

Key Words — Bridge fabrication requirements, construction steels, fracture control plan, steel bridges, stud welding, weld connection design, welding inspection

ANSI/AASHTO/AWS D1.5-96
An American National Standard

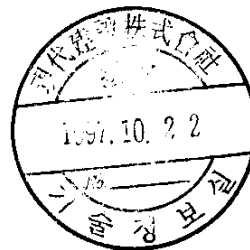
Approved by
American National Standards Institute
July 16, 1996

Bridge Welding Code

Prepared by
AWS Structural Welding Committee
AASHTO Highway Subcommittee on Bridges and Structures

Under the Direction of
AWS Technical Activities Committee
AASHTO Executive Committee

Approved by
AWS Board of Directors
AASHTO Board of Directors/Policy Committee



Abstract

This code covers the welding requirements for AASHTO welded highway bridges made from carbon and low-alloy constructional steels. This 1996 edition contains all dimensions in metric SI units. Sections 1 through 7 constitute a body of rules for the regulation of welding in steel construction. Section 9 contains additional rules applicable to bridges and supplements the first seven sections. Sections 8, 10, and 11 do not contain provisions, as their analogue D1.1 sections are not applicable to the D1.5 Code. Section 12 contains the requirements for fabricating fracture critical members.

A Joint Publication of:

**American Association of State
Highway and Transportation Officials**
444 N. Capitol Street, N.W., Suite 225
Washington, D.C. 20001

American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

Statement on Use of AWS Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute. When AWS 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.

International Standard Book Number: 0-87171-471-X

American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126

© 1996 by American Welding Society and
the American Association of State Highway and Transportation Officials

All rights reserved

Printed in the United States of America

Note: The primary purpose of AWS is to serve and benefit its members. To this end, AWS provides a forum for the exchange, consideration, and discussion of ideas and proposals that are relevant to the welding industry and the consensus of which forms the basis for these standards. By providing such a forum, AWS does not assume any duties to which a user of these standards may be required to adhere. By publishing this standard, the American Welding Society does not insure anyone using the information it contains against any liability arising from that use. Publication of a standard by the American Welding Society does not carry with it any right to make, use, or sell any patented items. Users of the information in this standard should make an independent investigation of the validity of that information for their particular use and the patent status of any item referred to herein.

With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. However, 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 joint collaboration between the AWS Structural Welding Committee and the AASHTO Technical Committee on Welding. It must be reviewed every five years and if not revised, it must be either reapproved 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 joint AASHTO/AWS subcommittee and the AWS Structural Welding Committee 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 Structural Welding Committee 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.

Personnel

AWS Committee on Structural Welding Main Committee

<i>J. L. Skiles, Chair</i>	Omaha Public Power District
<i>D. L. McQuaid, Vice Chair</i>	D & L Incorporated
<i>K. K. Verma, Vice Chair</i>	Federal Highway Administration
<i>D. D. Rager, Vice Chair</i>	Reynolds Metals Company
<i>H. H. Campbell III, Secretary</i>	American Welding Society
<i>W. G. Alexander*</i>	Consultant
<i>E. M. Beck</i>	Law Engineering Industrial Services
<i>F. R. Beckmann</i>	American Institute of Steel Construction
<i>R. D. Block</i>	Diamond Power Specialty Company
<i>O. W. Blodgett*</i>	The Lincoln Electric Company
<i>J. A. Bradley*</i>	J. A. Bradley and Associates, Incorporated
<i>F. C. Breisemeister</i>	Bechtel Corporation
<i>L. E. Collins</i>	Team Industries, Incorporated
<i>R. B. Corbit</i>	General Public Utilities Nuclear Corporation
<i>W. F. Crozier</i>	California Department of Transportation
<i>M. V. Davis</i>	Consultant
<i>J. D. Duncan</i>	Fluor Daniel
<i>G. L. Fox</i>	Texas Department of Public Transportation
<i>A. R. Fronduti</i>	Steel Fabrication Consultant
<i>G. A. Gix</i>	NTH Consultant
<i>M. A. Grieco</i>	Massachusetts Highway Department
<i>C. R. Hess</i>	High Steel Structures, Incorporated
<i>G. J. Hill</i>	G. J. Hill and Associates, Incorporated
<i>M. L. Hoitomt</i>	Thomas and Betts-Meyer Industries
<i>C. W. Holmes</i>	West Virginia Department of Transportation
<i>A. J. Julicher, P.E.</i>	A. J. Julicher and Associates
<i>R. M. Kotan, P.E.</i>	Omaha Public Power District
<i>P. W. Marshall</i>	Moonshine Hill Proprietary
<i>W. A. Milek, Jr.</i>	Consultant
<i>D. K. Miller</i>	The Lincoln Electric Company
<i>J. L. Munnerlyn</i>	Consultant
<i>J. E. Myers</i>	SMI Owen Steel Company
<i>M. L. Peterson</i>	Consultant
<i>J. W. Post</i>	J. W. Post and Associates, Incorporated
<i>D. E. H. Reynolds</i>	Canadian Welding Bureau
<i>J. E. Roth</i>	James E. Roth, Incorporated
<i>W. W. Sanders, Jr.</i>	Iowa State University
<i>A. W. Sindel</i>	Sindel and Associates
<i>D. L. Sprow</i>	McDermott Incorporated (Retired)
<i>R. W. Stieve</i>	New York Department of Transportation
<i>P. J. Sullivan</i>	Massachusetts Highway Department (Retired)
<i>J. D. Theisen</i>	Exxon Research and Engineering
<i>B. D. Wright</i>	Consultant

*Advisor

AASHTO Technical Committee for Welding

<i>J. E. Sothen, Chairman</i>	West Virginia Department of Transportation
<i>A. K. Bardow, Vice Chairman</i>	Massachusetts Highway Department
<i>D. J. Flemming</i>	Minnesota Department of Transportation
<i>P. Liles</i>	Georgia Department of Transportation
<i>S. Kulkarni</i>	Michigan Department of Transportation
<i>R. A. Pege</i>	New Jersey Department of Transportation
<i>J. E. Roberts</i>	California Department of Transportation
<i>C. C. Terry</i>	Texas Department of Transportation

Joint AASHTO/AWS Bridge Welding Subcommittee

<i>M. A. Grieco, AWS Co-chair</i>	Massachusetts Highway Department
<i>W. F. Crozier, AASHTO Co-chair</i>	California Department of Transportation

AASHTO Representatives

<i>J. J. Edwards</i>	Illinois Department of Transportation
<i>C. W. Holmes</i>	West Virginia Department of Transportation
<i>R. Medlock</i>	Texas Department of Transportation
<i>R. W. Stieve</i>	New York Department of Transportation

AWS Representatives

<i>W. G. Alexander*</i>	Consultant
<i>N. J. Atlebrando*</i>	Hardesty and Hanover
<i>F. R. Beckmann</i>	American Institute of Steel Construction
<i>L. E. Collins</i>	Team Industries, Incorporated
<i>A. R. Fronduti*</i>	Trinity Industries
<i>C. R. Hess</i>	High Steel Structures, Incorporated
<i>D. L. McQuaid</i>	D & L Incorporated
<i>J. K. Mieske*</i>	PDM Bridge
<i>D. K. Miller</i>	The Lincoln Electric Company
<i>J. E. Myers*</i>	SMI Owen Steel Company
<i>K. K. Verma</i>	Federal Highway Administration

*Advisor

Foreword

(This Foreword is not a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, but is included for information purposes only.)

The preparation of this specification was undertaken in response to a need for a common welding specification for the fabrication of steel highway bridges by welding. The departments of highways and transportation in the 50 states, the District of Columbia, and Puerto Rico that make up the American Association of State Highway and Transportation Officials have routinely used the specifications of the American Welding Society Structural Welding Committee, with appropriate modifications, to produce contract documents suitable for the construction of bridges using Federal Highway funds. The proliferation of requirements by the 50 states, District of Columbia and Puerto Rico that make up AASHTO (American Association of State Highway and Transportation Officials) resulted in the recognition of the need for a single document that could produce greater economies in bridge fabrication, while at the same time addressing the issues of structural integrity and public safety.

The first AWS code for *Fusion Welding and Gas Cutting in Building Construction* was published in 1928. In 1934, a committee was appointed to prepare specifications for the design, construction, alteration, and repair of highway and railway bridges. The first bridge specification was published in 1936. Until 1963, there were separate AWS committees for bridges and buildings. These two committees joined in 1963 to form the Structural Welding Committee of the American Welding Society. The committee has since promulgated standards for the application of welding to the design and construction of structures.

The Federal Highway Administration of the United States Department of Transportation requires states using federal funds for the construction of welded highway bridges to conform to specified standards for design and construction. Conformance to the AWS *Specification for Welded Highway and Railway Bridges* was first specified in the third edition of the AASHTO *Standard Specifications for Highway Bridges* in 1941. In 1962, the Bureau of Public Roads, now the Federal Highway Administration (FHWA), required conformance to a Circular Memorandum, dated November 13, 1962, which transmitted additional provisions for welding A36 steel pending publication of an AWS specification which would contain certain essential provisions not then in the code. Another Circular Memorandum, dated February 11, 1965, specified requirements for Charpy V-notch impact testing, and a further Circular Memorandum, dated August 19, 1966, modified provisions of the 1966 Edition of the AWS D2.0-66, *Specification for Welded Highway and Railway Bridges*. An FHWA notice, dated July 7, 1971, recommended that ultrasonic inspection not be used for final acceptance of welds made by electrogas or electroslog procedures because of concern that the acceptance levels of AWS D2.0-69, Appendix C, were not suitable to detect or reject piping porosity of major dimensions.

In 1974, AASHTO published the first edition of the *Standard Specification for Welding of Structural Steel Highway Bridges*. The Eleventh Edition of the AASHTO *Standard Specifications for Highway Bridges*, dated 1977, directed "Welding shall conform to the requirements of the AASHTO *Standard Specifications for Welding of Structural Steel Highway Bridges* 1974 and subsequent interim specifications..." AASHTO published the Second and Third editions of the *Standard Specifications for Welding of Structural Steel Highway Bridges* in 1977 and 1981. All of the AASHTO specifications were required to be part of the Contract Documents as modifications or additions to the ANSI/AWS *Structural Welding Code—Steel*. This was a cumbersome procedure.

In 1982, a subcommittee was formed jointly by AASHTO and AWS, with equal representation from both organizations, to seek accommodation between the separate and distinct requirements of bridge owners and existing provisions of ANSI/AWS D1.1. The *Bridge Welding Code* is the result of an agreement between AASHTO and AWS to produce a joint AASHTO/AWS *Structural Welding Code* for steel highway bridges that addresses essential AASHTO needs and makes AASHTO revisions mandatory.

The 1988 version of the *Bridge Welding Code* provided for the qualification of welding procedures by test to assure that weld had the strength, ductility, and toughness necessary for use in redundant structures. Nonredundant fracture critical bridge members were not provided for in the first edition of the code. While qualification of welding procedures is

required, a major effort has been made to specify the minimum number of tests and the simplest tests that give reasonable assurance of required mechanical properties. Efforts are made to discourage individual States from requiring duplication of weld testing unless that testing is specified in the bid documents. Special attention is directed to avoidance of unnecessary hardening of base metal heat-affected zones and the avoidance of hydrogen and other items that can lead to weld or base-metal cracking.

Consequently, while the D1.5-88 document has a superficial resemblance to D1.1 in its general format, there are significant differences that users should be aware of, among them the lack of provisions relating to statically loaded structures, tubular construction or the modification of existing structures. Users are encouraged to develop their own requirements for these applications or use existing documents (e.g., D1.1) with the appropriate modifications.

The publication of ANSI/AASHTO/AWS D1.5-95 was justified by the need to monitor, revise and update code provisions based on the needs of AASHTO member states and industry. The following is a list of the major revisions in D1.5-95 which are carried over to the 1996 edition:

(1) Incorporation of a Fracture Control Plan for Nonredundant Bridge Members. The new section 12 incorporates many of the provisions of the AASHTO *Guide Specification for Fracture Critical Non-redundant Steel Bridge Members* in addition to new and revised provisions.

(2) Reorganization of Section 5 on Qualification. The qualification section has been extensively reorganized to enhance utility. The section 5 provision numbers of D1.5-88 are included parenthetically in the Table of Contents next to the D1.5-96 numbers in order to facilitate location.

(3) Electrical Parameters for Maximum Heat Input Qualification Tests. Production welding current and voltage have been restricted in their deviation from the PQR maximums (see 5.12.3.2).

(4) Frequency of WPS Testing. This previous requirement of 36 months has been revised to sixty months (see 5.3).

(5) SAW and FCAW Stickout Essential Variable. The stickout length limits for WPS requalification have been changed (see 5.12.1.2 and 5.12.2.2).

(6) Qualification Test Strength Limits. The limits on yield and tensile strength for WPS specimen testing have been changed (see Table 4.1 and 4.2).

(7) Camber Tolerances. The bridge camber tolerance requirements have been changed (see 3.5.1.3).

(8) References to AASHTO Steels. All references to steels now employ AASHTO M270M and ASTM A709M designations.

(9) NDT Requirements. See 6.7 and associated provisions for the new NDT requirements for various types of loading and welded joints.

(10) Revision of Carbon Equivalent Formula for M270M Grade 50W Steel. The previous chemical requirements for M270M Grade 50W test plates in order to qualify all code steels have been revised (see 5.4.2.)

(11) Prequalification of WPS for Use on Ancillary Products. The welding of various bridge appurtenances is exempted from qualification testing in accordance with 1.3.6.

Technical changes to the 1995 edition that appear in D1.5-96 include:

(a) Revision of tolerances in 3.5.

(b) Previous references in section 6 to a CRT (Cathode Ray Tube) for UT equipment has been revised to indicate a screen or display.

(c) The requirements for the magnetic-particle yoke method have been revised in 6.7.6.2.

The publication of ANSI/AASHTO/AWS D1.5-96 has been motivated by the U.S. government mandate to conduct all future federally funded construction work exclusively in metric (SI) units commencing in October 1996. Consequently, a joint AASHTO/AWS task group was established to make the conversions in the code necessary to ensure rational design, manufacturing and construction usage. The product of their work was completed and approved by AWS and AASHTO as the 1996 edition. Changes made to the code for metrication are not intended to invalidate the provisions of previous code editions.

Changes in Code Requirements. Where changes have been made in old requirements, a double vertical line appears in the margin immediately adjacent to the subsection affected. New requirements are also indicated in this manner. Major editorial changes in material will be indicated by a single vertical line in the margin of the subsection affected. This style continues the style and format that have been used throughout the previous edition of the code.

Future revisions to this code will be made based on proposals from the Joint AASHTO/AWS Committee as well as those from document users. It should be re-emphasized here that the Joint Committee is the primary agency for receiving feedback from industry, and requires this input in order to produce a quality document. Other documents that do not receive the ANSI/AASHTO/AWS accreditation should not be relied on as substitutes for the Joint Committee's interpretation of D1.5 provisions.

While the D1.1 and D1.5 codes do share a number of common provisions, it should not be assumed that revisions to one document provision automatically revises its analogous provision in the other; therefore, users are encouraged to treat each code as an independent document.

This code was prepared by the AASHTO/AWS Bridge Welding Committee operating as a Subcommittee of the AWS Structural Welding Committee. The Committee is made up of representatives from the AWS Structural Welding Committee and the AASHTO Technical Committee for Welding. Accommodation was sought on all items where there was disagreement between AASHTO and AWS members. Specific issues considered essential by AASHTO were included in this code to eliminate the need for supplemental exclusions or additions by AASHTO.

The ANSI/AASHTO/AWS D1.5, *Bridge Welding Code*, will be subject to regular review by the Bridge Welding Committee and will be republished or reaffirmed on an as-needed basis, at intervals not to exceed five years. Changes to AWS D1.1, *Structural Welding Code—Steel*, do not automatically become part of this document. All proposed changes to this code will be subject to approval by AWS and AASHTO prior to publication.

