

**AWS D1.1/D1.1M:2008  
An American National Standard**

**Approved by the  
American National Standards Institute  
July 2, 2008**

# **Structural Welding Code— Steel**

**21st Edition**

**Supersedes AWS D1.1/D1.1M:2006**

Prepared by the  
American Welding Society (AWS) D1 Committee on Structural Welding

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

This code covers the welding requirements for any type of welded structure made from the commonly used carbon and low-alloy constructional steels. Clauses 1 through 8 constitute a body of rules for the regulation of welding in steel construction. There are eight normative and twelve informative annexes in this code. A Commentary of the code is included with the document.



**American Welding Society**

550 N.W. LeJeune Road, Miami, FL 33126

International Standard Book Number: 978-0-87171-090-1  
American Welding Society  
550 N.W. LeJeune Road, Miami, FL 33126  
© 2008 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](http://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 the 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 are entrusted to appropriately qualified and competent personnel.

This standard may be superseded by the issuance of new editions. Users should ensure that they have the latest edition.

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.

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

On occasion, text, tables, or figures are printed incorrectly, constituting errata. Such errata, when discovered, are posted on the AWS web page ([www.aws.org](http://www.aws.org)).

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, Technical Services Division, 550 N.W. LeJeune Road, Miami, FL 33126 (see Annex O). 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 D1 Committee on Structural Welding. 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 required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D1 Committee on Structural Welding 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 D1 Committee on Structural Welding 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, 550 N.W. LeJeune Road, Miami, FL 33126.

# Table of Contents

	<b>Page No.</b>
<i>Personnel</i> .....	v
<i>Foreword</i> .....	xi
<i>List of Tables</i> .....	xxii
<i>List of Figures</i> .....	xxiv
<b>1. General Requirements</b> .....	<b>1</b>
1.1 Scope.....	1
1.2 Limitations.....	1
1.3 Definitions.....	1
1.4 Responsibilities.....	2
1.5 Approval.....	2
1.6 Welding Symbols.....	3
1.7 Safety Precautions.....	3
1.8 Standard Units of Measurement.....	3
1.9 Reference Documents.....	3
<b>2. Design of Welded Connections</b> .....	<b>5</b>
2.0 Scope of Clause 2.....	5
Part A—Common Requirements for Design of Welded Connections (Nontubular and Tubular Members).....	5
2.1 Scope of Part A.....	5
2.2 Contract Plans and Specifications.....	5
2.3 Effective Areas.....	6
Part B—Specific Requirements for Design of Nontubular Connections (Statically or Cyclically Loaded).....	8
2.4 General.....	8
2.5 Stresses.....	8
2.6 Joint Configuration and Details.....	9
2.7 Joint Configuration and Details—Groove Welds.....	10
2.8 Joint Configuration and Details—Fillet Welded Joints.....	10
2.9 Joint Configuration and Details—Plug and Slot Welds.....	11
2.10 Filler Plates.....	11
2.11 Built-Up Members.....	12
Part C—Specific Requirements for Design of Nontubular Connections (Cyclically Loaded).....	12
2.12 General.....	12
2.13 Limitations.....	12
2.14 Calculation of Stresses.....	13
2.15 Allowable Stresses and Stress Ranges.....	13
2.16 Detailing, Fabrication, and Erection.....	14
2.17 Prohibited Joints and Welds.....	15
2.18 Inspection.....	15
Part D—Specific Requirements for Design of Tubular Connections (Statically or Cyclically Loaded).....	15
2.19 General.....	15
2.20 Allowable Stresses.....	15
2.21 Identification.....	17
2.22 Symbols.....	17

