1/4 [6]$	1/8 [3]
$1/4 [6] < T \leq 1/2 [13]$	3/16 [5]
$1/2 [13] < T \leq 3/4 [20]$	1/4 [6]
$3/4 [20] < T$	5/16 [8]

^a The weld size need not exceed the thickness of the thinner part joined.

Table 7.7
Minimum Size Double Fillet Welds to Develop Full Static Strength^a

Thinner Plate Thickness (t)		Full Static Strength ^b Weld ($S = 3/4 t$) ^c		Thinner Plate Thickness (t)		Full Static Strength ^b Weld ($S = 3/4 t$) ^c	
in	mm	in	mm	in	mm	in	mm
1/4	6	3/16	5	1 3/8	35	1 1/32	26
5/16	8	15/64	6	1 1/2	38	1 1/8	28
3/8	10	9/32	8	1 5/8	41	1 7/32	31
7/16	11	21/64	9	1 3/4	45	1 5/16	34
1/2	13	3/8	10	2	50	1 1/2	38
9/16	14	27/64	11	2 1/8	54	1 19/32	41
5/8	16	15/32	12	2 1/4	57	1 11/16	43
3/4	20	9/16	15	2 3/8	60	1 25/32	45
7/8	22	21/32	16	2 1/2	64	1 7/8	48
1	25	3/4	20	2 5/8	67	1 31/32	50
1 1/8	29	27/32	22	2 3/4	70	2 1/16	53
1 1/4	32	15/16	24	3	75	2 1/4	56

^a The fillet sizes listed do not take into consideration the effective throat thickness obtainable from GMAW [13], FCAW [13, 114] and SAW [12] processes.

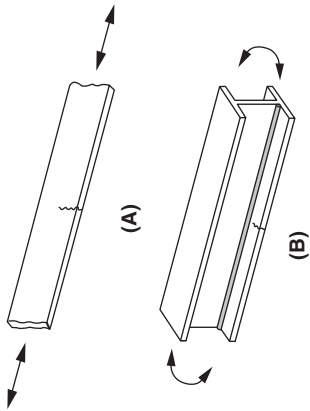
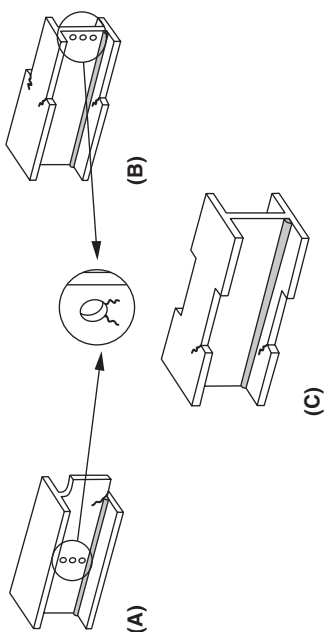
^b Filler metal strength shall match that of base metal

^c S = fillet weld size.

Table 7.8
Arc Stud Welding, Stud Diameter Recommendations

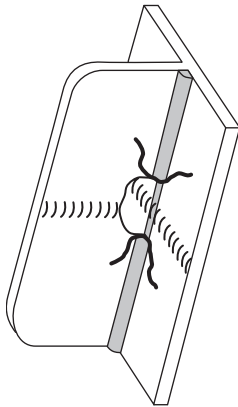
Base Diameter of Stud		Minimum Recommended Base Material Thickness		
in	mm	in	mm	gage
3/16	5	0.036	1.0	20
1/4	6	0.048	1.5	18
5/16	8	0.060	1.5	16
3/8	10	0.075	2.0	14
1/2	12	0.120	3.0	13
5/8	16	0.148	4.0	11
3/4	19	0.187	5.0	—
7/8	22	0.250	6.0	—

Table 7.9
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 1—Plain Material Away from Any Welding						
1.1 Base metal, except non-coated weathering steel, with as-rolled or cleaned surfaces. Flame cut edges with surface roughness value of 1000 μin [25 μm] or less, but without reentrant corners.	A	N/A	25	24 [165]	Away from all welds or structural connections	
1.2 Non-coated weathering steel base metal with as-rolled or cleaned surfaces. Flame cut edges with surface roughness value of 1000 μin [25 μm] or less, but without reentrant corners.	B	N/A	12	16 [110]	Away from all welds or structural connections	
1.3 Member with reentrant corners at copes, cuts, block-outs or other geometrical discontinuities, except weld access holes. $R \geq 1$ in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface. $R \geq 3/8$ in [10 mm] and the radius need not be ground to a bright metal surface.	C E'	N/A N/A	4.4 0.39	10 [69] 2.6 [18]	At any external edge or at hole perimeter	