Comments or inquiries pertaining to this code are welcome (see Annex D). They should be addressed to the Secretary, Structural Welding Committee, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, or to the Chairman of the AASHTO Technical Committee for Welding, American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Suite No. 225, Washington, D.C. 20001.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director of Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

Table of Contents

	Page No.
<i>Personnel</i>	iii
<i>Foreword</i>	v
<i>List of Tables</i>	xvii
<i>List of Figures</i>	xviii
1. General Provisions	1
1.1 Application.....	1
1.2 Base Metal	1
1.3 Welding Processes	1
1.4 Definitions	2
1.5 Welding Symbols.....	2
1.6 Safety Precautions.....	2
1.7 Standard Units of Measurement	2
1.8 Welding Procedure Specifications (WPSs).....	2
1.9 Mechanical Testing	2
2. Design of Welded Connections	3
Part A, General Requirements	3
2.1 Drawings.....	3
2.2 Basic Unit Stresses.....	3
2.3 Effective Weld Areas, Lengths, Throats, and Sizes	3
Part B, Structural Details	4
2.4 Welded Filler Plates	4
2.5 Partial Joint Penetration Groove Welds	4
Part C, Details of Welded Joints	5
2.6 Joint Qualification.....	5
2.7 Details of Fillet Welds	5
2.8 Details of Plug and Slot Welds	7
2.9 Complete Joint Penetration Groove Welds	7
2.10 Partial Joint Penetration Groove Welds	7
3. Workmanship	25
3.1 General Requirements.....	25
3.2 Preparation of Base Metal.....	25
3.3 Assembly	28
3.4 Control of Distortion and Shrinkage.....	30
3.5 Dimensional Tolerances.....	31
3.6 Weld Profiles.....	32
3.7 Repairs	34
3.8 Peening.....	35
3.9 Caulking.....	35
3.10 Arc Strikes	35
3.11 Weld Cleaning.....	35

Contents

3.12	Weld Termination.....	35
3.13	Weld Backing.....	36
4.	<i>Technique</i>	37
	Part A, General Requirements	37
4.1	Filler Metal Requirements	37
4.2	Preheat and Interpass Temperature Requirements	43
4.3	Heat Input Control for Grade 690 and 690W	44
4.4	Stress Relief Heat Treatment	44
	Part B, Shielded Metal Arc Welding (SMAW).....	45
4.5	Electrodes for SMAW.....	45
4.6	Procedures for SMAW	46
	Part C, Submerged Arc Welding (SAW).....	46
4.7	General Requirements.....	46
4.8	Electrodes and Fluxes for SAW	47
4.9	Procedures for SAW with a Single Electrode	48
4.10	Procedures for SAW with Parallel Electrodes	48
4.11	Procedures for SAW with Multiple Electrodes.....	49
	Part D, Gas Metal Arc Welding (GMAW) and Flux Cored Arc Welding (FCAW)	50
4.12	Electrodes.....	50
4.13	Shielding Gas	50
4.14	Procedures for GMAW and FCAW with a Single Electrode.....	50
	Part E, Electroslag Welding (ESW) and Electrogas Welding (EGW)	51
4.15	Qualification of Process, WPSs, and Joint Details	51
4.16	Mechanical Properties.....	51
4.17	Condition of Electrodes and Guide Tubes	51
4.18	Shielding Gas	51
4.19	Condition of Flux.....	51
4.20	Procedures for ESW and EGW	51
	Part F, Plug and Slot Welds.....	52
4.21	Plug Welds	52
4.22	Slot Welds	52
4.23	Plug and Slot Welds	52
	Part G, Control of Production Welding Variables.....	52
4.24	Tests	52
4.25	Control of Variables	53
4.26	Calibration of Equipment.....	53
4.27	Current Control	53
5.	<i>Qualification</i>	55
	Part A, Welding Procedure Specification (WPS) Qualification	55
D1.5-88	D1.5-96	
Subsection No.	Subsection No. and Title	
(New)	5.0 Scope	55
(Intro. in D1.5-88)	5.1 Approval.....	55
(5.5.1)	5.1.1 Purpose of WPS Qualification Tests	55
(5.9.1)	5.2 Qualification Responsibility	55
(5.9.3)	5.2.1 Acceptance Requirements	55
(4.26.5)	5.2.2 Contractor.....	55
(5.9.3)	5.2.3 Engineer	55

Contents

D1.5-88	D1.5-96
Subsection No.	Subsection No. and Title
(5.5.7)	5.2.4 Excess Testing55
(5.16)	5.2.5 Records.....55
(5.5.6)	5.3 Duration55
(5.3)	5.4 Base Metal.....56
(5.3.1)	5.4.1 Base-Metal Qualification Requirements.....56
(5.3.2)	5.4.2 M270M Grade 345W Test Plate Chemistry Requirements.....56
(5.3.5)	5.4.3 Unlisted Steels with $F_y \geq 485$ MPa56
(5.3.6)	5.4.3.1 Charpy V-Notch Requirements.....56
(5.3.3)	5.4.4 CMTRs.....56
(5.3.4)	5.4.5 WPS Backing56
(5.4.1)	5.5 Welding Consumables.....56
(5.4.3)	5.5.1 WPS Requirements for Consumables56
(4.26.7 and 5.3.10)	5.5.2 Active Flux.....56
(New)	5.6 Test Plate Thickness57
(New)	5.7 General Requirements for WPS Qualification.....57
(5.2.1)	5.7.1 WPS Qualification Test.....57
(5.2.2)	5.7.2 Pretest.....57
(5.2.3 and 5.1.7)	5.7.3 Verification of Pretest PQRs57
(5.1.3)	5.7.4 Table 4.1 Processes57
(5.4.2)	5.7.4.1 Consumables60
(5.1.4)	5.7.5 Table 4.2 Processes60
(5.1.6)	5.7.6 Exemption from Further Testing.....60
(5.1.9)	5.7.7 Joints Not Conforming to Figures 2.4 or 2.560
(5.3.13)	5.7.8 Aging.....60
(5.1.8)	5.7.9 Combination of WPSs.....60
(New)	5.7.10 Previous Code Editions.....60
(5.11)	5.8 Position of Test Welds.....60
(5.11.1)	5.8.1 Qualification Requirements60
(5.11.2)	5.8.2 Groove Weld Test Positions60
(5.11.2.1)	5.8.2.1 Position of 1G (Flat)60
(5.11.2.2)	5.8.2.2 Position 2G (Horizontal).....60
(5.11.2.3)	5.8.2.3 Position 3G (Vertical).....60
(5.11.2.4)	5.8.2.4 Position 4G (Overhead)60
(5.11.3)	5.8.3 Fillet Weld Test Positions.....60
(5.11.3.1)	5.8.3.1 Position 1F (Flat)60
(5.11.3.2)	5.8.3.2 Position 2F (Horizontal).....60
(5.11.3.3)	5.8.3.3 Position 3F (Vertical)60
(5.11.3.4)	5.8.3.4 Position 4F (Overhead)60
(New)	5.9 Options for WPS Qualification or Prequalification66
(5.13.2)	5.9.1 Partial Joint Penetration Groove Welds66
(New)	5.10 Fillet Weld WPS Qualification.....66
(5.5.4 and 5.5.3)	5.10.1 Groove Weld PQRs66
(5.13.3.1)	5.10.2 Fillet Weld Properties.....66
(5.13.3.2)	5.10.3 Fillet Weld Soundness Test66
(5.1.1)	5.11 Prequalified WPS66
(5.1.10)	5.11.1 Prequalified Tack Weld WPS66
(New and 5.2.4)	5.12 Heat Input WPS66
(5.6 and 5.6.1)	5.12.1 Maximum Heat Input.....66
(5.6.1.1)	5.12.1.1 Electrodes.....68
(5.6.1.2)	5.12.1.2 Electrical Parameters.....68
(5.6.1.3)	5.12.1.3 Maximum Current.....68
(5.6.1.4)	5.12.1.4 Maximum Voltage.....68

D1.5-88	D1.5-96
Subsection No.	Subsection No. and Title
(5.6.1.6)	5.12.1.5 Minimum Gas Flow 68
(5.6.1.7)	5.12.1.6 Maximum Preheat/Interpass Temperature 68
(5.6.2)	5.12.2 Maximum-Minimum Heat Input 68
(5.6.2.1)	5.12.2.1 Maximum Heat Input 68
(5.6.2.2)	5.12.2.2 Minimum Heat Input 68
(New)	5.12.3 Production Welding Limitations 68
(4.25.1)	5.12.3.1 Maximum Heat Input Envelope 68
(4.26.1)	5.12.3.2 Maximum Heat Input PQR Current, Voltage, and Travel Speed 68
(4.25.2)	5.12.3.3 Maximum-Minimum Heat Input Envelope 68
(4.26.2)	5.12.3.4 Maximum-Minimum Heat Input Current, Voltage and Travel Speed 68
(5.7)	5.13 Production Procedure WPS 68
(5.7.1)	5.13.1 Filler Metals Not Listed in Table 4.1 68
(5.1.2)	5.13.2 Non-Prequalified SMAW WPS 68
(5.10, 5.10.1, and 5.10.2)	5.13.3 Limitations 68
(5.1.5)	5.14 Electroslag and Electrogas Welding 73
(5.5.2.4)	5.14.1 Figure 5.1 73
(5.10.2.10)	5.14.2 Limitations 73
(5.5.5 and 5.12)	5.15 Type of Tests and Purpose 73
(5.12.1)	5.15.1 Groove Welds 73
(5.12.2)	5.15.2 Fillet Welds 73
(5.12.2.1)	5.15.2.1 Mechanical Properties 73
(5.12.2.2)	5.15.2.2 Macroetch 73
(5.13)	5.16 Weld Specimens—Number, Type, and Preparation 73
(5.13.1.1)	5.16.1 Configuration 73
(5.13.1.3)	5.16.2 Corner and T-Joints 73
(5.13.1.5 and 5.13.1.6)	5.16.3 Mechanical Testing 73
(5.13.1.7)	5.16.4 Charpy V-Notch Tests 73
(5.13.1.4)	5.17 Nondestructive Testing 75
(5.14)	5.18 Method of Testing Specimens 75
(5.14.1)	5.18.1 Reduced Section Tension Specimens 75
(5.14.2)	5.18.2 Macroetch Test 75
(5.14.3)	5.18.3 Root, Face, and Side Bend Specimens 75
(5.14.3.1)	5.18.3.1 Specimen Placement 75
(5.14.3.2)	5.18.3.2 Weld and HAZ Placement 75
(5.14.3.3)	5.18.3.3 Wraparound Jig 75
(5.14.4)	5.18.4 All-Weld-Metal Tension Test 75
(5.14.5)	5.18.5 Charpy V-Notch Impact Test 75
(5.15)	5.19 Test Results Required 79
(5.15.1)	5.19.1 Reduced-Section Tension Tests 79
(5.15.2)	5.19.2 Root, Face, and Side Bend Tests 79
(5.15.3)	5.19.3 Macroetch Tests 79
(5.15.3.4)	5.19.3.1 PJP Groove Welds and Fillet Welds 79
(5.15.3.3 and 5.15.3.2)	5.19.3.2 Fillet Weld Size and Fusion 81
(5.15.4)	5.19.4 All-Weld-Metal Tension Tests 81
(5.15.5)	5.19.5 Charpy V-Notch Tests 81
(5.15.5.1)	5.19.5.1 SMAW, SAW, FCAW, and GMAW Specimens 81
(5.15.5.2)	5.19.5.2 ESW and EGW Specimens 81
(5.15.7)	5.19.6 Visual Inspection 81
(5.17)	5.20 Retests 81
(5.17.1)	5.20.1 Tension and Bend 81
(5.17.2)	5.20.2 Charpy V-Notch 81

D1.5-88	D1.5-96	
Subsection No.	Subsection No. and Title	
	Part B Welder, Welding Operator, and Tack Welder Qualification	81
(5.8)	5.21 General Requirements	81
(5.18, 5.33, and 5.44)	5.21.1 Purpose	81
(5.26.1 and 5.37.1)	5.21.2 WPS Compliance	81
(5.25, 5.36, and 5.47)	5.21.3 Base Metal	81
(5.31, 5.42 and 5.52)	5.21.4 Period of Effectiveness	81
(New)	5.21.5 Weld Cleaning	82
(5.26.2 and 5.37.3)	5.21.5.1 Chipping and Brushing	82
(5.26.3)	5.21.5.2 Root and Fill Pass Cleaning	82
(5.26.4 and 5.37.2)	5.21.5.3 Cleaning Position	82
(New)	5.21.6 Responsibility	82
(5.9.2)	5.21.6.1 Contractor	82
(5.32, 5.43, and 5.53)	5.21.7 Records	82
(New)	5.21.8 Previous Code Editions	82
(New)	5.22 Production Welding Positions Qualified	82
(5.24)	5.22.1 Welder Qualification (Groove Welds)	82
(5.24.1.1)	5.22.1.1 1G (Flat)	82
(5.24.1.2)	5.22.1.2 2G (Horizontal)	82
(5.24.1.3)	5.22.1.3 3G (Vertical)	82
(5.24.1.4)	5.22.1.4 4G (Overhead)	82
(5.24.2)	5.22.2 Welder Qualification (Fillet Welds)	82
(5.24.2.1)	5.22.2.1 1F (Flat)	82
(5.24.2.2)	5.22.2.2 2F (Horizontal)	82
(5.24.2.3)	5.22.2.3 3F (Vertical)	82
(5.24.2.4)	5.22.2.4 4F (Overhead)	82
(New)	5.22.3 Welding Operator Qualification	83
(5.50.3)	5.22.4 Tack Welder Qualification	83
(5.20)	5.23 Qualification Tests Required	83
(5.20.1)	5.23.1 Welder Qualification	83
(5.20.2)	5.23.1.1 WPS Qualification	83
(5.21)	5.23.1.2 Groove Weld Qualification Test for Plate of Unlimited Thickness	83
(5.22)	5.23.1.3 Groove Weld Qualification Test for Plate of Limited Thickness	83
(5.23.1)	5.23.1.4 Qualification Tests for Fillet Welds Only	83
(5.23.2)	5.23.1.5 Plug Weld Qualification Tests for Plug Welds Only	83
(New)	5.23.2 Welding Operator Qualification	83
(5.35.1.1)	5.23.2.1 Joint Requirements for Processes Other Than ESW or EGW	83
(5.35.1.2)	5.23.2.2 Joint Requirements for ESW or EGW	83
(5.35.2)	5.23.2.3 WPS Qualification	84
(5.35.3, 5.35.3.1 and 5.35.3.2)	5.23.2.4 Qualification Tests for Fillet Welds Only	84
(5.46)	5.23.3 Tack Welder Qualification	84
(New)	5.24 Limitations of Variables	87
(New)	5.24.1 Common Requirements for Welder, Welding Operators, and Tack Welders	87
(5.19.1, 5.34.1, and 5.45.1)	5.24.1.1 Base Metal	87
(5.19.2 and 5.45.4)	5.24.1.2 Process	87
(5.19.4, 5.34.2 and 5.45.3)	5.24.1.3 Approved Electrode and Shielding Medium	87
(New)	5.24.2 Welder Qualification Variables Only	87
(5.19.3)	5.24.2.1 SMAW Restrictions	87
(5.19.5 and 5.19.6)	5.24.2.2 Position	87
(5.19.7)	5.24.2.3 Backing	90

D1.5-88	D1.5-96	
Subsection No.	Subsection No. and Title	
(New)	5.24.3 Welding Operator Qualification Variables Only	90
(5.34.4)	5.24.3.1 ESW/EGW	90
(5.34.3)	5.24.3.2 Processes Other than ESW/EGW	90
(5.34.5)	5.24.3.3 Position.....	90
(5.34.6)	5.24.3.4 Semiautomatic Welder Qualification	90
(New)	5.24.4 Tack Welder Qualification Variables Only.....	90
(5.45.2)	5.24.4.1 SMAW Restrictions	90
(5.45.5)	5.24.4.2 Position.....	90
(5.27)	5.25 Test Specimens: Number, Type, and Preparation.....	90
(5.27.1)	5.25.1 Welder Requirements	90
(5.38.1)	5.25.2 Welding Operator Requirements.....	92
(5.48)	5.25.3 Tack Welder Requirements	92
(New)	5.26 Method of Testing Specimens	92
(5.8.2)	5.26.1 Radiographic Testing	92
(5.38.2.2)	5.26.1.1 Weld Reinforcement.....	92
(5.28.4)	5.26.1.2 RT Procedure for Welder Qualification	92
(5.39.2)	5.26.1.3 RT Procedure for Welding Operator Qualification	94
(5.27.2)	5.26.2 Guided Bend Test for Welder Qualification.....	94
(New)	5.26.2.1 Root, Face, and Side Bend Specimens.....	94
(New)	5.26.3 Fillet Weld Break and Macroetch Test Requirements.....	94
(5.27.3 and 5.28.2)	5.26.3.1 Welder Qualification	94
(5.38.3 and 5.39.3)	5.26.3.2 Welding Operator Qualification	94
(5.49)	5.26.3.3 Tack Welder Qualification	94
(5.28.3 and 5.39.4)	5.26.3.4 Macroetch Test	94
(New)	5.27 Test Results Required.....	94
(5.29.5 and 5.40.5)	5.27.1 Visual Inspection of Welder and Welding Operator Test Plates	94
(5.29.4 and 5.40.2)	5.27.2 Radiographic Test.....	94
(5.40.1 and 5.29.1)	5.27.3 Root or Side Bend Tests.....	94
(New)	5.27.4 Fillet Weld Break Test (Welder and Welding Operator)	95
(5.40.3.1 and 5.29.2.1)	5.27.4.1 Visual Examination	95
(5.40.3.2 and 5.29.2.2)	5.27.4.2 Fracture Surface	95
(New)	5.27.5 Fillet Weld Break Test (Tack Welder).....	95
(5.50.1)	5.27.5.1 Visual Examination	95
(5.50.2)	5.27.5.2 Fracture Surface	95
(5.29.3)	5.27.6 Macroetch Test.....	95
(5.29.3.3)	5.27.6.1 Fillet Welds	95
(5.29.3.1, 5.29.3.2, and 5.29.3.4)	5.27.6.2 Plug Welds	95
(New)	5.28 Retests	95
(5.30 and 5.41)	5.28.1 Welder and Welding Operator.....	95
(5.30.1 plus 5.41.1)	5.28.1.1 Immediate Retest.....	95
(5.30.2 and 5.41.2)	5.28.1.2 Retest After Further Training or Practice.....	95
(5.51)	5.28.2 Tack Welder	95
6.	Inspection.....	97
	Part A, General Requirements	97
6.1	General.....	97
6.2	Inspection of Materials	98
6.3	Inspection of WPS Qualification and Equipment.....	98
6.4	Inspection of Welder, Welding Operator, and Tack Welder Qualifications	98
6.5	Inspection of Work and Records.....	98
6.6	Obligations of the Contractor	99

D1.5-96**Subsection No. and Title**

6.7	Nondestructive Testing	99
Part B, Radiographic Testing of Groove Welds in Butt Joints.....		101
6.8	Extent of Testing	101
6.9	General.....	101
6.10	Radiographic Procedure.....	101
6.11	Acceptability of Welds.....	108
6.12	Examination, Report, and Disposition of Radiographs	108
Part C, Ultrasonic Testing of Groove Welds.....		108
6.13	General.....	108
6.14	Extent of Testing	108
6.15	Ultrasonic Equipment	109
6.16	Reference Standards	109
6.17	Equipment Qualification.....	109
6.18	Calibration for Testing	110
6.19	Testing Procedures	113
6.20	Preparation and Disposition of Reports	116
6.21	Calibration of the Ultrasonic Unit with IIW or Other Approved Reference Blocks	116
6.22	Equipment Qualification Procedures	118
6.23	Flaw Size Evaluation Procedures	119
6.24	Scanning Patterns.....	120
6.25	Examples of dB Accuracy Certification	120
7.	<i>Stud Welding</i>	121
7.1	Scope.....	121
7.2	General Requirements.....	121
7.3	Mechanical Requirements.....	122
7.4	Workmanship	123
7.5	Technique.....	123
7.6	Stud Application Qualification Requirements.....	124
7.7	Production Control.....	125
7.8	Inspection Requirements.....	126
8.	<i>Statically Loaded Structures (No Applications within this Code)</i>	127
9.	<i>Welded Steel Bridges</i>	129
Part A, General Requirements		129
9.1	Application.....	129
9.2	Base Metal	129
Part B, Structural Details		130
9.3	General.....	130
9.4	Noncontinuous Beams	130
9.5	Participation of Floor System	130
9.6	Lap Joints.....	130
9.7	Corner and T-Joints	131
9.8	Prohibited Types of Joints and Welds	131
9.9	Combinations of Welds.....	131
9.10	Welds in Combination with Rivets and Bolts	131
9.11	Fillet Weld Details	131
9.12	Eccentricity of Connections.....	131
9.13	Connections or Splices—Tension and Compression Members	132
9.14	Connections or Splices in Compression Members with Milled Joints	132