2.23	Weld Design.....	17
2.24	Limitations of the Strength of Welded Connections.....	18
2.25	Thickness Transition.....	22
2.26	Material Limitations.....	22
<b>3.</b>	<b>Prequalification of WPSs.....</b>	<b>59</b>
3.1	Scope.....	59
3.2	Welding Processes.....	59
3.3	Base Metal/Filler Metal Combinations.....	59
3.4	Engineer's Approval for Auxiliary Attachments.....	60
3.5	Minimum Preheat and Interpass Temperature Requirements.....	60
3.6	Limitation of WPS Variables.....	60
3.7	General WPS Requirements.....	60
3.8	Common Requirements for Parallel Electrode and Multiple Electrode SAW.....	61
3.9	Fillet Weld Requirements.....	61
3.10	Plug and Slot Weld Requirements.....	61
3.11	Common Requirements of PJP and CJP Groove Welds.....	61
3.12	PJP Requirements.....	62
3.13	CJP Groove Weld Requirements.....	62
3.14	Postweld Heat Treatment.....	63
<b>4.</b>	<b>Qualification.....</b>	<b>123</b>
4.0	Scope.....	123
	Part A—General Requirements.....	123
4.1	General.....	123
4.2	Common Requirements for WPS and Welding Personnel Performance Qualification.....	124
	Part B—Welding Procedure Specification (WPS).....	124
4.3	Production Welding Positions Qualified.....	124
4.4	Type of Qualification Tests.....	124
4.5	Weld Types for WPS Qualification.....	124
4.6	Preparation of WPS.....	124
4.7	Essential Variables.....	125
4.8	Methods of Testing and Acceptance Criteria for WPS Qualification.....	125
4.9	CJP Groove Welds for Nontubular Connections.....	127
4.10	PJP Groove Welds for Nontubular Connections.....	127
4.11	Fillet Welds for Tubular and Nontubular Connections.....	127
4.12	CJP Groove Welds for Tubular Connections.....	128
4.13	PJP Tubular T-, Y-, or K-Connections and Butt Joints.....	129
4.14	Plug and Slot Welds for Tubular and Nontubular Connections.....	129
4.15	Welding Processes Requiring Qualification.....	129
4.16	WPS Requirement (GTAW).....	130
4.17	WPS Requirements (ESW/EGW).....	130
	Part C—Performance Qualification.....	130
4.18	General.....	130
4.19	Type of Qualification Tests Required.....	130
4.20	Weld Types for Welder and Welding Operator Performance Qualification.....	131
4.21	Preparation of Performance Qualification Forms.....	131
4.22	Essential Variables.....	131
4.23	CJP Groove Welds for Nontubular Connections.....	131
4.24	PJP Groove Welds for Nontubular Connections.....	132
4.25	Fillet Welds for Nontubular Connections.....	132

4.26	CJP Groove Welds for Tubular Connections .....	132
4.27	PJP Groove Welds for Tubular Connections .....	132
4.28	Fillet Welds for Tubular Connections .....	132
4.29	Plug and Slot Welds for Tubular and Nontubular Connections.....	132
4.30	Methods of Testing and Acceptance Criteria for Welder and Welding Operator Qualification .....	132
4.31	Method of Testing and Acceptance Criteria for Tack Welder Qualification.....	134
4.32	Retest.....	134
	Part D—Requirements for CVN Testing .....	134
4.33	General .....	134
4.34	Test Locations .....	134
4.35	CVN Tests.....	135
4.36	Test Requirements.....	135
4.37	Retest.....	135
4.38	Reporting.....	135
<b>5.</b>	<b>Fabrication.....</b>	<b>191</b>
5.1	Scope.....	191
5.2	Base Metal.....	191
5.3	Welding Consumables and Electrode Requirements .....	191
5.4	ESW and EGW Processes .....	193
5.5	WPS Variables .....	193
5.6	Preheat and Interpass Temperatures .....	194
5.7	Heat Input Control for Quenched and Tempered Steels .....	194
5.8	Stress-Relief Heat Treatment .....	194
5.9	Backing, Backing Gas, or Inserts.....	195
5.10	Backing .....	195
5.11	Welding and Cutting Equipment.....	195
5.12	Welding Environment .....	195
5.13	Conformance with Design .....	196
5.14	Minimum Fillet Weld Sizes .....	196
5.15	Preparation of Base Metal.....	196
5.16	Reentrant Corners .....	197
5.17	Beam Copes and Weld Access Holes .....	197
5.18	Tack Welds <u>and Construction Aids</u> .....	198
5.19	Camber in Built-Up Members.....	198
5.20	Splices in Cyclically Loaded Structures .....	199
5.21	Control of Distortion and Shrinkage.....	199
5.22	Tolerance of Joint Dimensions .....	199
5.23	Dimensional Tolerance of Welded Structural Members.....	200
5.24	Weld Profiles.....	202
5.25	Technique for Plug and Slot Welds .....	203
5.26	Repairs .....	203
5.27	Peening.....	204
5.28	Caulking.....	204
5.29	Arc Strikes.....	205
5.30	Weld Cleaning.....	205
5.31	Weld Tabs .....	205
<b>6.</b>	<b>Inspection.....</b>	<b>213</b>
	Part A—General Requirements .....	213
6.1	Scope.....	213
6.2	Inspection of Materials and Equipment .....	214