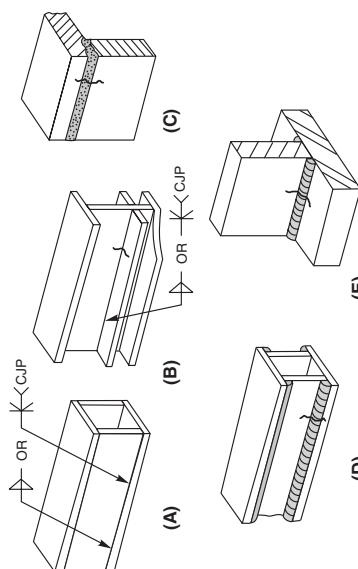
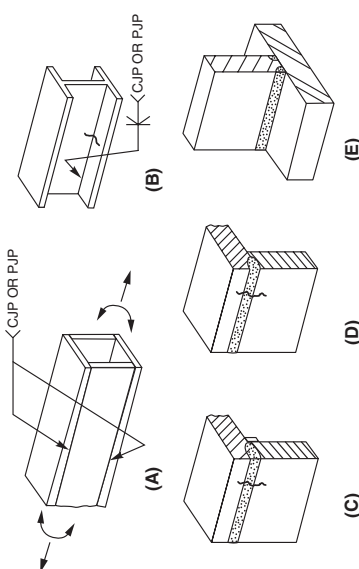
(Continued)

Table 7.9 (Continued)
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_r	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 1—Plain Material Away from Any Welding (Cont'd)						
1.4 Rolled cross sections with weld access holes made to the requirements of 6.11.4.						1.4
Access hole $R \geq 1$ in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface.	C	N/A	4.4	10 [69]	At reentrant corner of weld access hole	
Access hole $R \geq 3/8$ in [10 mm] and the radius need not be ground to a bright metal surface.	E'	N/A	0.39	2.6 [18]		
Section 2—Connected Material in Mechanically Fastened Joints—Not Used ^a						

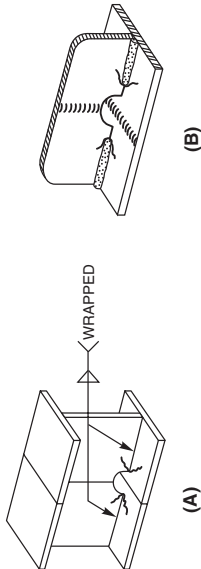
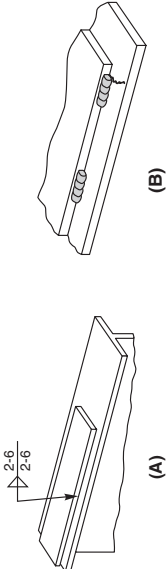
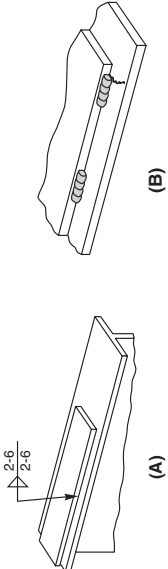
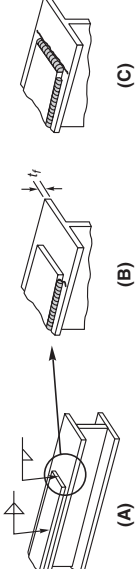
(Continued)

Table 7.9 (Continued)
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members						
3.1 Base metal and weld metal in members without attachments built up of plates or shapes connected by continuous longitudinal CJP groove welds, backgouged and welded from second side, or by continuous fillet welds.	B	III	12	16 [110]	From surface or internal discontinuities in weld	3.1 
3.2 Base metal and weld metal in members without attachments built up of plates or shapes, connected by continuous longitudinal CJP groove welds with left in place continuous steel backing, or by continuous PJP groove welds.	B'	III	6.1	12 [83]	From surface or internal discontinuities in weld	3.2 