Contents

D1.5-96

Subsection No. and Title

9.15	Connection of Components of Built-Up Members	132
9.16	Transition of Thicknesses or Widths at Butt Joints	132
9.17	Girders and Beams	132
Part C, Workmanship		132
9.18	Preparation of Material	132
9.19	Dimensional Tolerances	134
9.20	Temporary Welds	135
9.21	Quality of Welds	135
Part D, Supplemental Requirements		137
S9.22	Weldability Investigation	137
S9.23	Proof of Weldability	140
S9.24	Weldable Steels	140
S9.25	Longitudinal-Bead-Weld Underbead Cracking Tests	140
S9.26	Testing Procedure	140
S9.27	WPS Qualification Tests	140
10.	<i>Tubular Structures (No Applications within this Code)</i>	141
11.	<i>Strengthening and Repairing Existing Structures (No Applications within this Code)</i>	143
12.	<i>AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members</i>	145
12.1	General Provisions	145
12.2	Definitions	145
12.3	Contract Documents	145
12.4	Base Metal Requirements	146
12.5	Welding Processes	146
12.6	Consumable Requirements	146
12.7	Welding Procedure Specification (WPS)	150
12.8	Contractor Requirements	150
12.9	As-Received Inspection of Base Metal	151
12.10	Thermal Cutting	151
12.11	Repair of Base Metal	151
12.12	Straightening, Curving and Cambering	151
12.13	Tack Welds and Temporary Welds	152
12.14	Preheat and Interpass Temperature Control	152
12.15	Postweld Thermal Treatments	152
12.16	Weld Inspection	154
12.17	Repair Welding	155
<i>Annexes—Mandatory Information</i>		157
Annex I:	Effective Throat	159
Annex II:	Effective Throats of Fillet Welds in Skewed T-Joints	159
Annex III:	Suggested Sample Welding Forms	161
Annex IV:	Flatness of Girder Webs—Bridges	169
Annex V:	Terms and Definitions	173
Annex VI:	Manufacturer's Stud Base Qualification Requirements	181
Annex VII:	Qualification and Calibration of the Ultrasonic Unit with Other Approved Reference Blocks	185
Annex VIII:	Guidelines on Alternative Methods for Determining Preheat	195
<i>Annexes—Nonmandatory Information</i>		203
Annex A:	Welding Quality Requirements for Tension Joints	203
Annex B:	Description of Common Weld and Base Metal Discontinuities	205

Contents

D1.5-96

Subsection No. and Title

Annex C:	Short Circuiting Transfer.....	217
Annex D:	Guidelines for Preparation of Technical Inquiries for the Joint AASHTO/AWS Subcommittee on Bridge Welding.....	219
<i>Index</i>		221

List of Tables

	Page No.
2.1 Minimum Fillet Weld Size	6
2.2 Minimum Effective Weld Size for Partial Joint Penetration Groove Welds	7
3.1 Limits on Acceptability and Repair of Cut Edge Discontinuities of Material	27
3.2 Camber Tolerance for Typical Girder	31
3.3 Camber Tolerance for Girders without a Designed Concrete Haunch	32
4.1 Matching Filler Metal Requirements for WPSs Qualified in Accordance with 5.12	38
4.2 Matching Filler Metal Requirements for WPSs Qualified in Accordance with 5.13	40
4.3 Filler Metal Requirements for Exposed Bare Application of M270M (A709M), Gr. 345W Steel	43
4.4 Minimum Preheat and Interpass Temperature, °C	43
4.5 Minimum Holding Time	44
4.6 Alternate Stress-Relief Heat Treatment	45
4.7 Permissible Atmospheric Exposure of Low-Hydrogen Electrodes	45
5.1 WPS Qualification Requirements for Consumables	57
5.2 Production Welding Thickness Qualified by PQR Test Plate Thickness	57
5.3 PQR Essential Variable Changes for WPSs Qualified per 5.13.3	69
5.4 Additional PQR Essential Variable Changes Requiring WPS Requalification for Electroslag or Electrogas Welding	74
5.5 Required Number of Test Specimens—WPS Qualification	75
5.6 Welder Qualification—Type and Position Limitations	82
5.7 Number and Type of Specimens and Range of Thickness Qualified—Welder and Welding Operator Qualification	84
6.1 Hole-Type Image Quality Indicator (IQI) Requirements	102
6.1A Wire Image Quality Indicator (IQI) Requirements	102
6.2 Testing Angle	114
7.1 Mechanical Property Requirements for Studs	122
7.2 Minimum Fillet Weld Size for Small Diameter Studs	123
9.1 Ultrasonic Acceptance-Rejection Criteria—Tensile Stress	138
9.2 Ultrasonic Acceptance-Rejection Criteria—Compressive Stress	139
12.1 Toughness of Weld Metal with Matching Strength	147
12.2 Tack Weld Requirements	152
12.3 M270M (A709M) Gr. 250, 345 Minimum Preheat and Interpass Temperatures, °C	153
12.4 M270M (A709M) Gr. 345W, 485W Minimum Preheat and Interpass Temperatures, °C	153
12.5 M270M (A709M) Gr. 600, 690W Minimum and Maximum Preheat/Interpass Temperatures, °C	153
II.1 Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints, R = 0	160
VIII.1 Susceptibility Index Grouping as Function of Hydrogen Level “H” and Composition Parameter P_{cm}	203
VIII.2 Minimum Preheat and Interpass Temperatures for Three Levels of Restraint	203
B1 Common Types of Discontinuities	208

List of Figures

D1.5-88 Figure No.	D1.5-96 Figure No. and Title	Page No.
	2.1 Filler Plates Less Than 6 mm Thick	5
	2.2 Filler Plates 6 mm or Thicker	5
	2.3 Details for Fillet Welds	6
	2.4 Details of Welded Joints for Complete Joint Penetration (CJP) Groove Welds	9
	2.5 Details of Welded Joints for Partial Joint Penetration (PJP) Groove Welds	19
	3.1 Discontinuities in Cut Plate	27
	3.2 Workmanship Tolerances in Assembly of Groove Welded Joints	29
	3.3 Acceptable and Unacceptable Weld Profiles	33
	4.1 Weld Bead in Which Depth and Width Exceed the Width of the Weld Face	48
(5.1A)	5.1 WPS Qualification or Pretest—Test Plate A	58
(5.1B)	5.2 WPS Qualification or Pretest—Test Plate B	59
(5.1C)	5.3 Weld Soundness Test Plate for Details Not Conforming to Figure 2.4 or Figure 2.5— Test Plate C	61
(5.2A)	5.4 Positions of Fillet Welds	62
(5.2B)	5.5 Positions of Groove Welds	63
(5.3)	5.6 Position of Test Plates for Groove Welds	64
(5.4)	5.7 Position of Test Plates for Fillet Welds	65
(5.1D)	5.8 Fillet Weld Soundness Test (Macroetch) for WPS Qualification—Test Plate D	67
(5.5A)	5.9 Standard Round All-Weld-Metal Tension Specimen	76
(5.5B)	5.10 Reduced Section Tension Specimen	76
(5.5C)	5.11 Side Bend Specimen	77
(5.5D)	5.12 Face and Root Bend Specimen	77
(5.5E)	5.13 Charpy V-Notch Impact Test Specimen—Type A	78
(5.9A)	5.14 Guided Bend Test Jig	79
(5.9B)	5.15 Alternative Wraparound Guided Bend Test Jig	80
(5.9C)	5.16 Alternative Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen	80
(5.6A)	5.17 Test Plate for Unlimited Thickness—Welder Qualification	85
(5.6B)	5.18 Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification	85
(5.7A)	5.19 Test Plate for Limited Thickness—All Positions—Welder Qualification	86
(5.7B)	5.20 Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification	86
(5.8A)	5.21 Fillet-Weld-Break and Macroetch Test Plate—Welder Qualification—Option 1	87
(5.8B)	5.22 Fillet Weld Root-Bend Test Plate—Welder Qualification—Option 2	88
(5.8C)	5.23 Plug Weld Macroetch Test Plate—Welder Qualification	89
(5.10)	5.24 Test Plate for Unlimited Thickness—Welding Operator Qualification	90
(5.11)	5.25 Butt Joint for Welding Operator Qualification—Electroslag and Electrode Gas Welding	91
(5.12)	5.26 Fillet-Weld-Break and Macroetch Test Plate—Welding Operator Qualification—Option 1	92
(5.13)	5.27 Fillet Weld Root Bend Test Plate—Welding Operator Qualification—Option 2	93
(5.14)	5.28 Fillet-Weld-Break Specimen—Tack Welder Qualification	94
(5.15)	5.29 Method of Rupturing Specimen—Tack Welder Qualification	95
	6.1A Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 250 mm and Greater in Length	103
	6.1B Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less than 250 mm in Length	103

D1.5-96**Figure No. and Title**

6.1C Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 250 mm and Greater in Length	104
6.1D Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less than 250 mm in Length.....	104
6.1E Hole-Type Image Quality Indicator (IQI) Design.....	106
6.1F Image Quality Indicator (Wire Penetrameter).....	107
6.2 Transducer Crystal.....	109
6.3 Qualification Procedure of Search Unit Using IIW Reference Block.....	110
6.4A International Institute of Welding (IIW) Ultrasonic Reference Blocks.....	111
6.4B Other Approved Ultrasonic Reference Blocks.....	112
6.5 Transducer Positions (Typical).....	117
6.6 Plan View of UT Scanning Patterns	120
7.1 Dimension and Tolerances of Standard-Type Shear Connectors.....	121
7.2 Typical Tension Test Fixture.....	122
7.3 Torque Testing Arrangement and Table of Testing Torques.....	124
9.1 Fillet Welds on Opposite Sides of a Common Plane of Contact	130
9.2 Transition of Thickness at Butt Joints of Parts Having Unequal Thickness	133
9.3 Transition of Width at Butt Joints of Parts Having Unequal Width	134
9.4 Weld Quality Requirements for Discontinuities Occurring in Tension Welds (Limitations of Porosity and Fusion Discontinuities).....	136
9.5 Weld Requirements for Discontinuities Occurring in Compression Welds (Limitations of Porosity or Fusion Type Discontinuities).....	137
VI-1A Bend Testing Device	183
VI-1B Suggested Type of Device for Qualification Testing of Small Studs.....	183
VII-1 Example of the Use of Form VII-8 Ultrasonic Unit Certification.....	188
VII-2 Example of Form VII-9	189
VII-3 Example of the Use of Form VII-9.....	190
VII-4 Example of Form VII-10	191
VII-5 Example of the Use of Form VII-10.....	192
VII-6 Form VII-11—Report of Ultrasonic Testing of Welds	193
VIII-1 Zone Classification of Steels.....	197
VIII-2 Critical Cooling Rate for 350 VH and 400 VH.....	198
VIII-3 Charts to Determine Cooling Rates for Single-Pass Submerged Arc Fillet Welds.....	199
VIII-4 Relation Between Fillet Weld Size and Energy Input	202
B1 Weld in Butt Joint	209
B2 Weld in Corner Joint	210
B3 Weld in T-Joint.....	211
B4 Weld in Lap Joint	212
B5 Single-Pass Fillet Weld in T-Joint	213
B6 Single-V-Groove Weld in Butt Joint.....	214
C1 Oscillograms and Sketches of Short Circuiting Arc Metal Transfer	217

Bridge Welding Code

1. General Provisions

1.1 Application

1.1.1 This code covers welding fabrication requirements applicable to welded highway bridges. It is to be used in conjunction with the *AASHTO Standard Specification for Highway Bridges* or the *AASHTO LRFD Bridge Design Specifications*.

1.1.2 The fundamental premise of the code is to provide general stipulations applicable to any routine bridge situation. Acceptance criteria for production welds different from those specified in the code may be used for a particular application, provided they are suitably documented by the proposer and approved by the Engineer.

Such alternate acceptance criteria can be based upon evaluation of suitability for service using past experience, experimental evidence, or engineering analysis considering material type, service load effects, and environmental factors.

1.1.3 The term *Engineer* as used in this code shall mean the State Bridge Engineer, or the Bridge Engineer's designated representative. The Engineer acts on behalf of the State or Owner and unless otherwise specified shall be the Owner's official representative. All references to acceptance or approval shall mean acceptance or approval by the Engineer.

1.1.4 The term *Contractor* as used in this code indicates the party responsible for performing the work as required by the contract documents. The term Contractor is used collectively to mean contractor, manufacturer, fabricator, erector, or other party performing the work.

1.2 Base Metal

1.2.1 Specified Base Metal. The contract documents shall designate the specification and classification of base metals to be used.

1.2.2 Approved Base Metals. Unless otherwise specified, base metals to be welded under this code shall meet the requirements of the latest edition of AASHTO M270M (ASTM A709M) for the grade of steel shown on the plans or listed in the specifications. All Grade 345 steel that is to be welded shall be Type 1, 2, or 3. Other steels may be approved by the Engineer.

M270M steels of a designated grade are essentially the same as ASTM A709M steels of the same grade. A709M may be used as a reference and a guide to other ASTM "referenced documents;" however, when there is a difference, the provisions of M270M, including the documents referenced in M270M, shall govern.

1.2.3 Thickness Limitations. The provisions of this code do not apply to welding base metals less than 3 mm thick. Where base metals thinner than 3 mm are to be welded, the requirements of ANSI/AWS D1.3, *Structural Welding Code—Sheet Steel*, should apply. When used in conjunction with ANSI/AWS D1.3, the applicable provisions of this code shall be observed.

1.3 Welding Processes

1.3.1 Shielded metal arc welding (SMAW) WPSs (Welding Procedure Specifications) which conform to the provisions of sections 2, 3, 4, and 9, are operated within the limitation of variables recommended by the manufacturer, and which produce weld metal with a minimum specified yield strength less than 620 MPa, shall be deemed prequalified and exempt from the tests described in section 5. WPSs for SAW, FCAW, GMAW, ESW, and EGW shall be qualified as described in 5.12 or 5.13, as applicable.

1.3.2 Electroslag (ESW) and electrogas (EGW) welding may be used for groove welds in butt joints in compression members, provided the WPSs conform to the applicable provisions of sections 2, 3, and 4, and the contractor qualifies them in accordance with the requirements of 5.13. ESW and EGW shall be subject to nondestructive testing, as specified in section 6.

1.3.3 Stud welding may be used, provided the WPSs conform to the applicable provisions of section 7.

1.3.4 GMAW-S (short circuit arc) is not recommended for the construction of bridge members and shall not be used without written approval of the Engineer.

1.3.5 Other welding processes not listed in this code may be used if approved by the Engineer. These processes shall be qualified by applicable tests prescribed in 5.13 and any other tests required by the Engineer. In conjunction with the tests, the WPSs and limitation of essential variables applicable to the specific welding process must be established by the contractor developing the WPS. The range of essential variables shall be based on documented evidence of experience with the process, or a series of tests shall be conducted to establish the limits of variables. Any change in essential variables outside the range so established shall require requalification.

1.3.6 Welding of Ancillary Products. Unless otherwise provided in the contract documents, ancillary products, such as drainage components, expansion dams, curb plates, bearings, hand rails, cofferdams, sheet piling, and other products not subject to calculated tensile stress from live load and not welded to main members in tension areas as determined by the Engineer, may be fabricated without performing the WPS qualification tests described in section 5, subject to the following restrictions:

(1) SMAW, SAW, FCAW, and GMAW WPSs shall be considered prequalified and exempt from the qualification tests described in section 5, provided that welding is performed in accordance with all other provisions of the code.

(2) All welding performed in accordance with the provisions of this subsection shall be conducted within the limitations of welding variables recommended by the filler metal manufacturer. Welds attaching ancillary products to main members shall meet all requirements of the code, including WPS qualification testing.

(3) The Engineer shall be the final judge of which products are considered ancillary and exempt from qualification tests.

1.4 Definitions

The welding terms used in this code shall be interpreted in accordance with the definitions given in the lat-

est edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*, supplemented by Annex V of this code.

1.5 Welding Symbols

Welding symbols shall be those shown in the latest edition of ANSI/AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by notes or details.

1.6 Safety Precautions

Safety precautions shall conform to the latest edition of ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society.

NOTE: This code may involve hazardous materials, operations, and equipment. The code does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices. The user should determine the applicability of any regulatory limitations prior to use.

1.7 Standard Units of Measurement

The values used in this document are based on the International System of Units (SI) [the Modernized Metric System] in accordance with ASTM E380, *Standard Practice for the Use of the International System of Units (SI)* (the Modernized Metric System¹).

1.8 Welding Procedure Specifications (WPSs)

All production welding shall be performed in accordance with the provisions of an approved Welding Procedure Specification (WPS), which is based upon successful test results as recorded in a Procedure Qualification Record (PQR) unless qualified in accordance with 1.3.1. All WPSs shall reference the PQR that is the basis for acceptance. A copy of the proposed WPS and referenced PQR shall be submitted to the Engineer for approval. Suggested forms for WPSs and PQRs are provided in Annex III. WPSs for SMAW that meet the requirements of 5.11 are prequalified and exempt from qualification testing.