	<b>Page No.</b>
6.3 Inspection of WPSs.....	214
6.4 Inspection of Welder, Welding Operator, and Tack Welder Qualifications.....	214
6.5 Inspection of Work and Records.....	214
Part B—Contractor Responsibilities.....	215
6.6 Obligations of the Contractor.....	215
Part C—Acceptance Criteria.....	215
6.7 Scope.....	215
6.8 Engineer’s Approval for Alternate Acceptance Criteria.....	215
6.9 Visual Inspection.....	215
6.10 PT and MT.....	215
6.11 NDT.....	216
6.12 RT.....	216
6.13 UT.....	217
Part D—NDT Procedures.....	218
6.14 Procedures.....	218
6.15 Extent of Testing.....	219
Part E—Radiographic Testing (RT).....	219
6.16 RT of Groove Welds in Butt Joints.....	219
6.17 RT Procedures.....	219
6.18 Supplementary RT Requirements for Tubular Connections.....	221
6.19 Examination, Report, and Disposition of Radiographs.....	222
Part F—Ultrasonic Testing (UT) of Groove Welds.....	222
6.20 General.....	222
6.21 Qualification Requirements.....	222
6.22 UT Equipment.....	222
6.23 Reference Standards.....	223
6.24 Equipment Qualification.....	223
6.25 Calibration for Testing.....	224
6.26 Testing Procedures.....	224
6.27 UT of Tubular T-, Y-, and K-Connections.....	226
6.28 Preparation and Disposition of Reports.....	227
6.29 Calibration of the UT Unit with IIW or Other Approved Reference Blocks (Annex H).....	228
6.30 Equipment Qualification Procedures.....	229
6.31 Discontinuity Size Evaluation Procedures.....	230
6.32 Scanning Patterns.....	231
6.33 Examples of dB Accuracy Certification.....	231
Part G—Other Examination Methods.....	231
6.34 General Requirements.....	231
6.35 Radiation Imaging Systems.....	231
6.36 Advanced Ultrasonic Systems.....	231
6.37 Additional Requirements.....	232
<b>7. Stud Welding.....</b>	<b>275</b>
7.1 Scope.....	275
7.2 General Requirements.....	275
7.3 Mechanical Requirements.....	276
7.4 Workmanship/ <u>Fabrication</u> .....	276
7.5 Technique.....	276
7.6 Stud Application Qualification Requirements.....	277

**Page No.**

7.7	Production Control .....	278
7.8	Fabrication and Verification Inspection Requirements .....	279
7.9	Manufacturers' Stud Base Qualification Requirements.....	279
<b>8.</b>	<b>Strengthening and Repairing Existing Structures.....</b>	<b>285</b>
8.1	General.....	285
8.2	Base Metal.....	285
8.3	Design for Strengthening and Repair.....	285
8.4	Fatigue Life Enhancement .....	285
8.5	Workmanship and Technique .....	286
8.6	Quality.....	286
<i>Annexes</i> .....		287
Annex A	(Normative)—Effective Throat.....	289
Annex B	(Normative)—Effective Throats of Fillet Welds in Skewed T-Joints .....	291
Annex D	(Normative)—Flatness of Girder Webs—Statically Loaded Structures .....	295
Annex E	(Normative)—Flatness of Girder Webs—Cyclically Loaded Structures.....	299
Annex F	(Normative)—Temperature-Moisture Content Charts.....	305
Annex G	(Normative)—Manufacturers' Stud Base Qualification Requirements .....	309
Annex H	(Normative)—Qualification and Calibration of UT Units with Other Approved Reference Blocks .....	311
Annex I	(Normative)—Guideline on Alternative Methods for Determining Preheat.....	315
Annex J	(Normative)—Symbols for Tubular Connection Weld Design .....	325
Annex K	(Informative)—Terms and Definitions.....	327
Annex L	(Informative)—Guide for Specification Writers .....	335
Annex M	(Informative)—UT Equipment Qualification and Inspection Forms .....	337
Annex N	(Informative)—Sample Welding Forms.....	347
Annex O	(Informative)—Guidelines for the Preparation of Technical Inquiries for the Structural Welding Committee .....	359
Annex P	(Informative)—Local Dihedral Angle.....	361
Annex Q	(Informative)—Contents of Prequalified WPS .....	367
Annex R	(Informative)—Safe Practices .....	369
Annex S	(Informative)—UT Examination of Welds by Alternative Techniques.....	373
Annex T	(Informative)—Ovalizing Parameter Alpha.....	389
Annex U	(Informative)—List of Reference Documents.....	391
Annex V	(Informative)—Filler Metal Strength Properties .....	393
<i>Commentary</i> .....		405
Foreword.....		407
Index.....		521
List of AWS Documents on Structural Welding.....		533