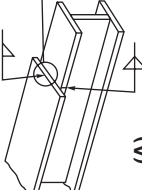
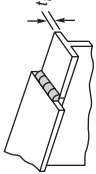
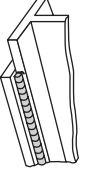
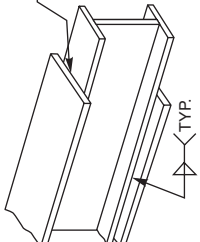
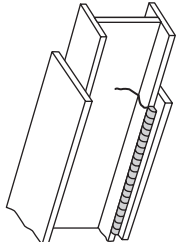
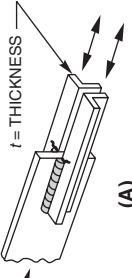
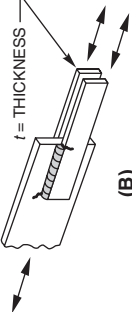
(Continued)

Table 7.9 (Continued)
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members (Cont'd)						
3.3 Base metal at the ends of longitudinal welds that terminate at weld access holes in connected built-up members, as well as weld toes of fillet welds that wrap around ends of weld access holes. Access hole $R \geq 1$ in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface. Access hole $R \geq 3/8$ in [10 mm] and the radius need not be ground to a bright metal surface.	D	IV	2.2	7 [48]	From the weld termination into the web or flange	
	E'	IV	0.39	2.6 [18]		
	E	IV	1.1	4.5 [31]	In connected material at start and stop locations of any weld	
3.4 Base metal at ends of longitudinal intermittent fillet weld segments.	E	IV	1.1	4.5 [31]	In connected material at start and stop locations of any weld	
3.5 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. Flange thickness ≤ 0.8 in [20 mm] Flange thickness > 0.8 in [20 mm]	E	IV	1.1	4.5 [31]	In flange at toe of end weld (if present) or in flange at termination of longitudinal weld	
	E'	IV	0.39	2.6 [18]		

(Continued)

Table 7.9 (Continued)
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members (Cont'd)						
3.6 Base metal at ends of partial length welded cover plates or other attachments wider than the flange with welds across the ends. Flange thickness ≤ 0.8 in [20 mm] Flange thickness > 0.8 in [20 mm]					In flange at toe of end weld or in flange at termination of longitudinal weld or in edge of flange	  
	E	IV	1.1	4.5 [31]		
	E'	IV	0.39	2.6 [18]		
3.7 Base metal at ends of partial length welded cover plates wider than the flange without welds across the ends. Flange thickness ≤ 0.8 in [20 mm] Flange thickness > 0.8 in [20 mm] is not permitted					In edge of flange at end of cover plate weld	 
	E'	IV	0.39	2.6 [18]		
Section 4—Longitudinal Fillet Welded End Connections						
4.1 Base metal at junction of axially loaded members with longitudinally welded end connections. Welds are on each side of the axis of the member to balance weld stresses. $t \leq 0.5$ in [12 mm] $t > 0.5$ in [12 mm]					Initiating from end of any weld termination extending into the base metal	 
	E	IV	1.1	4.5 [31]		
	E'	IV	0.39	2.6 [18]		

(Continued)

Table 7.9 (Continued)
Fatigue Stress Design Parameters (see 7.5)

Description	Stress Category	Inspection Class	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress						
5.1 Weld metal and base metal in or adjacent to CJP groove welded splices in plate, rolled shapes or built up cross sections with no change in cross section with welds meeting the finish and roughness criteria of Table 11.2 and inspected in accordance with 11.1.	B	I	12	16 [110]	From internal discontinuities in weld metal or along fusion boundary	
5.2 Weld metal and base metal in or adjacent to CJP groove welded splices with welds meeting the finish and roughness criteria of Table 11.2 at transitions in thickness or width made on a slope no greater than 1:2-1/2 and inspected in accordance with 11.1.	B	I	12	16 [110]	From internal discontinuities in weld metal or along fusion boundary or at start of transition when $F_y \geq 90$ ksi [620 MPa]	
$F_y < 90$ ksi [620 MPa] $F_y \geq 90$ ksi [620 MPa]	B B'	I I	12 6.1	16 [110] 12 [83]		
5.3 Base metal and weld metal in or adjacent to CJP groove welded splices with welds meeting the finish and roughness criteria of Table 11.2 at transitions in width made on a radius of not less than 24 in [600 mm] with the point of tangency at the end of the groove weld and inspected in accordance with 11.1.	B	I	12	16 [110]	From internal discontinuities in weld metal or along the fusion boundary	

(Continued)