1.9 Mechanical Testing

The latest edition of ANSI/AWS B4.0, *Standard for Mechanical Testing of Welds*, provides additional details of test specimen preparation and details of test fixture construction.

1. Available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

2. Design of Welded Connections

Part A General Requirements

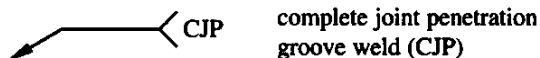
2.1 Drawings

2.1.1 Full and complete information regarding location, type, size, and extent of all welds shall be clearly shown on the drawings. The drawings shall clearly distinguish between shop and field welds. Unless specifically indicated in the design, all groove welds, both shop and field, shall be complete joint penetration groove welds.

2.1.2 Those joints or groups of joints for which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted on shop and working drawings.

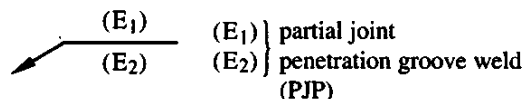
2.1.3 Contract design drawings shall specify the effective weld length and, for partial penetration groove welds, the required weld size, as defined in 2.3. Shop or working drawings shall specify the groove angles (α and β) and depths (S) applicable for the weld size (E) required for the welding processes and position of welding to be used.

2.1.3.1 It is recommended that contract design drawings show complete joint penetration or partial joint penetration groove weld requirements. The welding symbol without dimensions designates a complete joint penetration weld, as follows:



The welding symbol with dimensions above or below the arrow designates a partial joint penetration weld, as follows:

2.1.3.2 Special groove details shall be specified where required.



where

(E₁) = effective weld size, other side

(E₂) = effective weld size, arrow side

2.1.4 Detail drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of material required to make them. Both width and thickness of steel backing shall be detailed.

2.1.5 Any special inspection requirements shall be noted on the drawings or in the specifications.

2.2 Basic Unit Stresses

Basic unit stresses for base metals and for effective areas of weld metal for application to AASHTO highway bridges shall be as shown in the AASHTO *Standard Specifications for Highway Bridges* or the AASHTO *LRFD Bridge Design Specification*.

2.3 Effective Weld Areas, Lengths, Throats, and Sizes

2.3.1 Groove Welds. The effective area shall be the effective weld length multiplied by the effective groove weld size.

2.3.1.1 The effective weld length for any groove weld, square or skewed, shall be the width of the part joined, perpendicular to the direction of stress.

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

2.3.1.3 The effective weld size of a partial joint penetration groove weld shall be the depth of bevel less 3 mm for grooves having a groove angle less than 60 degrees but not less than 45 degrees at the root of the groove, when made by shielded metal arc welding (SMAW) or submerged arc welding (SAW), when made in the vertical or overhead welding positions by gas metal arc welding (GMAW) or flux cored arc welding (FCAW).

The effective weld size of a partial joint penetration groove weld shall be the depth of bevel, without reduction, for grooves

(1) having a groove angle of 60 degrees or greater at the root of the groove when made by any of the following welding processes: SMAW, SAW, GMAW, FCAW, EGW, or ESW, or

(2) having a groove angle not less than 45 degrees at the root of the groove when made in flat or horizontal positions by GMAW or FCAW.

2.3.1.4 Flare groove joints shall not be used to join structural steel in bridges.

2.3.1.5 The minimum effective weld size of a partial joint penetration groove weld shall be as specified in Table 2.2.

2.3.2 Fillet Welds. The effective area shall be the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load.

2.3.2.1 The effective length of a fillet weld shall be the overall length of the full-size fillet, including boxing. 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.

2.3.2.2 The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area found from 2.3.3, then this latter area shall be used as the effective area of the fillet weld.

2.3.2.3 The minimum effective length of a fillet weld shall be at least four times the nominal size, or 40 mm, whichever is greater.

2.3.2.4 The effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld (see Annex I). *Note: See Annex II for method of calculating effective throats for fillet welds in skewed T-joints.* A convenient tabulation of relative leg sizes (W) for joints with zero root opening ($R=0$) that will have the same strength as a 90 degree fillet weld has been provided for dihedral angles between 60 degrees and 135 degrees (see Annex II, Table II.1).

2.3.3 Plug and Slot Welds. 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.

2.3.4 The effective weld size of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld minus 3 mm, for any groove detail requiring such deduction (see Annex I).

Part B **Structural Details**

2.4 Welded Filler Plates

2.4.1 Welded filler plates (see Figures 2.1 and 2.2) are designated Category E fatigue details and shall be avoided when joining tension and reversal of stress members. When the design permits the use of filler plates, they may be used in the following:

(1) Splicing parts of different thicknesses

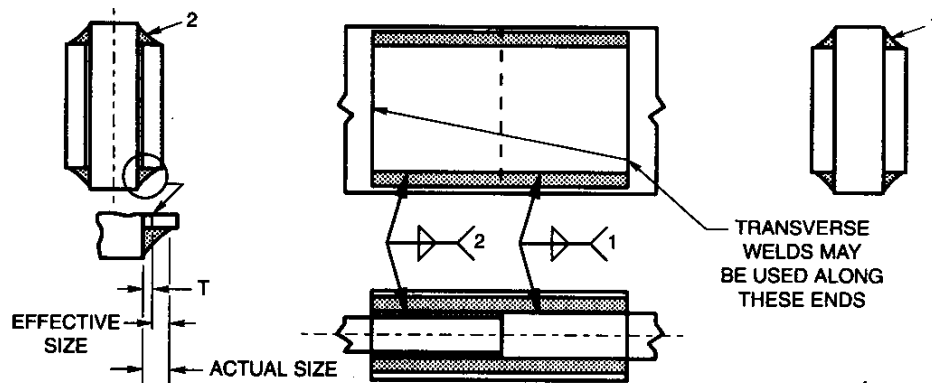
(2) Connections that, due to existing geometric alignment, must accommodate offsets to permit simple framing

2.4.2 A filler plate less than 6 mm thick shall not be used to transfer stress but shall be kept flush with the welded edges of the stress-carrying part. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler plate (see Figure 2.1).

2.4.3 Any filler plate 6 mm or more in thickness shall extend beyond the edges of the splice plate or connection material. It shall be welded to the part on which it is fitted, and the joint shall be of sufficient strength to transmit the splice plate or connection material stress applied at the surface of the filler plate as an eccentric load. The welds joining the splice plate or connection material to the filler plate shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid overstressing the filler plate along the toe of the weld (see Figure 2.2).

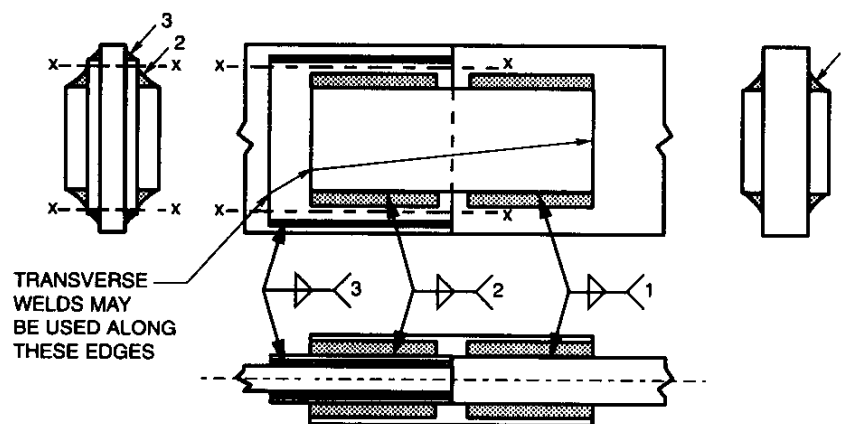
2.5 Partial Joint Penetration Groove Welds

Partial joint penetration (PJP) groove welds shall not be used where the applied tensile stress is normal to the effective throat of the weld. Joints containing partial joint penetration groove welds, made from one side only, shall be restrained to prevent rotation.



Note: The effective area of weld 2 shall equal that of weld 1, but its size shall be its effective size plus the thickness of the filler T.

Figure 2.1 — Fillers Less Than 6 mm Thick (see 2.4.1)



Notes:

1. The effective area of weld shall equal that of weld 1. The length of weld 2 shall be sufficient to avoid overstressing the filler plate in shear along planes x-x.
2. The effective area of weld 3 shall at least equal that of weld 1 and there shall be no overstress of the ends of weld 3 resulting from the eccentricity of the forces acting on the filler plate.

Figure 2.2 — Filler Plates 6 mm or Thicker (see 2.4.3)

Part C **Details of Welded Joints**

2.6 Joint Qualification

Details of welded joints that may be used in a prequalified WPS are described in 2.7 through 2.10.

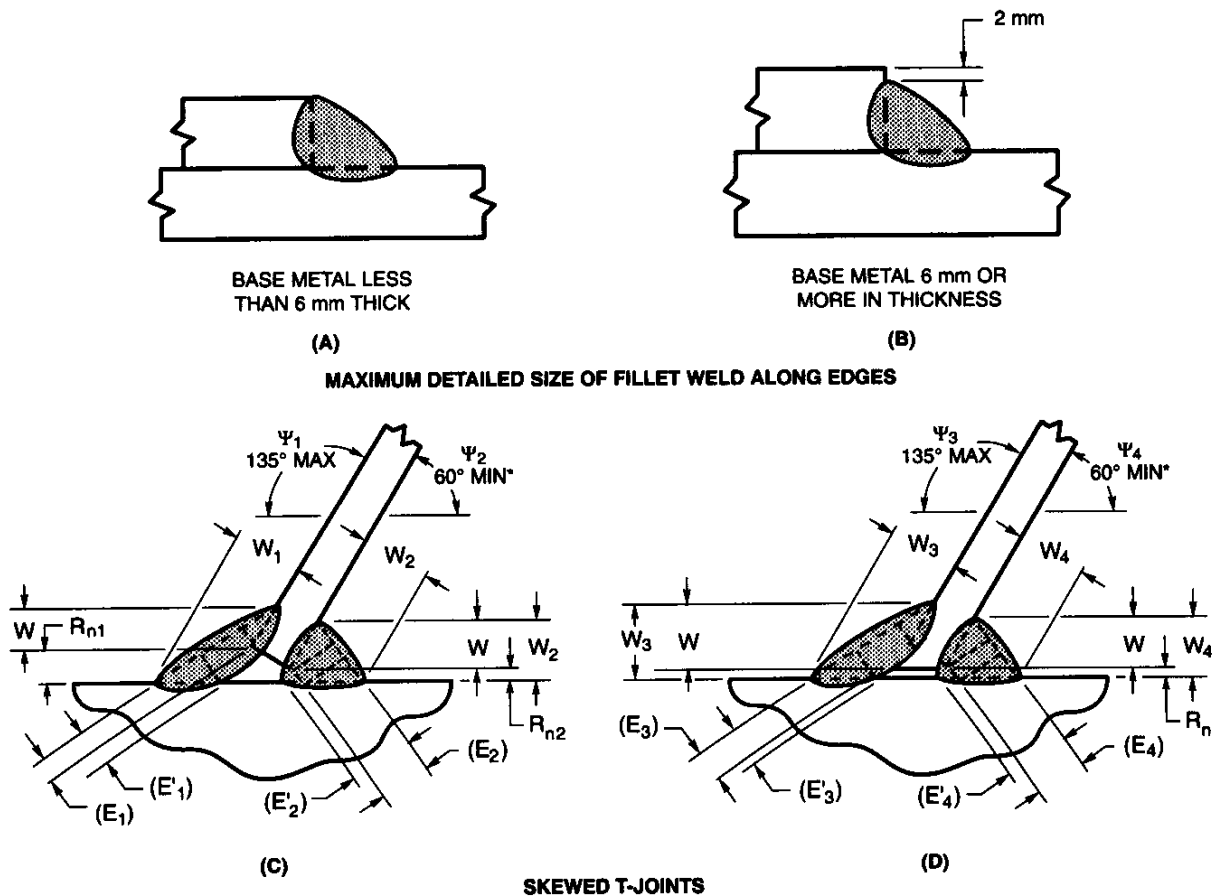
2.6.1 Joint details may depart from the details prescribed in 2.9 and 2.10 only if the contractor submits the proposed WPSs to the Engineer for approval, and at the contractor's expense, demonstrates their adequacy in accordance with the requirements of 5.13 of this code

and their conformance with applicable provisions of sections 3, 4, and 5.

2.7 Details of Fillet Welds

2.7.1 The details of fillet welds made by SMAW, SAW, GMAW, or FCAW to be used without WPS qualification under 5.13 are listed in 2.7.1.1 through 2.7.1.5 and detailed in Figure 2.3.

2.7.1.1 The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 2.1, or as calculated using procedures established to prevent cracking in accordance with 4.2.2. In both cases, the minimum size applies if it is sufficient to satisfy design requirements.



Note: $(E)(n)$, $(E')(n)$ = effective throats dependent on magnitude of root opening (R_n). See 3.3.1. Subscript (n) represents 1, 2, 3, or 4.
 *Angles smaller than 60 degrees are permitted; however, in such cases, the weld is considered to be a partial joint penetration groove weld.

Figure 2.3—Details for Fillet Welds (see 2.7.1)

Table 2.1
Minimum Fillet Weld Size (see 2.7)**

Base Metal Thickness of Thicker Part Joined (T)	Minimum Size of Fillet Weld*	
$T \leq 20 \text{ mm}$	6 mm	Single-pass welds must be used
$T > 20 \text{ mm}$	8 mm	

* Except that the weld size need not exceed the thickness of the thinner part joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.

** Smaller fillet welds may be approved by the Engineer based upon applied stress and the use of appropriate preheat.

2.7.1.2 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 6 mm thick (see Figure 2.3, Detail A).

(2) 2 mm less than the thickness of base metal, for metal 6 mm or more in thickness (see Figure 2.3, Detail B), unless the weld is designated on the drawing to be built out to obtain full throat thickness. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld may be more or less than 2 mm, provided the weld size is clearly verifiable.

2.7.1.3 Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, sub-

ject to the provisions of 2.3.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

2.7.1.4 Fillet welds may be used in skewed T-joints having a dihedral angle (Ψ) of not less than 60 degrees nor more than 135 degrees (see Figure 2.3, Details C and D). Detail D shall be used when R_n would exceed 5 mm using Detail C.

2.7.1.5 When the design permits intermittent fillet welds, the minimum length of an intermittent fillet weld shall be as specified in 2.3.2.3.

2.7.1.6 Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to the requirements of 2.8.

2.8 Details of Plug and Slot Welds

2.8.1 The details of plug and slot welds made by the SMAW, GMAW, or FCAW processes are listed in 2.8.2 through 2.8.8 and 3.3.1.

2.8.1.1 Plug and slot welds may be used without performing the WPS qualification prescribed in 5.13, provided the technique provisions of 4.21, 4.22, and 4.23, as applicable, are met.

2.8.2 The minimum diameter of the hole for a plug weld shall be no less than the thickness of the part containing it plus 8 mm. The maximum diameter shall equal the minimum diameter plus 3 mm or 2-1/4 times the thickness of the member, whichever is greater.

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

2.8.4 The length of the slot for a slot weld shall not exceed ten times the thickness of the part containing it. The width of the slot shall be no less than the thickness of the part containing it plus 8 mm. The maximum width shall equal the minimum width plus 3 mm or 2-1/4 times the thickness of the member, whichever is greater.

2.8.5 The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

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

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

2.9 Complete Joint Penetration Groove Welds

2.9.1 Dimensional Tolerances. Dimensions of groove welds specified on design or detailed drawings may vary as shown in Figure 2.4.

2.9.2 Corner Joints. For corner joints using single-bevel groove welds, either plate may be bevelled, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting. Joint preparation that bevels the plate that will be stressed in the short transverse direction will help to reduce lamellar tearing.

2.10 Partial Joint Penetration Groove Welds (see Figure 2.5)

2.10.1 Definition. Except as provided in Figure 2.5, groove welds without steel backing, welded from one side, and groove welds welded from both sides but without backgouging, are considered partial joint penetration groove welds.

2.10.1.1 All partial joint penetration groove welds made by GMAW-S (short circuiting) shall be qualified by the WPS qualification tests prescribed in 5.13.

2.10.2 Minimum Effective Weld Size. The minimum effective weld size of partial joint penetration square-, single-, or double-V-, bevel-, J-, and U-groove welds shall be as shown in Table 2.2.

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

2.10.3 Corner Joints. For corner joints using single-bevel groove welds, either plate may be beveled, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting. Joint preparation that bevels the plate that will be stressed in the short-transverse direction will help to reduce lamellar tearing.

Table 2.2
Minimum Effective Weld Size for
Partial Joint Penetration Groove Welds**
(see 2.10.3)

Base Metal Thickness of Thicker Part Joined (T)	Minimum Effective Weld Size*
$T \leq 20$ mm	6 mm
$T > 20$ mm	8 mm

* Except that the weld size need not exceed the thickness of the thinner part.