## List of Tables

Table	Page No.
2.1	Effective Size of Flare-Groove Welds Filled Flush..... 24
2.2	Z Loss Dimension (Nontubular) ..... 24
2.3	Allowable Stresses ..... 25
2.4	<u>Equivalent Strength Coefficients for Obliquely Loaded Fillet Welds</u> ..... 26
2.5	Fatigue Stress Design Parameters ..... 27
2.6	Allowable Stresses in Tubular Connection Welds ..... 37
2.7	Stress Categories for Type and Location of Material for Circular Sections ..... 39
2.8	Fatigue Category Limitations on Weld Size or Thickness and Weld Profile (Tubular Connections) ..... 41
2.9	Z Loss Dimensions for Calculating Prequalified PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes ..... 41
2.10	Terms for Strength of Connections (Circular Sections) ..... 42
3.1	Prequalified Base Metal—Filler Metal Combinations for Matching Strength ..... 64
3.2	Prequalified Minimum Preheat and Interpass Temperature ..... 68
3.3	Filler Metal Requirements for Exposed Bare Applications of Weathering Steels ..... 71
3.4	Minimum Prequalified PJP Weld Size (E) ..... 71
3.5	Joint Detail Applications for Prequalified CJP T-, Y-, and K-Tubular Connections ..... 71
3.6	Prequalified Joint Dimensions and Groove Angles for CJP Groove Welds in Tubular T-, Y, and K-Connections Made by SMAW, GMAW-S, and FCAW ..... 72
3.7	Prequalified WPS Requirements ..... 73
4.1	WPS Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests ..... 136
4.2	WPS Qualification—CJP Groove Welds: Number and Type of Test Specimens and Range of Thickness and Diameter Qualified ..... 137
4.3	Number and Type of Test Specimens and Range of Thickness Qualified—WPS Qualification; PJP Groove Welds ..... 139
4.4	Number and Type of Test Specimens and Range of Thickness Qualified—WPS Qualification; Fillet Welds ..... 139
4.5	PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW ..... 140
4.6	PQR Supplementary Essential Variable Changes for CVN Testing Applications Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW ..... 143
4.7	PQR Essential Variable Changes Requiring WPS Requalification for ESW or EGW ..... 144
4.8	Table 3.1, Table 4.9, and Unlisted Steels Qualified by PQR ..... 145
4.9	Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 4 ..... 146
4.10	Welder and Welding Operator Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests ..... 147
4.11	Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified ..... 148
4.12	Welding Personnel Performance Essential Variable Changes Requiring Requalification ..... 152
4.13	Electrode Classification Groups ..... 152
4.14	CVN Test Requirements ..... 153
4.15	CVN Test Temperature Reduction ..... 153
5.1	Allowable Atmospheric Exposure of Low-Hydrogen Electrodes ..... 206
5.2	Minimum Holding Time ..... 206
5.3	Alternate Stress-Relief Heat Treatment ..... 206
5.4	Limits on Acceptability and Repair of Mill Induced Laminar Discontinuities in Cut Surfaces ..... 206