** Smaller welds may be approved by the Engineer based upon applied stress and the use of appropriate preheat.

Legend for Figures 2.4 and 2.5

Symbols for joint types

- B — butt joint
- C — corner joint
- T — T-joint
- BC — butt or corner joint
- TC — T- or corner joint
- BTC — butt, T-, or corner joint

Symbols for base-metal thickness and penetration

- L — limited thickness—complete joint penetration
- U — unlimited thickness—complete joint penetration
- P — partial joint penetration

Symbol for weld types

- 1 — square-groove
- 2 — single-V-groove
- 3 — double-V-groove
- 4 — single-bevel-groove
- 5 — double-bevel-groove
- 6 — single-U-groove
- 7 — double-U-groove
- 8 — single-J-groove
- 9 — double-J-groove

Symbols for welding processes if not shielded metal arc

- S — submerged arc welding
- G — gas metal arc welding
- F — flux cored arc welding

Welding processes

- SMAW — shielded metal arc welding
- GMAW — gas metal arc welding
- FCAW — flux cored metal arc welding
- SAW — submerged arc welding

Welding positions

- F — flat
- H — horizontal
- V — vertical
- OH — overhead

Dimensions

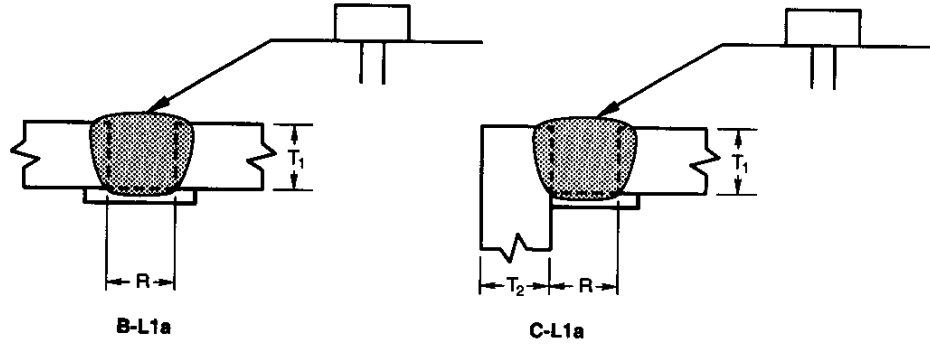
- R = Root Opening
- α, β = Groove Angles
- f = Root Face
- r = J- or U-groove Radius
- S, S₁, S₂ = PJP Groove Weld Depth of Groove
- E, E₁, E₂ = PJP Groove Weld Sizes corresponding to S, S₁, S₂, respectively

Joint Designation

The lower case letters, e.g., a, b, c, etc., are used to differentiate between joints that would otherwise have the same joint designation.

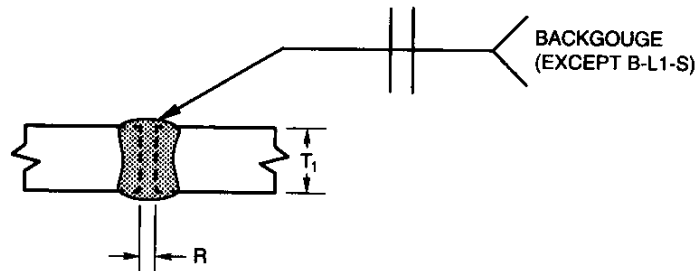
See Notes on Page 24

Square-groove weld (1)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-L1a	6 max	—	R = T ₁	+2, -0	+6, -2	All	—	A, I
	C-L1a	6 max	U	R = T ₁	+2, -0	+6, -2	All	—	A
FCAW GMAW	B-L1a-GF	10 max	—	R = T ₁	+2, -0	+6, -2	All	Not required	I

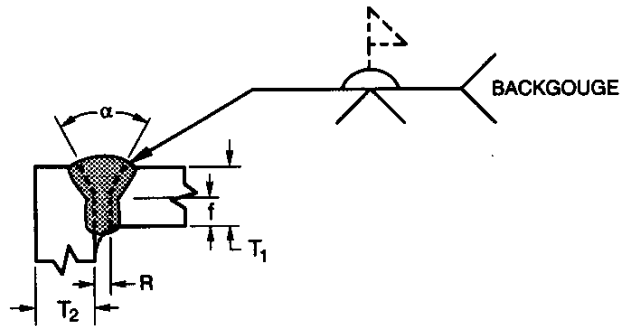
Square-groove weld (1)
Butt joint (B)



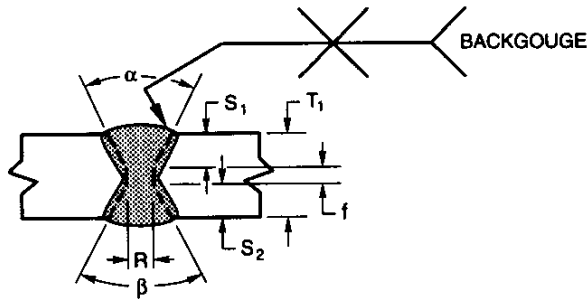
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-L1b	6 max	—	$R = \frac{T_1}{2}$	+2, -0	+2, -3	All	—	A, C, I
GMAW FCAW	B-L1b-GF	10 max	—	R = 0 to 3	+2, -0	+2, -3	All	Not required	C, I
SAW	B-L1-S	10 max	—	R = 0	±0	+2, -0	F	—	E, I
SAW	B-L1a-S	16 max	—	R = 0	±0	+2, -0	F	—	C, N

Figure 2.4—Details of Welded Joints for Complete Joint Penetration Groove Welds (see 2.9.1)

See Notes on Page 24

Single-V-groove weld (2)
Corner joint (C)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	C-U2	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+2, -0 +2, -0 + 10°, -0°	+2, -3 Not limited +10°, -5°	All	—	A, C, L
GMAW FCAW	C-U2-GF	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+2, -0 +2, -0 + 10°, -0°	+2, -3 Not limited +10°, -5°	All	Not required	C, L
SAW	C-U2b-S	25 max	U	R = 0 f = 6 max α = 60°	±0 +6, -0 +10°, -0°	+2, -0 ±2 +10°, -5°	F	—	C, L

Double-V-groove weld (3)
Butt joint (B)

For B-U3c-S only

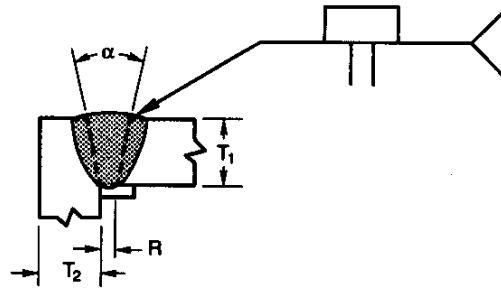
T ₁		S ₁
Over	to	
50	60	35
60	80	45
80	90	55
90	100	60
100	120	70
120	140	80
140	160	95

For T₁ > 160 or T₁ ≤ 50
S₁ = 2/3 (T₁ - 6)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-U3b	U	—	R = 0 to 3 f = 0 to 3 α = β = 60°	+2, -0 +2, -0 +10°, -0°	+2, -3 Not limited +10°, -5°	All	—	A, C, G, I
GMAW FCAW	B-U3-GF			All	Not required	C, G, I			
SAW	B-U3c-S	U	—	R = 0 f = 6 min α = β = 60°	+2, -0 +6, -0 +10°, -0°	+2, -0 +6, -0 +10°, -5°	F	—	C, G, I
				To find S ₁ , see table above: S ₂ = T ₁ - (S ₁ + f)					

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration
Groove Welds (see 2.9.1)

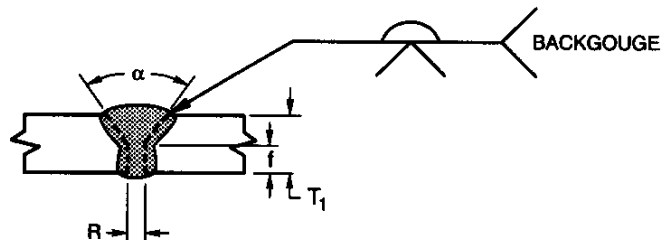
See Notes on Page 24

Single-V-groove weld (2)
Corner joint (C)

Tolerances

As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
$R = +2, -0$	$+6, -2$
$a = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	C-U2a	U	U	$R = 6$	$\alpha = 45^\circ$	All	—	A, L
				$R = 10$	$\alpha = 30^\circ$	F, V, OH	—	A, L
				$R = 12$	$\alpha = 20^\circ$	F, V, OH	—	A, L
GMAW FCAW	C-U2a-GF	U	U	$R = 5$	$\alpha = 30^\circ$	F, V, OH	Required	L
				$R = 10$	$\alpha = 30^\circ$	F, V, OH	Not req.	L
				$R = 6$	$\alpha = 45^\circ$	F, V, OH	Not req.	L
SAW	C-L2a-S	50 max	U	$R = 6$	$\alpha = 30^\circ$	F	—	L
SAW	C-U2-S	U	U	$R = 16$	$\alpha = 20^\circ$	F	—	L

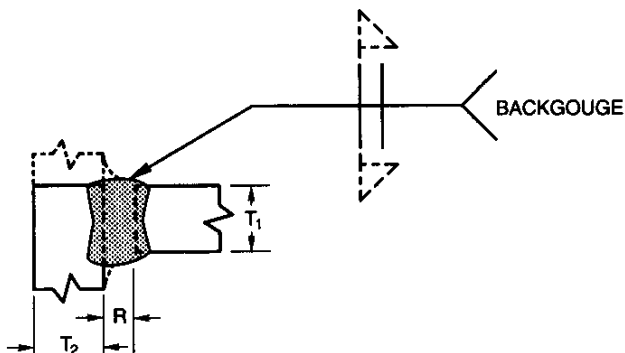
Single-V-groove weld (2)
Butt joint (B)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-U2	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+2, -0 +2, -0 + 10°, -0°	+2, -3 Not limited +10°, -5°	All	—	A, C, I
GMAW FCAW	B-U2-GF	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+2, -0 +2, -0 + 10°, -0°	+2, -3 Not limited +10°, -5°	All	Not required	C. I
SAW	B-L2c-S	Over 12 to 25	—	R = 0 f = 6 min α = 60°	R = ±0 f = +6, -0 α = +10°, -0°	+2, -0 Not limited +10°, -5°	F	—	C, I
		Over 25 to 38	—	R = 0 f = 10 min α = 60°					
		Over 38 to 50	—	R = 0 f = 12 min α = 60°					

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration
Groove Welds (see 2.9.1)

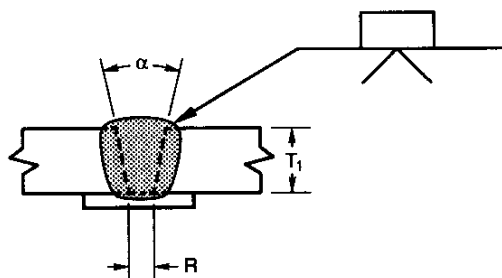
See Notes on Page 24

Square-groove weld (1)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 2.9.1)			
SMAW	TC-L1b	6 max	U	$R = \frac{T_1}{2}$	+2, -0	+2, -3	All	—	A, C
GMAW FCAW	TC-L1-GF	10 max	U	R = 0 to 3	+2, -0	+2, -3	All	Not required	C
SAW	TC-L1-S	10 max	U	R = 0	±0	+2, -0	F	—	C

Single-V-groove weld (2)
Butt joint (B)



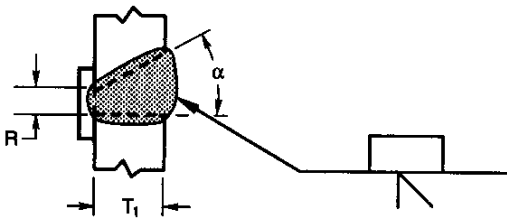
Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
$R = +2, -0$	+6, -2
$\alpha = +10^\circ, -0^\circ$	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	B-U2a	U	—	$R = 6$	$\alpha = 45^\circ$	All	—	A, I
				$R = 10$	$\alpha = 30^\circ$	F, V, OH	—	A, I
				$R = 12$	$\alpha = 20^\circ$	F, V, OH	—	A, I
GMAW FCAW	B-U2a-GF	U	—	$R = 5$	$\alpha = 30^\circ$	F, V, OH	Required	I
				$R = 10$	$\alpha = 30^\circ$	F, V, OH	Not req.	I
				$R = 6$	$\alpha = 45^\circ$	F, V, OH	Not req.	I
SAW	B-L2a-S	50 max	—	$R = 6$	$\alpha = 30^\circ$	F	—	I
SAW	B-U2-S	U	—	$R = 16$	$\alpha = 20^\circ$	F	—	I

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration Groove Welds (see 2.9.1)

See Notes on Page 24

Single-bevel-groove weld (4)
Butt joint (B)



Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
R = +2, -0	+6, -2
a = +10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	B-U4a	U	—	R = 6	α = 45°	H	—	A, I
				R = 10	α = 30°	H	—	A, I
GMAW FCAW	B-U4a-GF	U	—	R = 5	α = 30°	H	Required	I
				R = 6	α = 45°	H	Not req.	I
				R = 10	α = 30°	H	Not req.	I

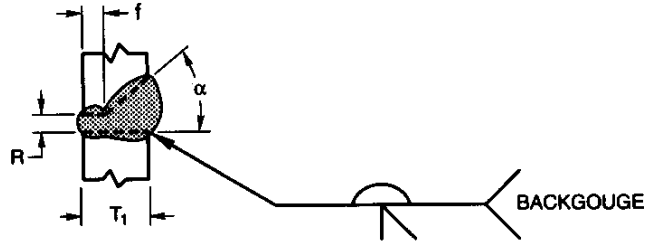
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
R = +2, -0	+6, -2
α = +10°, -0°	+10°, -5°

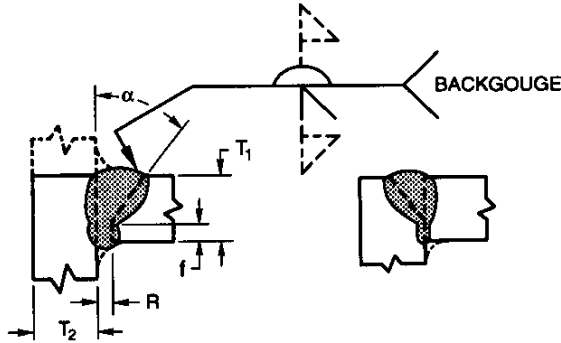
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	TC-U4c	U	U	R = 6	α = 45°	All	—	A, L
				R = 10	α = 30°	F, OH, H	—	A, L
GMAW FCAW	TC-U4c-GF	U	U	R = 5	α = 30°	All	Required	L
				R = 10	α = 30°	F	Not req.	L
				R = 6	α = 45°	All	Not req.	L
SAW	TC-U4a-S	U	U	R = 10	α = 30°	F	—	L
				R = 6	α = 45°			

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration Groove Welds (see 2.9.1)

See Notes on Page 24

Single-bevel-groove weld (4)
Butt joint (B)

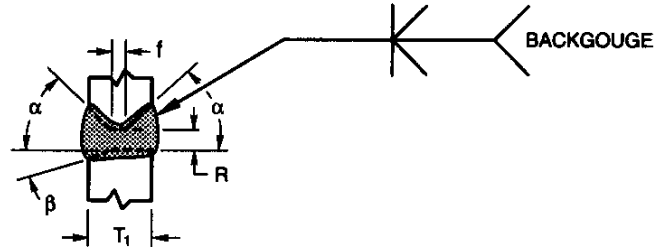
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-U4b	U	—	R = 0 to 3 f = 0 to 3 α = 45°	+2, -0 +2, -0 +10°, -0°	+2, -3 Not limited 10°, -5°	H	—	A, C, I
GMAW FCAW	B-U4b-GF	U	—				H	Not required	C, I

Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

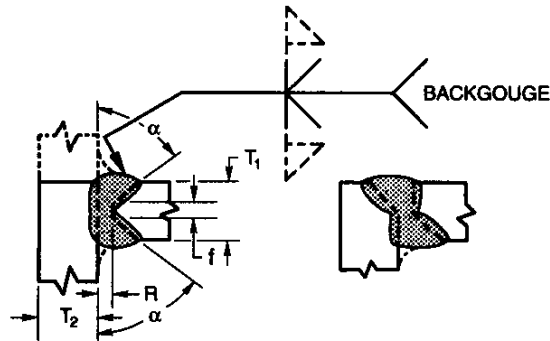
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-U4b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+2, -0 +2, -0 +10°, -0°	+2, -3 Not limited 10°, -5°	All	—	A, C, L
GMAW FCAW	TC-U4b-GF	U	U				All	Not required	C, L
SAW	TC-U4b-S	U	U	R = 0 f = 3 max α = 60°	±0 +0, -3 +10°, -0°	+6, -0 ±2 10°, -5°	F	—	C, L

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration
Groove Welds (see 2.9.1)

See Notes on Page 24

Double-bevel-groove weld (5)
Butt joint (B)

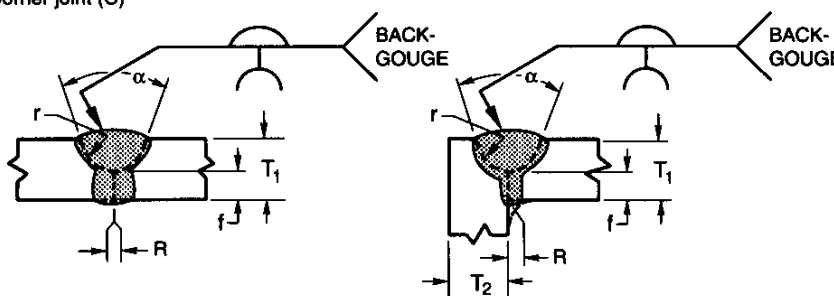
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	B-U5a	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+2, -0 +2, -0 α + β +10° -0°	+2, -3 Not limited α + β +10° -5°	H	—	A, C, G, I
GMAW FCAW	B-U5-GF	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+2, -0 +2, -0 α + β = +10°, -0°	+2, -3 Not limited α + β = +10°, -5°	H	Not required	C, G, I

Double-bevel-groove weld (5)
T-joint (T)
Corner joint (C)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-U5b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+2, -0 +2, -0 + 10°, -0°	+2, -3 Not limited +10°, -5°	All	—	A, C, G, L
GMAW FCAW	TC-U5-GF	U	U				All	Not required	C, G, L
SAW	TC-U5-S	U	U	R = 0 f = 5 max α = 60°	±0 +0, -5 +10°, -0°	+2, -0 ±2 +10°, -5°	F	—	C, G, L

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration
Groove Welds (see 2.9.1)