<b>Table</b>	<b>Page No.</b>
5.5 Tubular Root Opening Tolerances .....	207
5.6 Camber Tolerance for Typical Girder .....	207
5.7 Camber Tolerance for Girders without a Designed Concrete Haunch .....	207
5.8 Minimum Fillet Weld Sizes .....	207
6.1 Visual Inspection Acceptance Criteria .....	233
6.2 UT Acceptance-Rejection Criteria (Statically Loaded Nontubular Connections) .....	234
6.3 UT Acceptance-Rejection Criteria (Cyclically Loaded Nontubular Connections) .....	235
6.4 Hole-Type IQI Requirements .....	236
6.5 Wire IQI Requirements .....	236
6.6 IQI Selection and Placement .....	237
6.7 Testing Angle .....	238
7.1 Mechanical Property Requirements for Studs .....	281
7.2 Minimum Fillet Weld Size for Small Diameter Studs .....	281
B.1 Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints .....	294
D.1 Intermediate Stiffeners on Both Sides of Web .....	296
D.2 No Intermediate Stiffeners .....	296
D.3 Intermediate Stiffeners on One Side Only of Web .....	297
E.1 Intermediate Stiffness on Both Sides of Web, Interior Girders .....	300
E.2 Intermediate Stiffness on One Side Only of Web, Fascia Girders .....	301
E.3 Intermediate Stiffness on One Side Only of Web, Interior Girders .....	302
E.4 Intermediate Stiffness on Both Sides of Web, Fascia Girders .....	303
E.5 No Intermediate Stiffeners, Interior or Fascia Girders .....	303
I.1 Susceptibility Index Grouping as Function of Hydrogen Level “H” and Composition Parameter $P_{cm}$ .....	318
I.2 Minimum Preheat and Interpass Temperatures for Three Levels of Restraint .....	318
S.1 Acceptance-Rejection Criteria .....	378
<i>Commentary</i>	
C-2.1 Survey of Diameter/Thickness and Flat Width/Thickness Limits for Tubes .....	430
C-2.2 Suggested Design Factors .....	431
C-2.3 Values of JD .....	431
C-2.4 Structural Steel Plates .....	432
C-2.5 Structural Steel Pipe and Tubular Shapes .....	433
C-2.6 Structural Steel Shapes .....	433
C-2.7 Classification Matrix for Applications .....	434
C-2.8 CVN Testing Conditions .....	434
C-3.1 Typical Current Ranges for GMAW-S on Steel .....	452
C-4.1 CVN Test Values .....	463
C-4.2 HAZ CVN Test Values .....	463
C-6.1 UT Acceptance Criteria for 2 in [50 mm] Welding, Using a 70° Probe .....	494
C-8.1 Guide to Welding Suitability .....	511
C-8.2 Relationship Between Plate Thickness and Burr Radius .....	511

## List of Figures

Figure	Page No.
2.1	Maximum Fillet Weld Size Along Edges in Lap Joints..... 43
2.2	Transition of Butt Joints in Parts of Unequal Thickness ( <u>Cyclically Loaded</u> Nontubular) ..... 44
2.3	Transition of <u>Thicknesses</u> ( <u>Statically</u> Loaded Nontubular) ..... 45
2.4	Transversely Loaded Fillet Welds ..... 45
2.5	Minimum Length of Longitudinal Fillet Welds at End of Plate or Flat Bar Members..... 46
2.6	Termination of Welds Near Edges Subject to Tension..... 46
2.7	End Return at Flexible Connections ..... 47
2.8	Fillet Welds on Opposite Sides of a Common Plane ..... 47
2.9	Thin Filler Plates in Splice Joint ..... 48
2.10	Thick Filler Plates in Splice Joint ..... 48
2.11	Allowable Stress Range for Cyclically Applied Load (Fatigue) in Nontubular Connections (Graphical Plot of Table 2.5) ..... 49
2.12	Transition of Width (Cyclically Loaded Nontubular)..... 50
2.13	Allowable Fatigue Stress and Strain Ranges for Stress Categories (see Table 2.7), Redundant Tubular Structures for Atmospheric Service ..... 50
2.14	Parts of a Tubular Connection ..... 51
2.15	Fillet Welded Lap Joint (Tubular) ..... 54
2.16	Tubular T-, Y-, and K-Connection Fillet Weld Footprint Radius ..... 54
2.17	Punching Shear Stress..... 55
2.18	Detail of Overlapping Joint..... 55
2.19	Limitations for Box T-, Y-, and K-Connections..... 56
2.20	Overlapping K-Connections ..... 56
2.21	Transition of Thickness of Butt Joints in Parts of Unequal Thickness (Tubular)..... 57
3.1	Weld Bead in which Depth and Width Exceed the Width of the Weld Face ..... 74
3.2	Fillet Welded Prequalified Tubular Joints Made by SMAW, GMAW, and FCAW ..... 74
3.3	Prequalified PJP Groove Welded Joint Details (Dimensions in Millimeters) ..... 76
3.4	Prequalified CJP Groove Welded Joint Details (Dimensions in Inches)..... 92
3.5	Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections..... 114
3.6	Prequalified Joint Details for CJP T-, Y-, and K-Tubular Connections ..... 117
3.7	Definitions and Detailed Selections for Prequalified CJP T-, Y-, and K-Tubular Connections..... 118
3.8	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections— Standard Flat Profiles for Limited Thickness ..... 119
3.9	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections— Profile with Toe Fillet for Intermediate Thickness ..... 120
3.10	Prequalified Joint Details for CJP Groove Welds in Tubular T-, Y-, and K-Connections— Concave Improved Profile for Heavy Sections or Fatigue ..... 121
3.11	Prequalified Skewed T-Joint Details (Nontubular)..... 122
4.1	Positions of Groove Welds ..... 154
4.2	Positions of Fillet Welds ..... 155
4.3	Positions of Test Plates for Groove Welds ..... 156
4.4	Positions of Test Pipe or Tubing for Groove Welds..... 157
4.5	Positions of Test Plate for Fillet Welds ..... 158
4.6	Positions of Test Pipes or Tubing for Fillet Welds ..... 159
4.7	Location of Test Specimens on Welded Test Pipe ..... 160
4.8	Location of Test Specimens for Welded Box Tubing..... 161

<b>Figure</b>	<b>Page No.</b>
4.9	Location of Test Specimens on Welded Test Plates—ESW and EGW—WPS Qualification ..... 162
4.10	Location of Test Specimens on Welded Test Plate Over 3/8 in [10 mm] Thick—WPS Qualification..... 163
4.11	Location of Test Specimens on Welded Test Plate 3/8 in [10 mm] Thick and Under— WPS Qualification ..... 164
4.12	Face and Root Bend Specimens ..... 165
4.13	Side Bend Specimens ..... 166
4.14	Reduced-Section Tension Specimens ..... 167
4.15	Guided Bend Test Jig ..... 168
4.16	Alternative Wraparound Guided Bend Test Jig ..... 169
4.17	Alternative Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen ..... 169
4.18	All-Weld-Metal Tension Specimen ..... 170
4.19	Fillet Weld Soundness Tests for WPS Qualification ..... 171
4.20	Pipe Fillet Weld Soundness Test—WPS Qualification ..... 172
4.21	Test Plate for Unlimited Thickness—Welder Qualification ..... 173
4.22	Test Plate for Unlimited Thickness—Welding Operator Qualification..... 173
4.23	Location of Test Specimen on Welded Test Plate 1 in [25 mm] Thick—Consumables Verification for Fillet Weld WPS Qualification ..... 174
4.24	Tubular Butt Joint—Welder or WPS Qualification—without Backing ..... 175
4.25	Tubular Butt Joint—WPS Qualification with and without Backing..... 175
4.26	Acute Angle Heel Test (Restraints not Shown) ..... 176
4.27	Test Joint for T-, Y-, and K-Connections without Backing on Pipe or Box Tubing—Welder and WPS Qualification ..... 177
4.28	Test Joint for T-, Y-, and K-Connections without Backing on Pipe or Box Tubing ( $<4$ in [100 mm] O.D.)—Welder and WPS Qualification ..... 178
4.29	Corner Macroetch Test Joint for T-, Y-, and K-Connections without Backing on Box Tubing for CJP Groove Welds—Welder and WPS Qualification ..... 179
4.30	Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification..... 180
4.31	Test Plate for Limited Thickness—All Positions—Welder Qualification..... 181
4.32	Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification ..... 182
4.33	Fillet Weld Root Bend Test Plate—Welder or Welding Operator Qualification—Option 2 ..... 183
4.34	Location of Test Specimens on Welded Test Pipe and Box Tubing—Welder Qualification..... 184
4.35	Method of Rupturing Specimen—Tack Welder Qualification ..... 185
4.36	Butt Joint for Welding Operator Qualification—ESW and EGW ..... 185
4.37	Fillet Weld Break and Macroetch Test Plate—Welder or Welding Operator Qualification Option 1 ..... 186
4.38	Plug Weld Macroetch Test Plate— <u>Welder or Welding Operator Qualification and WPS Qualification</u> ... 187
4.39	Fillet Weld Break Specimen—Tack Welder Qualification ..... 188
4.40	CVN Test Specimen Locations ..... 189
5.1	Edge Discontinuities in Cut Material ..... 208
5.2	Weld Access Hole Geometry ..... 209
5.3	Workmanship Tolerances in Assembly of Groove Welded Joints ..... 210
5.4	Acceptable and Unacceptable Weld Profiles ..... 211
6.1	<u>Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections</u> ..... 241
6.2	<u>Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension (Limitations of Porosity and Fusion Discontinuities)</u> ..... 246
6.3	<u>Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Compression (Limitations of Porosity or Fusion-Type Discontinuities)</u> ..... 251
6.4	Class R Indications ..... 256
6.5	Class X Indications ..... 258
6.6	Hole-Type IQI ..... 259
6.7	Wire IQI ..... 260