See Notes on Page 24

Single-U-groove weld (6) Butt joint (B) Corner joint (C)				Tolerances <table><tr><th>As Detailed (see 2.9.1)</th><th>As Fit-Up (see 3.3.4)</th></tr><tr><td>$R = +2, -0$</td><td>$+2, -3$</td></tr><tr><td>$\alpha = +10^\circ, -0^\circ$</td><td>$+10^\circ, -5^\circ$</td></tr><tr><td>$f = \pm 2$</td><td>Not Limited</td></tr><tr><td>$r = +3, -0$</td><td>$+3, -0$</td></tr></table>				As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)	$R = +2, -0$	$+2, -3$	$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$	$f = \pm 2$	Not Limited	$r = +3, -0$	$+3, -0$
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)																
$R = +2, -0$	$+2, -3$																
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$																
$f = \pm 2$	Not Limited																
$r = +3, -0$	$+3, -0$																
																	
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes							
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius										
SMAW	B-U6	U	U	R = 0 to 3	$\alpha = 45^\circ$	f = 3	r = 6	All	—	A, C, I							
				R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	F, OH	—	A, C, I							
	C-U6	U	U	R = 0 to 3	$\alpha = 45^\circ$	f = 3	r = 6	All	—	A, C, L							
				R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	F, OH	—	A, C, L							
GMAW FCAW	B-U6-GF	U	U	R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	All	Not req.	C, I							
	C-U6-GF	U	U	R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	All	Not req.	C, L							
SAW	B-U6-S	16 min	16 min	R = 0	$\alpha = 20^\circ$	f = 6 min	r = 6	F	—	C, I							
	C-U6-S	16 min	16 min	R = 0	$\alpha = 20^\circ$	f = 6 min	r = 6	F	—	C, L							

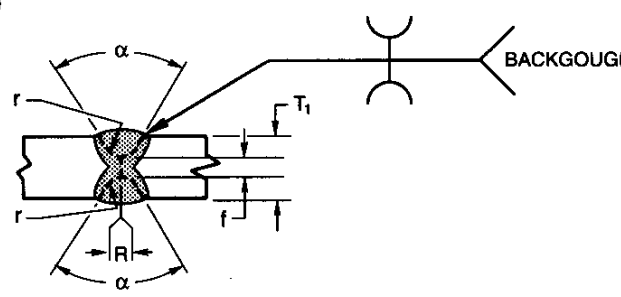
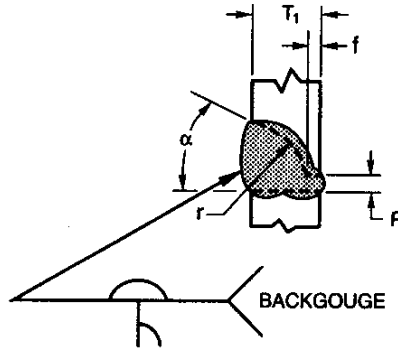
Double-U-groove weld (7) Butt joint (B)		Tolerances <table><tr><th>As Detailed (see 2.9.1)</th><th>As Fit-Up (see 3.3.4)</th></tr><tr><td colspan="2">For B-U7 and B-U7-GF</td></tr><tr><td>$R = +2, -0$</td><td>$+2, -3$</td></tr><tr><td>$\alpha = +10^\circ, -0^\circ$</td><td>$+10^\circ, -5^\circ$</td></tr><tr><td>$f = \pm 2, -0$</td><td>Not Limited</td></tr><tr><td>$r = +6, -0$</td><td>± 2</td></tr><tr><td colspan="2">For B-U7-S</td></tr><tr><td>$R = \pm 0$</td><td>$+2, -0$</td></tr><tr><td>$f = +0, -6$</td><td>± 2</td></tr></table>				As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)	For B-U7 and B-U7-GF		$R = +2, -0$	$+2, -3$	$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$	$f = \pm 2, -0$	Not Limited	$r = +6, -0$	± 2	For B-U7-S		$R = \pm 0$	$+2, -0$	$f = +0, -6$	± 2
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)																						
For B-U7 and B-U7-GF																							
$R = +2, -0$	$+2, -3$																						
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$																						
$f = \pm 2, -0$	Not Limited																						
$r = +6, -0$	± 2																						
For B-U7-S																							
$R = \pm 0$	$+2, -0$																						
$f = +0, -6$	± 2																						
																							
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes													
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius																
SMAW	B-U7	U	—	R = 0 to 3	$\alpha = 45^\circ$	f = 3	r = 6	All	—	A, C, G, I													
				R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	F, OH	—	A, C, G, I													
GMAW FCAW	B-U7-GF	U	—	R = 0 to 3	$\alpha = 20^\circ$	f = 3	r = 6	All	Not required	C, G, I													
SAW	B-U7-S	U	—	R = 0	$\alpha = 20^\circ$	f = 6 max	r = 6	F	—	C, G, I													

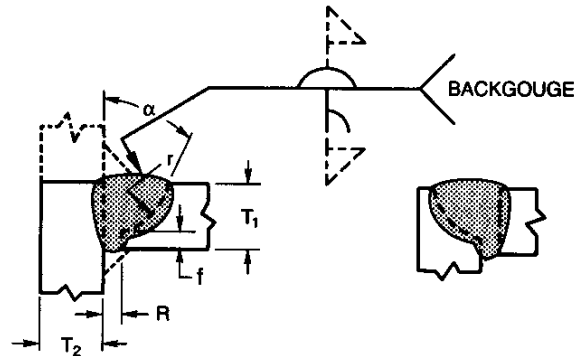
Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration Groove Welds (see 2.9.1)

See Notes on Page 24

Single-J-groove weld (8)
Butt joint (B)

Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
$R = +2, -0$	$+2, -3$
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = +2, -0$	Not Limited
$r = +6, -0$	± 2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U8	U	—	$R = 0 \text{ to } 3$	$\alpha = 45^\circ$	$f = 3$	$r = 10$	H	—	A, C, I
GMAW FCAW	B-U8-GF	U	—	$R = 0 \text{ to } 3$	$\alpha = 30^\circ$	$f = 3$	$r = 10$	H	Not required	C, I

Single-J-groove weld (8)
T-joint (T)
Corner joint (C)

Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
$R = +2, -0$	$+2, -3$
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = +2, -0$	Not Limited
$r = +6, -0$	± 2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U8a	U	U	$R = 0 \text{ to } 3$	$\alpha = 45^\circ$	$f = 3$	$r = 10$	All	—	A, C, I
				$R = 0 \text{ to } 3$	$\alpha = 30^\circ$	$f = 3$	$r = 10$	F, OH	—	A, C, I
GMAW FCAW	TC-U8a-GF	U	U	$R = 0 \text{ to } 3$	$\alpha = 30^\circ$	$f = 3$	$r = 10$	All	Not required	C, I
SAW	TC-U8a-S	16 min	16 min	$R = 0$	$\alpha = 30^\circ$	$f = 6 \text{ min}$	$r = 10$	F	—	C, I

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration
Groove Welds (see 2.9.1)

See Notes on Page 24

Double-J-groove weld (9)
Butt joint (B)

Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
R = +2, -0	+2, -3
α = +10°, -0°	+10°, -5°
f = +2, -0	Not Limited
r = +3, -0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U9	U	—	R = 0 to 3	α = 45°	f = 3	r = 10	H	—	A, C, G, I
GMAW FCAW	B-U9-GF	U	—	R = 0 to 3	α = 30°	f = 3	r = 10	H	Not required	C, G, I

Double-J-groove weld (9)
T-joint (T)
Corner joint (C)

NOTE: DASHED LINE
FILLET WELD SYMBOLS
INDICATE THAT THE
FILLET WELD IS
OPTIONAL

Tolerances	
As Detailed (see 2.9.1)	As Fit-Up (see 3.3.4)
$R = +2, -0$	$+2, -3$
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = +2, -0$	Not Limited
$r = +3, -0$	± 2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U9a	U	U	R = 0 to 3	$\alpha = 45^\circ$	f = 3	r = 10	All	—	A, C, G, L
				R = 0 to 3	$\alpha = 30^\circ$	f = 3	r = 10	F, OH	—	C, G, L
GMAW FCAW	TC-U9a-GF	U	U	R = 0 to 3	$\alpha = 30^\circ$	f = 3	r = 10	All	Not required	C, G, L
sAW	TC-U9a-s	10 min	10 min	R = 0	$\alpha = 30^\circ$	f = 6	r = 10	F	—	C, G, L

Figure 2.4 (Continued)—Details of Welded Joints for Complete Joint Penetration Groove Welds (see 2.9.1)

See Notes on Page 24

Square-groove weld (1)
Butt joint (B)

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	B-P1a	3 max	—	R = 0 to 2	+2, -0	±2	All	T ₁ - 1	A, B
	B-P1c	6 max	—	R = $\frac{T_1}{2}$ min	+2, -0	±2	All	$\frac{T_1}{2}$	A, B

Square-groove weld (1)
Butt joint (B)

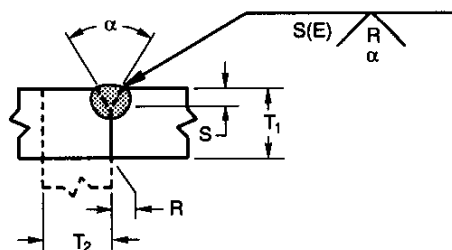
E₁ + E₂ MUST NOT EXCEED $\frac{3T_1}{4}$

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

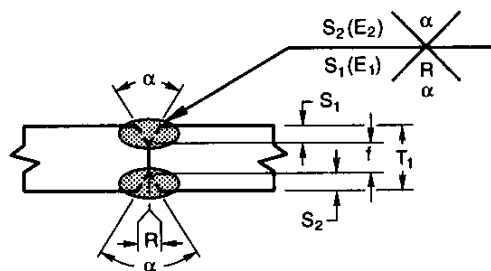
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size (E ₁ + E ₂)	Notes
				Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	B-P1b	6 max	—	R = $\frac{T_1}{2}$	+2, -0	±2	All	$\frac{3T_1}{4}$	A

Figure 2.5—Details of Welded Joints for Partial Joint Penetration Groove Welds (see 2.10.1)

See Notes on Page 24

Single-V-groove weld (2)
Corner joint (C)FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	C-P2	6 min	U	R = 0 f = 1 min α = 60°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S	A, B, D, K
GMAW FCAW	C-P2-GF	6 min	U	R = 0 f = 3 min α = 60°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S	B, D, K
SAW	C-P2-S	11 min	U	R = 0 f = 6 min α = 60°	±0 Unlimited +10°, -0°	+2, -0† ±2 +10°, -5°	F	S	B, D, K

[†]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.Double-V-groove weld (3)
Butt joint (B)FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size (E ₁ + E ₂)	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	B-P3	12 min	—	R = 0 f = 3 min α = 60°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S ₁ + S ₂	A, D, H, K
GMAW FCAW	B-P3-GF	12 min	—	R = 0 f = 3 min α = 60°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S ₁ + S ₂	D, H, K
SAW	B-P3-S	20 min	—	R = 0 f = 6 min α = 60°	±0 Unlimited +10°, -0°	+2, -0 ±2 +10°, -5°	F	S ₁ + S ₂	D, H, K

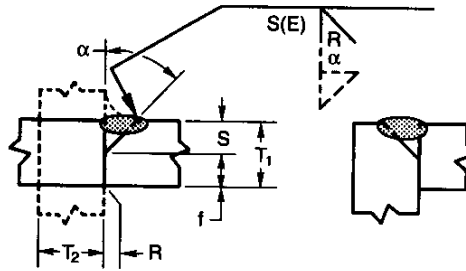
Figure 2.5 (Continued)—Details of Welded Joints for Partial Joint Penetration
Groove Welds (see 2.10.1)

See Notes on Page 24

Single-bevel-groove (4)
T-joint (T)
Corner joint (C)

FOR CORNER AND T-JOINT
RESTRICTIONS, SEE 9.7

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8



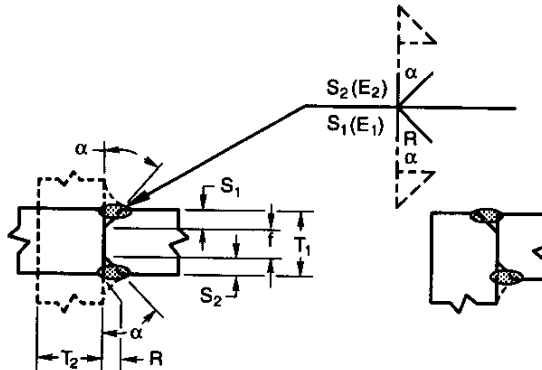
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-P4	U	U	R = 0 f = 3 min α = 45°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S-3	A, B, D, F, K
GMAW FCAW	TC-P4-GF	6 min	U	R = 0 f = 3 min α = 45°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	S-3	B, D, F, K
SAW	TC-P4-S	11 min	U	R = 0 f = 6 min α = 60°	±0 Unlimited +10°, -0°	+2, -0 [†] ±2 +10°, -5°	F	S	B, D, F, K

[†]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.

Double-bevel-groove weld (5)
T-joint (T)
Corner joint (C)

FOR CORNER AND T-JOINT
RESTRICTIONS, SEE 9.7

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

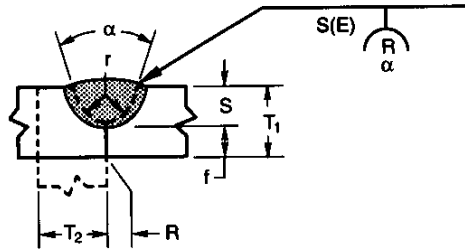


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size (E ₁ + E ₂)	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-P5	8 min	U	R = 0 f = 3 min α = 45°	+2, -0 Unlimited + 10°, -0°	+3, -2 ±2 +10°, -5°	All	(S ₁ + S ₂) -6	A, D, F, H, K
GMAW FCAW	TC-P5-GF	12 min	U	R = 0 f = 3 min α = 45°	+2, -0 Unlimited +10°, -0°	+3, -2 ±2 +10°, -5°	All	(S ₁ + S ₂) -6	D, F, H, K
SAW	TC-P5-S	20 min	U	R = 0 f = 6 min α = 60°	±0 Unlimited +10°, -0°	+2, -0 ±2 +10°, -5°	F	S ₁ + S ₂	D, F, H, K

[†]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.

Figure 2.5 (Continued)—Details of Welded Joints for Partial Joint Penetration Groove Welds (see 2.10.1)

See Notes on Page 24

Single-U-groove weld (6)
Corner joint (C)FOR CORNER AND T-JOINT
RESTRICTIONS, SEE 9.7FOR BUTT JOINT RESTRICTIONS,
SEE 9.8

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Root Opening Root Face Groove Radius Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	C-P6	6 min	U	R = 0 f = 1 min r = 6 α = 45°	+2, -0 +U, -0 +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	A, B, D, K
GMAW FCAW	C-P6-GF	6 min	U	R = 0 f = 3 min r = 6 α = 20°	+2, -0 +U, -0 +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	B, D, K
SAW	C-P6-S	11 min	U	R = 0 f = 6 min r = 6 α = 20°	±0 +U, -0 +6, -0 +10°, -0°	+2, -0† ±2 ±2 +10°, -5°	F	S	B, D, K

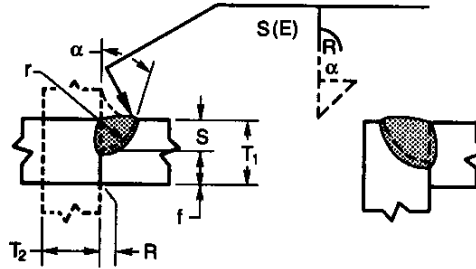
[†]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.**Figure 2.5 (Continued)—Details of Welded Joints for Partial Joint Penetration
Groove Welds (see 2.10.1)**

See Notes on Page 24

Single-J-groove weld (B)
T-joint (T)
Corner joint (C)

FOR CORNER AND T-JOINT
RESTRICTIONS, SEE 9.7

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Radius Groove Angle	Tolerances				
					As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-P8	6 min	U	R = 0 f = 3 min r = 10 α = 45°	+2, -0 Not limited +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	A, D, F, K
SMAW	C-P8*	6 min	U	R = 0 f = 3 min r = 10 α = 30°	+2, -0 Not limited +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	A, D, F, K
GMAW FCAW	TC-P8-GF	6 min	U	R = 0 f = 3 min r = 10 α = 45°	+2, -0 Not limited +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	D, F, K
GMAW FCAW	C-P8-GF*	6 min	U	R = 0 f = 3 min r = 10 α = 30°	+2, -0 Not limited +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S	D, F, K
SAW	TC-P8-S	11 min	U	R = 0 f = 6 min r = 12 α = 45°	±0 Not limited +6, -0 +10°, -0°	+2, -0 [†] ±2 ±2 +10°, -5°	F	S	D, F, K
SAW	C-P8-S*	11 min	U	R = 0 f = 6 min r = 12 α = 30°	±0 Not limited +6, -0 +10°, -0°	+2, -0 [†] ±2 ±2 +10°, -5°	F	S	D, F, K

[†]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.

*Applies to outside corner joints.