<b>Figure</b>	<b>Page No.</b>
6.8	RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length ..... 261
6.9	RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less than 10 in [250 mm] in Length ..... 262
6.10	RT Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length ..... 263
6.11	RT Identification and Hole-Type or Wire IQI Locations on Transition Joints Less than 10 in [250 mm] in Length ..... 264
6.12	RT Edge Blocks ..... 264
6.13	Single-Wall Exposure—Single-Wall View ..... 265
6.14	Double-Wall Exposure—Single-Wall View ..... 265
6.15	Double-Wall Exposure—Double-Wall (Elliptical) View, Minimum Two Exposures ..... 266
6.16	Double-Wall Exposure—Double-Wall View, Minimum Three Exposures ..... 266
6.17	Transducer Crystal ..... 267
6.18	Qualification Procedure of Search Unit Using IIW Reference Block ..... 267
6.19	International Institute of Welding (IIW) UT Reference Blocks ..... 268
6.20	Qualification Blocks ..... 269
6.21	Plan View of UT Scanning Patterns ..... 271
6.22	Scanning Techniques ..... 272
6.23	Transducer Positions (Typical) ..... 273
7.1	Dimension and Tolerances of Standard-Type Shear Connectors ..... 282
7.2	Typical Tension Test Fixture ..... 282
7.3	Torque Testing Arrangement and Table of Testing Torques ..... 283
7.4	Bend Testing Device ..... 284
7.5	Suggested Type of Device for Qualification Testing of Small Studs ..... 284
F.1	Temperature-Moisture Content Chart to be Used in Conjunction with Testing Program to Determine Extended Atmospheric Exposure Time of Low-Hydrogen SMAW Electrodes ..... 306
F.2	Application of Temperature-Moisture Content Chart in Determining Atmospheric Exposure Time of Low-Hydrogen SMAW Electrodes ..... 307
H.1	Other Approved Blocks and Typical Transducer Position ..... 313
I.1	Zone Classification of Steels ..... 320
I.2	Critical Cooling Rate for 350 HV and 400 HV ..... 320
I.3	Graphs to Determine Cooling Rates for Single-Pass SAW Fillet Welds ..... 321
I.4	Relation Between Fillet Weld Size and Energy Input ..... 324
S.1	Standard Reference Reflector ..... 379
S.2	Recommended Calibration Block ..... 379
S.3	Typical Standard Reflector (Located in Weld Mock-Ups and Production Welds) ..... 380
S.4	Transfer Correction ..... 381
S.5	Compression Wave Depth (Horizontal Sweep Calibration) ..... 381
S.6	Compression Wave Sensitivity Calibration ..... 382
S.7	Shear Wave Distance and Sensitivity Calibration ..... 382
S.8	Scanning Methods ..... 383
S.9	Spherical Discontinuity Characteristics ..... 384
S.10	Cylindrical Discontinuity Characteristics ..... 384
S.11	Planar Discontinuity Characteristics ..... 385
S.12	Discontinuity Height Dimension ..... 385
S.13	Discontinuity Length Dimension ..... 386
S.14	Display Screen Marking ..... 386
S.15	Report of UT (Alternative Procedure) ..... 387
T.1	Definition of Terms for Computed Alpha ..... 388
<i>Commentary</i>	
C-2.1	Balancing of Fillet Welds About a Neutral Axis ..... 435
C-2.2	Shear Planes for Fillet and Groove Welds ..... 435