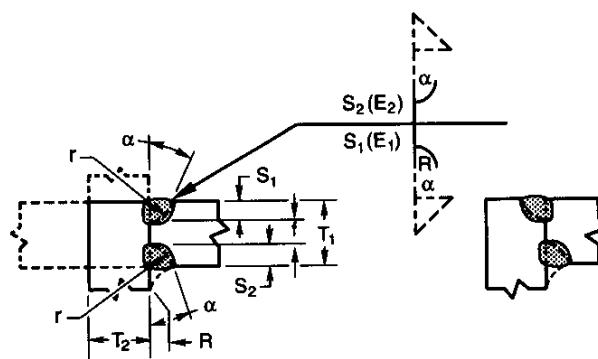
Figure 2.5 (Continued)—Details of Welded Joints for Partial Joint Penetration Groove Welds (see 2.10.1)

See Notes on Page 24

Double-J-groove weld (9)
T-joint (T)
Corner joint (C)

FOR CORNER AND T-JOINT
RESTRICTIONS, SEE 9.7

FOR BUTT JOINT RESTRICTIONS,
SEE 9.8



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size (E ₁ + E ₂)	Notes
				Root Opening Root Face Groove Radius Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 2.10.1)	As Fit-Up (see 3.3.4)			
SMAW	TC-P9	12 min	U	R = 0 f = 3 min r = 10 α = 45°	+2, -0 -0 +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S ₁ + S ₂	A, D, H, K
GMAW FCAW	TC-P9-GF*	12 min	U	R = 0 f = 3 min r = 10 α = 30°	+2, -0 Not limited +6, -0 + 10°, -0°	+3, -2 ±2 ±2 +10°, -5°	All	S ₁ + S ₂	D, H, K
SAW	C-P9-S	20 min	U	R = 0 f = 6 min r = 12 α = 45°	±0 Not limited +6, -0 + 10°, -0°	+2, -0 ±2 ±2 +10°, -5°	F	S ₁ + S ₂	D, H, K
SAW	C-P9-S*	20 min	U	R = 0 f = 6 min r = 12 α = 20°	±0 Not limited +6, -0 +10°, -0°	+2, -0 [‡] ±2 ±2 +10°, -5°	F	S ₁ + S ₂	D, H, K
SAW	T-P9-S	20 min	U	R = 0 f = 6 min r = 12 α = 45°	±0 Not limited +6, -0 +10°, -0°	+2, -0 [‡] ±2 ±2 +10°, -5°	F	S ₁ + S ₂	D, H, K

[‡]Fit-up tolerance, see 3.3.2, for rolled shapes R may be 8 mm in thick plates if backing is provided.

*Applies to outside corner joints.

Figure 2.5 (Continued)—Details of Welded Joints for Partial Joint Penetration Groove Welds (see 2.10.1)

Notes for Figures 2.4 and 2.5

Notes:

- A: Groove preparations detailed for shielded metal arc welded joints may be used for gas metal arc or flux cored arc welding.
- B: Joint is welded from one side only.
- Br: Gouge root to sound metal before welding second side.
- C: Backgouge root to sound metal before welding second side.
- D: Minimum weld size (E) as shown in Table 2.2; S as specified on drawings.
- E: Evidence of complete joint penetration is required (see 4.7.5).
- F: Groove welds in corner and T-joints shall be reinforced with fillet welds equal to 1/4 T₁, but need not exceed 10 mm.
- G: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.
- H: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note D. Also the weld size (E), less any reduction, applies individually to each groove.
- I: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remains the same and that the design weld size is maintained.
- J: For corner and T-joints, the member orientation may be changed provided the groove angle is maintained as specified.
- K: The member orientation may be changed provided that the groove dimensions are maintained as specified.
- L: The orientation of the two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remains the same and that the design weld size is maintained.

3. Workmanship

3.1 General Requirements

3.1.1 All applicable paragraphs of this section shall be observed in the fabrication of welded bridges under this code.

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

3.1.3 Welding shall not be done when the ambient temperature is lower than -20°C (see 4.2), when surfaces are wet or exposed to rain, snow, or high wind velocities, nor when welders are exposed to inclement conditions.

3.1.4 Size and lengths of welds shall be no less than those specified by design requirements and detailed drawings except as permitted by 9.21.1.7. The location of welds shall not be changed without approval.

3.1.5 No welds shall be permitted on the work except as follows:

(1) Base-metal repair performed in accordance with AASHTO M160/M160M (ASTM A6/A6M), *Specification for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use*, Article 9, by the mill or fabricator

(2) All welds detailed on approved shop drawings

(3) Repair welds authorized by this code

(4) Other welds approved by the Engineer

3.2 Preparation of Base Metal

3.2.1 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other discontinuities which would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to a weld shall also be free from loose or thick

scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that can withstand vigorous wire brushing, a thin rust-inhibitive coating, or antispat-ter compound may remain except that all mill scale shall be removed from the surfaces on which web-to-flange welds are to be made. This provision shall apply to all girders, stringers, beams, columns, towers, rigid frames, arches, truss chord members, and truss web members, but shall not apply to secondary (bracing) members. No mill scale shall be permitted to remain in the joint boundary of groove welds subject to calculated tensile stress.

3.2.2 In all thermal cutting, the cutting flame shall be so adjusted and manipulated as to avoid cutting beyond (inside) the prescribed lines. The roughness of thermal cut surfaces shall be no greater than that defined by the American National Standards Institute, ANSI B46.1, *Surface Texture*. For material up to 100 mm thick, a maximum surface roughness value of 25 μm is permitted.

Note: The AWS C4.1-G, Oxygen Cutting Surface Roughness Gauge, may be used as a guide for evaluating surface roughness of these edges. For materials up to and including 100 mm thick, use Sample No. 3, and for materials over 100 mm up to 200 mm thick, use Sample No. 2.

For material over 100 mm through 200 mm thick, a maximum surface roughness value of 50 μm is permitted. The following exception is permitted: the ends of members not subject to calculated stress at the ends shall meet the surface roughness value of 50 μm . Roughness exceeding these values and occasional notches or gouges no more than 5 mm deep on otherwise satisfactory surfaces shall be removed by machining or grinding. Cut surfaces and edges shall be left free of slag. Occasional notches or gouges in material edges, which are not subsequently to be welded, shall be removed by machining or grinding if the actual net cross-sectional area which would remain after removal of the discontinuity is 98 percent or greater of the area of the material based on

nominal dimensions. Such removal shall be faired to the material edge with a slope not steeper than one in ten and with machine or grinding marks parallel to the material surfaces.

3.2.2.1 For steels other than M270M Grades 690/690W (A709M Grades 690/690W) steels, occasional notches or gouges in thermal-cut surfaces, resulting from improper operation of the cutting process, may, with the approval of the Engineer, be repaired by welding. Material defects exposed by thermal cutting, such as significant nonmetallic inclusions, shall not be repaired by welding unless radiographic or ultrasonic tests have defined the limits of the defects and the Engineer has approved the methods of defect removal and repair.

Approved repairs shall be made by (1) suitably preparing the discontinuity for welding, (2) welding using an approved low-hydrogen WPS, (3) observing all applicable requirements of this code, and (4) grinding the completed weld smooth and flush with the adjacent surface to produce a workmanlike finish (see 3.6.3). Repair welds in members subject to tension or reversal of stress shall be inspected as described in 3.2.2.3.

3.2.2.2 For M270M Grades 690/690W (A709M Grades 690/690W) steels, defects in thermal cut surfaces shall not be repaired by welding except with the approval of the Engineer for occasional gouges and notches as follows:

(1) Notches or gouges of not more than 5 mm deep in plate edges which will form the faces of a groove welded joint and which will be subsequently completely fused with the weld may be repaired by welding. Nonmetallic stringers or pipe opening to those edges shall be removed to a depth of 6 mm below the surface by grinding or chipping, and the gouge shall be repaired by welding. Laminations opening to these edges shall be repaired in accordance with the provisions of 3.2.3.

(2) Notches or gouges not more than 5 mm deep in material edges which will form a fillet welded corner joint may be repaired by welding only on the part of the edge which will become the faying surface for the joint and the fusion zone of the fillet weld. The part of the defect outside the toe of the completed fillet weld shall be removed in accordance with 3.2.2.

(3) Repair shall be made by suitably preparing the defective area, then welding in conformance with following an approved WPS and the applicable requirements of section 4. The completed weld shall be ground smooth and flush (see 3.6.3) with the adjacent surface to produce a workmanlike finish.

3.2.2.3 Welded repairs to the surfaces and edges of tension and reversal-of-stress members shall be subject to ultrasonic testing and magnetic-particle testing. Weld quality shall conform to the requirements of 9.21.

3.2.3 Visual Inspection and Repair of Base Metal Cut Edges

Note: The requirements of 3.2.3 may not be adequate in cases of tensile load applied through the thickness of the material.

3.2.3.1 The following provisions shall apply to permissible repairs to discontinuities discovered by either (1) visual inspection of base-metal cut edges before fabrication or welding, or (2) during routine examination of welded joints by radiography or ultrasonic tests, in all steels covered by these specifications, in thicknesses up to and including 100 mm maximum.

These discontinuities principally result from gas pockets or blow holes and shrinkage cavities which are manifested as "laminations" or "pipe" characterized by a distinct separation of metal parallel to the plane of the base metal. To a lesser extent, these discontinuities result from entrapped slag, refractory, or deoxidation products manifested as deposits of foreign material in the steel, parallel to the plane of the base metal. Multiple discontinuities located in the same plane shall be considered continuous when they are separated by a distance less than five percent of the base metal thickness, or the length of the smaller of two adjacent discontinuities.

3.2.3.2 The limits of acceptability and the repair of visually observed edge discontinuities shall be in accordance with Table 3.1, in which the length of discontinuity is the visible long dimension on the cut edge of the base metal and the depth is the distance that the discontinuity extends into the base metal from the cut edge. Base-metal edges may be at any angle with respect to the direction of rolling, but the direction of discontinuities shall be considered with respect to the direction of the base-metal edges. The limits of all internal discontinuities required to be explored which are not explored to their full depth by other means, shall be determined by ultrasonic testing.

3.2.3.3 In making any repairs, the amount of metal removed shall be the minimum necessary to remove the discontinuity or determine that the permissible limit is not exceeded. Gouging of the discontinuity may be done from either the base-metal surface or edge. All repairs of discontinuities by welding shall conform to the applicable provisions of this code and an approved WPS.

3.2.3.4 The corrective procedures described in Table 3.1 shall not apply to discontinuities in rolled base-metal surfaces. Such discontinuities may be corrected by the fabricator in accordance with the provisions of AASHTO M160/M160M (ASTM A6/A6M).

3.2.3.5 Edges of base metal shall be inspected, and required repairs shall be completed as early as feasible in

Table 3.1
Limits on Acceptability and Repair of Cut Edge Discontinuities of Material (see 3.2.3.2)

Description of Discontinuity	Plate Repair Required
Any discontinuity 25 mm in length or less	None, need not be explored.
Any discontinuity over 25 mm in length and 3 mm maximum depth	None, but the depth should be explored*
Any discontinuity over 25 mm in length with depth over 3 mm but not greater than 6 mm	Remove, need not weld
Any discontinuity over 25 mm in length with depth over 6 mm but not greater than 25 mm	Completely remove and weld Aggregate length of welding shall not exceed 20% of the length of the material edge being repaired
Any discontinuity over 25 mm in length with depth greater than 25 mm	See 3.2.3.7

*A spot check of 10 percent of the discontinuities on the oxygen-cut surface in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 3 mm, then all of the discontinuities remaining on that edge shall be explored by grinding to determine depth. If none of the discontinuities explored on the 10 percent spot check have a depth exceeding 3 mm, then the remainder of the discontinuities on that edge need not be explored.

the fabrication sequence so as to allow maximum opportunity for the fabricator to incorporate repaired plates in the least critical areas.

3.2.3.6 Discontinuities in a base-metal edge such as Type Y, in Figure 3.1 shall be removed by machining or grinding if the actual net cross-sectional area which would remain after removal of the discontinuity is 98 percent or greater of the area of the base metal based on nominal dimensions. Such removals shall be faired to the base metal edge with a slope not exceeding one in ten.

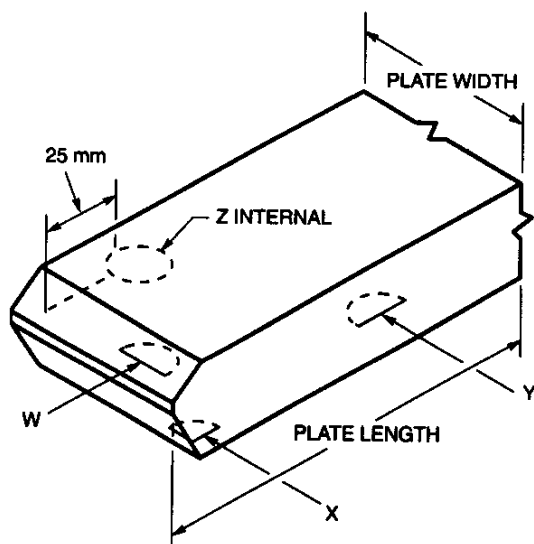


Figure 3.1—Discontinuities in Cut Plate (see 3.2.3.6)

Machining or grinding marks perpendicular to the applied stress shall not exceed a surface roughness of $3\text{ }\mu\text{m}$. No welding repairs shall be permitted for Type Y discontinuities in M270M Grades 690/690W (A709M Grades 690/690W) steels. In steels other than M270M Grades 690/690W (A709M Grades 690/690W) steels, a Type Y discontinuity with a depth greater than described herein may be repaired by welding with the approval of the Engineer.

3.2.3.7 For discontinuities over 25 mm in length with depth found to be greater than 25 mm, discovered before welding by visual inspection of cut edges of base metal, or found in welded joints during examination by radiographic or ultrasonic testing, the following procedures should be observed:

(1) Where discontinuities such as W, X, or Y in Figure 3.1 are observed prior to completing the joint, the size and shape of the discontinuity shall be determined by ultrasonic testing. The area of the discontinuity shall be determined as the area of total loss of back reflection, when tested in accordance with the procedure of ASTM A435/A435M, *Specification for Straight Beam Ultrasonic Examination of Steel Plates*.

(2) For acceptance of Type W, X, and Z discontinuities, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4 percent of the plate area (plate length X plate width) with the following exception. If the length of the discontinuity, or the aggregate width of discontinuities on any transverse section, as measured perpendicular to the base-metal length, exceeds 20 percent of the base-metal width, the 4 percent base-metal area shall be reduced by the percentage amount of the width exceeding 20 percent. (For

example, if a discontinuity is 30 percent of the base-metal width, the area of discontinuity cannot exceed 3.6 percent of the base-metal area.)

The discontinuity on the cut edge of the base metal shall be gouged out to a depth of 25 mm beyond its intersection with the surface by chipping, air carbon arc gouging, or grinding, and shall be blocked off by shielded metal arc welding (SMAW) in layers not exceeding 3 mm in thickness.

(3) If a discontinuity Z, not exceeding the allowable area in 3.2.3.7(2), is discovered after the joint has been completed and is determined to be 25 mm or more away from the face of the weld, as measured on the base-metal surface, no repair of the discontinuity is required. If the discontinuity Z is less than 25 mm away from the face of the weld, it shall be gouged out to a distance of 25 mm from the fusion zone of the weld by chipping, air carbon arc gouging, or grinding. It shall then be blocked off by welding with low-hydrogen SMAW electrodes for at least four layers not exceeding 3 mm in thickness per layer. Submerged arc welding (SAW) or other welding processes may be used for the remaining layers.

(4) If the area of the discontinuity W, X, Y, or Z exceeds the allowable in 3.2.3.7(2), the base metal or sub-component shall be rejected and replaced, or repaired at the discretion of the Engineer.

(5) The aggregate length of weld repair shall not exceed 20 percent of the length of the base-metal edge without approval of the Engineer.

(6) For discontinuities of Types W and X, all repair welds in M270M Grades 690/690W (A709M Grades 690/690W) steels shall be made with low-hydrogen electrodes not exceeding 4.0 mm in diameter. All repair welds in M270M Grades 690/690W (A709M Grades 690/690W) steels shall be inspected not less than 48 hours after they are completed, and the groove weld shall not be made until after the repair weld has been approved by the Engineer.

(7) All repair welding shall conform to the requirements of an approved WPS.

3.2.4 Reentrant corners of base-metal cut edges shall be formed to provide a smooth transition with a radius of not less than 25 mm that meets the adjacent edges without offset or cutting past the point of tangency. The reentrant corners may be formed by thermal cutting, followed by grinding to meet the surface requirements of 3.2.2.

3.2.5 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.

3.2.6 Joint and edge preparation may be done by machining, thermal cutting, air carbon arc cutting and gouging, or chipping and grinding. Removal of unacceptable weld

or base metal and backgouging shall be done by machining, air carbon arc gouging, or chipping and grinding.

Oxygen cutting shall not be used for partial removal of welds when slag or other materials may deflect the oxygen stream and damage the remaining metal. Where any carbon arc gouging or cutting is involved, proper arc gouging procedures shall be used to avoid the retention of carbon deposits and material or dross in the areas which are to be welded. Air carbon arc gouged surfaces shall be ground to bright metal.

3.2.7 Edges of built-up beam and girder webs shall be cut to the prescribed camber with suitable allowance for shrinkage due to cutting and welding. However, members with camber exceeding the tolerances of 3.5.1.3 may be corrected by heating as described in 3.7.3. Excess camber may be corrected by heating without the Engineer's approval.

3.2.8 Corrections of errors in camber of quenched and tempered steel must be given prior approval by the Engineer.

3.2.9 All corners of oxygen cut edges of main stress-carrying members, except bearing stiffeners and girder webs, shall have a 2 mm radius or equivalent flat surface at a suitable angle.

3.3 Assembly

3.3.1 The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening shall not exceed 5 mm except in cases involving either shapes or plates 75 mm or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 8 mm is acceptable, provided a backing weld or suitable backing is used. If the root opening is greater than 2 mm, the leg of the fillet weld shall be increased by the amount of the root opening or the contractor shall demonstrate that the required weld size has been obtained.

3.3.1.1 The separation between faying surfaces of plug and slot welds, and of butt joints landing on a backing, shall not exceed 2 mm.

3.3.1.2 The use of filler plates is prohibited except as specified on the drawings or as specially approved by the Engineer and made in accordance with 2.4.

3.3.2 The root opening between parts to be joined by partial joint penetration groove welds parallel to the member length (bearing joints excepted) shall be zero, or as small as practicable.

3.3.2.1 The root opening between parts shall not exceed 5 mm except in cases involving rolled shapes or plates 75 mm or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 8 mm is applicable, provided a backing weld or suitable backing is used and the final weld meets the requirements for weld size.

3.3.2.2 Tolerances for bearing joints shall be in accordance with the applicable contract specifications.

3.3.3 Parts to be joined by groove welds shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10 percent of the thickness of the thinner part joined, but in no case more than 3 mm, shall be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 12 mm in 300 mm. Measurement of offset shall be based upon the centerline of parts unless otherwise shown on the drawings.