<b>Figure</b>	<b>Page No.</b>
C-2.3 Eccentric Loading .....	436
C-2.4 Load Deformation Relationship for Welds .....	436
<u>C-2.5 Example of an Obliquely Loaded Weld Group .....</u>	<u>437</u>
<u>C-2.6 Graphical Solution of the Capacity of an Obliquely Loaded Weld Group .....</u>	<u>438</u>
C-2.7 Single Fillet Welded Lap Joints .....	439
C-2.8 Illustrations of Branch Member Stresses Corresponding to Mode of Loading .....	439
C-2.9 Improved Weld Profile Requirements .....	440
C-2.10 Simplified Concept of Punching Shear .....	440
C-2.11 Reliability of Punching Shear Criteria Using Computed Alpha .....	441
C-2.12 Transition Between Gap and Overlap Connections .....	442
C-2.13 Upper Bound Theorem.....	442
C-2.14 Yield Line Patterns.....	443
C-3.1 Oscillograms and Sketches of GMAW-S Metal Transfer .....	452
C-3.2 Examples of Centerline Cracking .....	453
C-3.3 Details of Alternative Groove Preparations for Prequalified Corner Joints .....	453
C-4.1 Type of Welding on Pipe That Does Not Require Pipe Qualification.....	463
C-5.1 Examples of Unacceptable Reentrant Corners.....	474
C-5.2 Examples of Good Practice for Cutting Copcs .....	474
C-5.3 Permissible Offset in Abutting Members.....	475
C-5.4 Correction of Misaligned Members .....	475
C-5.5 Typical Method to Determine Variations in Girder Web Flatness .....	476
C-5.6 Illustration Showing Camber Measurement Methods .....	477
C-5.7 Measurement of Flange Warpage and Tilt.....	478
C-5.8 Tolerances at Bearing Points.....	479
C-6.1 90° T- or Corner Joints with Steel Backing .....	495
C-6.2 Skewed T- or Corner Joints .....	495
C-6.3 Butt Joints with Separation Between Backing and Joint .....	496
C-6.4 Effect of Root Opening on Butt Joints with Steel Backing .....	496
C-6.5 Scanning with Seal Welded Steel Backing .....	497
C-6.6 Resolutions for Scanning with Seal Welded Steel Backing .....	497
<u>C-6.7 Illustration of Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections .....</u>	<u>498</u>
<u>C-6.8 Illustration of Discontinuity Acceptance Criteria for Statically Loaded Nontubular and Statically or Cyclically Loaded Tubular Connections 1-1/8 in [30 mm] and Greater, Typical of Random Acceptable Discontinuities .....</u>	<u>499</u>
<u>C-6.9 Illustration of Discontinuity Acceptance Criteria for Cyclically Loaded Nontubular Connections in Tension.....</u>	<u>500</u>
C-8.1 Microscopic Intrusions.....	512
C-8.2 Fatigue Life .....	512
C-8.3 Toe Dressing with Burr Grinder .....	513
C-8.4 Toe Dressing Normal to Stress .....	513
C-8.5 Effective Toe Grinding .....	514
C-8.6 End Grinding.....	514
C-8.7 Hammer Peening.....	515
C-8.8 Toe Remelting.....	516