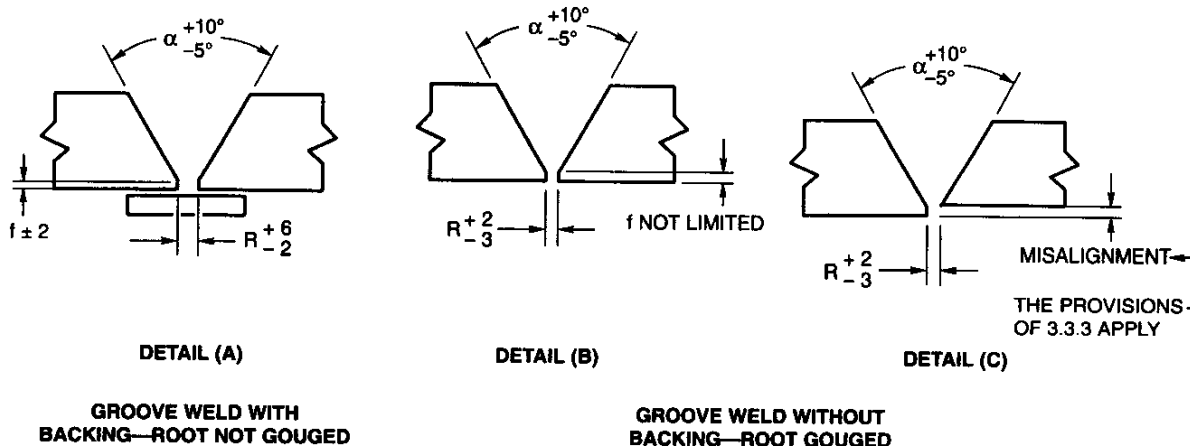
3.3.4 With the exclusion of electroslag welding (ESW) and electrogas welding (EGW), and with the exception of 3.3.4.1 for root openings in excess of those permitted below and illustrated in Figure 3.2, the dimensions of the cross section of the groove welded joints which vary

from those shown on the detail drawings by more than the tolerances shown in Figure 3.2 shall require approval by the Engineer for correction.

Permissible Root Openings		
	Root not gouged (mm)	Root gouged (mm)
(1) Root face of joint	± 2	Not limited
(2) Root opening of joints without steel backing	± 2	+2 -3
Root opening of joints with steel backing	+6 -2	Not applicable
(3) Groove angle of joint	+10 deg -5 deg	+10 deg -5 deg

3.3.4.1 Root openings wider than those permitted in 3.3.4, but not greater than twice the thickness of the thinner part or 20 mm, whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding.

3.3.4.2 Root openings larger than those permitted in 3.3.4.1 may be corrected by welding only with the approval of the Engineer.



Notes:

1. α — groove angle.
2. R — root opening.
3. f — foot face.
4. The groove configurations shown are for illustration only.
5. All dimensions in mm.

Figure 3.2—Workmanship Tolerances in Assembly of Groove Welded Joints (see 3.3.4)

3.3.5 Groove preparations produced by gouging shall be substantially in accordance with groove profile dimensions as specified in Figures 2.4 and 2.5.

3.3.6 Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practicable. Suitable allowances shall be made for warpage and shrinkage. (See 3.4.4, 3.4.5, 3.4.6, and 3.4.7.)

3.3.7 Tack Welds

3.3.7.1 Tack welds shall be subject to the same quality requirements as the final welds, with the following exceptions:

(1) Preheat is not mandatory for single-pass tack welds which are remelted and incorporated into continuous SAW, ESW, or EGW welds.

(2) Discontinuities such as undercut, unfilled craters, and porosity need not be removed before the final SAW, ESW, or EGW that remelts the tack weld (see 9.20).

3.3.7.2 Tack welds which are incorporated into the final weld shall be made with electrodes meeting the requirements of the final welds and shall be cleaned thoroughly. Multiple-pass tack welds shall have cascaded ends.

3.3.7.3 Tack welds not incorporated into the final weld shall be removed in such a manner that the base metal is not nicked or undercut. Repair of base metal accidentally removed shall be approved by the Engineer prior to making the repair. If the repair involves welding, it shall be in accordance with 3.7.1.

3.3.7.4 The removal of tack welds may expose unacceptably hard or cracked heat-affected zones (HAZ). Such areas on members subject to tension or reversal-of-stress shall be magnetic-particle tested (preferably by the yoke method) to assure that no cracks are present. Hardness tests are recommended to determine that HAZ remaining in the structure are not unacceptably hard. Hardness values shall not exceed Rockwell C30 in the HAZ or the hardness value measured in the unaffected base metal, whichever is higher. Since HAZ hardening generally extends less than 3 mm into the base metal, unacceptable hardening can be removed by shallow grinding.

3.3.7.5 Tack welding of steel backing shall preferably be done within the joint so that all tack welds will be remelted and incorporated within the final weld.

3.3.7.6 Tack welds used to attach steel backing and placed external to the weld joint shall be made continu-

ous by fillet welding for the full length of the backing or shall be removed.

3.3.8 Joint Root Openings. Joint root openings may vary as noted in 2.9 and 2.10. However, for automatic or machine welding using FCAW, GMAW, or SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) may not exceed 3 mm. Variations greater than 3 mm shall be locally corrected prior to automatic or machine welding.

3.3.9 Assembly Sequence. J- and U-grooves may be prepared before or after assembly. Second-side grooves may be prepared by air carbon arc gouging and grinding after welding the first side. Before welding, the J- or U-Groove shall conform to the provisions of this section.

3.3.10 Joint Detail Dimensional Tolerances. Dimensions of groove welds specified on design or detailed drawings may vary from the dimensions shown in Figure 2.4 or Figure 2.5 within the limits specified in 3.3.4. J- and U-grooves may be prepared before or after assembly.

3.4 Control of Distortion and Shrinkage

3.4.1 In assembling and joining parts of a structure or of built-up members and in welding reinforcing parts to members, the procedure and sequence shall minimize distortion and shrinkage.

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

3.4.3 The contractor shall prepare a welding sequence for a member or structure which, in conjunction with the WPSs and overall fabrication methods, will produce members or structures meeting the quality requirements specified. The welding sequence and distortion control program shall be submitted to the Engineer, for information and comment, before the start of welding on a member or structure in which shrinkage or distortion is likely to affect the adequacy of the member or structure.

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

3.4.5 Joints expected to have significant shrinkage should usually be welded before joints expected to have lesser shrinkage. They should also be welded with as little restraint as possible.

3.4.6 All shop splices in each component part of a cover-plated beam or built-up member shall be made before the component part is welded to other component parts of the member. Long members or member sections may be made by shop or field splicing subsections, each made in accordance with this subsection (see 9.17).

3.4.7 In making welds under conditions of severe external shrinkage restraint, the welding shall be carried continuously to completion or to a point that will ensure freedom from cracking before the joint is allowed to cool below the minimum specified preheat and interpass temperature.

3.5 Dimensional Tolerances

3.5.1 The dimensions of welded structural members shall conform to the tolerances of (1) the general specifications governing the work, and (2) the special dimensional tolerances in 3.5.1.1 to 3.5.1.12.

3.5.1.1 Permissible variations in straightness of welded columns and primary truss members, regardless of cross section, shall not exceed

Lengths of less than 10 m

|| 1 mm/m of total length (m)

Lengths of 10 to 15 m, 10 mm

Lengths over 15 m

10 mm + 1 mm/m × [length (m) – 15 m]

3.5.1.2 Permissible variations in straightness of welded beams or girders, regardless of cross section, where there is no specified camber or sweep, shall not exceed

|| 1 mm/m of total length(m)

3.5.1.3 For welded beams or girders, other than those whose top flange is embedded in concrete without a designed concrete haunch, regardless of cross section, the allowable variation from required camber at shop assembly (for drilling holes for field splices or preparing field welded splices) is

at midspan, –0, + 40 mm for spans ≥ 30 m

–0, + 20 mm for spans < 30 m

at supports, 0 for end supports

± 3 mm for interior supports

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

where

a = distance in meters from inspection point to nearest support

S = span length in meters

b = 40 mm for spans ≥ 30 m

b = 20 mm for spans < 30 m

See Table 3.2 for tabulated values.

For members whose top flange is embedded in concrete without a designed concrete haunch, the allowable variation from required camber at shop assembly (for drilling holes for field splices or preparing field welded splices) is

at midspan, ± 20 mm for spans ≥ 30 m

± 10 mm for spans < 30 m

at supports, 0 for end supports

± 3 mm for interior supports

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

where a and S are as defined above

b = 20 mm for spans ≥ 30 m

b = 10 mm for spans < 30 m

See Table 3.3 for tabulated values.

Regardless of how the camber is shown on the detail drawings, the sign convention for the allowable variation is plus (+) above, and minus (–) below, the detailed camber shape.

These provisions also apply to an individual member when no field splices or shop assembly is required.

Camber measurements shall be made in the no-load condition.

Table 3.2
Camber Tolerance for Typical Girder
(see 3.5.1.3)

Camber Tolerance (in millimeters)					
Span \ a/S	0.1	0.2	0.3	0.4	0.5
≥ 30 m	14	25	34	38	40
< 30 m	7	13	17	19	20

Table 3.3
Camber Tolerance for Girders without a
Designed Concrete Haunch (see 3.5.1.3)

Camber Tolerance (in millimeters)					
Span \ a/S	0.1	0.2	0.3	0.4	0.5
≥ 30 m	7	13	17	19	20
< 30 m	4	6	8	10	10

3.5.1.4 Permissible variation in specified sweep for horizontally curved welded beams or girders is 1 mm/m of total length (m), provided the member has sufficient lateral flexibility to permit the attachment of diaphragms, cross-frames, lateral bracing, etc., without damaging the structural member or its attachments.

3.5.1.5 Permissible lateral variation between the centerline of the web and the centerline of the flange of built-up H or I members at contact surface shall not exceed 6 mm.

3.5.1.6 For permissible variations from flatness of web for girders, see 9.19.

3.5.1.7 Combined warpage and tilt of flange at any cross section of welded I-shape beams or girders shall be determined by measuring the offset at the toe of the flange from a line normal to the plane of the web through the intersection of the centerline of the web with the outside surface of the flange plate. This offset shall not exceed 1/100 of the total width of the flange or 6 mm, whichever is greater, at any point along the member, except that at any bearing this offset should not exceed that specified in 3.5.1.9 and that abutting parts to be joined by groove welds in butt joints shall fulfill the requirements of 3.3.3.

3.5.1.8 The maximum permissible variation from specified depth for welded beams and girders, measured at the web centerline, shall not exceed

For depths up to 1 m inclusive ± 3 mm

For depths over 1 m to 2 m inclusive ± 5 mm

For depths over 2 m + 8 mm, - 5 mm

3.5.1.9 The bearing ends of bearing stiffeners shall be flush and square with the web and shall have at least 75 percent of this area in contact with the flanges.

When bearing against a steel base or seat, all steel components shall fit within 1 mm for 75 percent of the projected area of the web and stiffeners. Girders without

stiffeners shall bear on the projected area of the web on the outer flange surface within 1 mm and the included angle between web and flange shall not exceed 90 degrees in the bearing length.

3.5.1.10 Where tight fit of intermediate stiffeners is specified, it shall be defined as allowing a gap of up to 2 mm between stiffener and flange.

3.5.1.11 The out-of-straightness variation of intermediate stiffeners shall not exceed 12 mm with due regard to any members which frame into them.

3.5.1.12 The out-of-straightness variation of bearing stiffeners shall not exceed 6 mm up to 2 m or 12 mm over 2 m. The actual centerline of the stiffener shall lie within the thickness of the stiffener as measured from the theoretical centerline location.

3.5.1.13 Other dimensional tolerances not covered by 3.5 shall be individually determined and mutually agreed upon by the contractor and the Engineer with proper regard for erection requirements.

3.5.1.14 Mechanically connected joints and splices of main stress carrying members with surfaces intended to be parallel planes shall be nearly parallel after connection, and the surfaces to be in contact shall have an offset no greater than 2 mm after all filler plates have been added, if any.

3.5.1.15 The corresponding surfaces of secondary member parts, at mechanically fastened connections, shall show no offset greater than 3 mm.

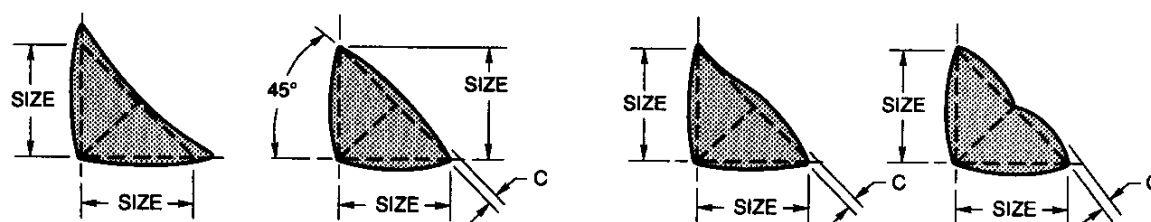
3.5.2 Ends of members fabricated by welding which are to be field connected by welding shall be shop assembled or assembled to a template to ensure conformance to 3.3.1, 3.3.2, 3.3.3 and 3.3.4.

3.6 Weld Profiles

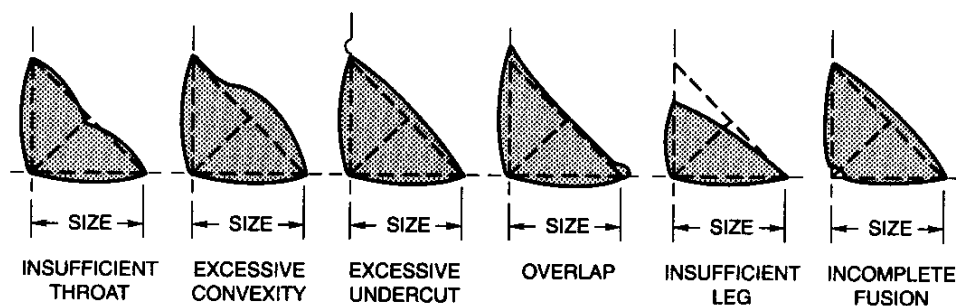
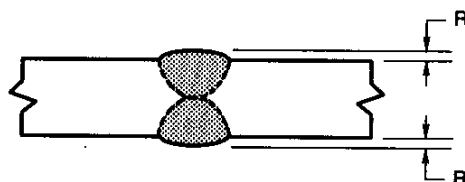
3.6.1 The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figure 3.3(A) and (B), with none of the unacceptable profiles shown in Figure 3.3(C).

3.6.1.1 Except at outside welds in corner joints, the convexity C of a weld or individual surface bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 1.5 mm. See Figure 3.3(B).

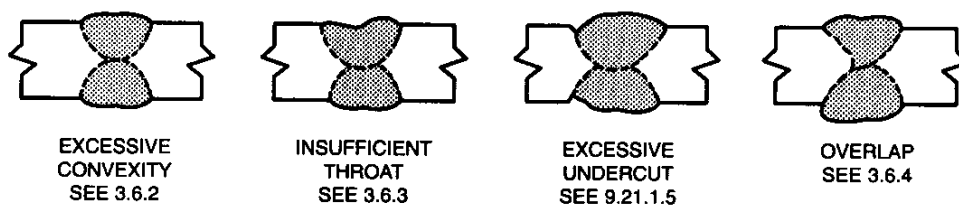
3.6.1.2 Except for undercut, as permitted by the code, these profile requirements do not apply to the ends of intermittent fillet welds outside their effective lengths. The profile exclusion at the end of intermittent fillet welds

**(A) DESIRABLE FILLET WELD PROFILES****(B) ACCEPTABLE FILLET WELD PROFILES**

NOTE: CONVEXITY, C, OF A WELD OR INDIVIDUAL SURFACE BEAD SHALL NOT EXCEED 0.07 TIMES THE ACTUAL FACE WIDTH OF THE WELD OR INDIVIDUAL BEAD, RESPECTIVELY, PLUS 1.5 mm.

**(C) UNACCEPTABLE FILLET WELD PROFILES****(D) ACCEPTABLE GROOVE WELD PROFILE**

NOTE: REINFORCEMENT R SHALL NOT EXCEED 3 mm. SEE 3.6.2.

**(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS****Figure 3.3—Acceptable and Unacceptable Weld Profiles (see 3.6)**

outside their effective lengths does not modify the weld quality provisions of 9.21.

3.6.2 Groove welds shall preferably be made with slight or minimum face reinforcement except as may be otherwise provided. In the case of butt and corner joints, the face reinforcement shall not exceed 3 mm in height and shall have gradual transition to the plane of the base metal surface. See Figure 3.3(D). They shall be free of the discontinuities shown for butt joints in Figure 3.3(E).

3.6.3 Surfaces of butt joints required to be flush shall be finished so as not to reduce the thickness of the thinner base metal or weld metal by more than 1 mm or 5 percent of the thickness, whichever is smaller, nor leave reinforcement that exceeds 1 mm. Unless otherwise approved by the Engineer, all reinforcement shall be removed where the weld forms a part of a faying surface. Any reinforcement must blend smoothly into the plate surfaces with transition areas free from weld edge undercut. Chipping may be used, provided it is followed by grinding.

3.6.4 Where surface finishing is required, surface roughness values shall not exceed 6 μm . Surfaces finished to values over 3 μm through 6 μm shall be finished parallel to the direction of primary stress. Surfaces finished to values of 3 μm or less may be finished in any direction, subject to the following additional requirements: butt joints between parts subject to tensile stress, whether joining parts of equal or unequal width or thicknesses shall be finished flush, or to a smooth transition, to a roughness not exceeding 3 μm .

3.6.5 Welds shall be free from overlap.

3.7 Repairs

3.7.1 The removal of weld metal or portions of the base metal may be done by machining, air carbon arc cutting and gouging, thermal cutting, chipping, or grinding. It shall be done in such a manner that the remaining weld metal or base metal is not nicked or undercut. (See 3.2.6 for restrictions on the use of air carbon arc gouging and thermal cutting.) Unacceptable portions of the weld shall be removed without substantial removal of the base metal. Any additional weld metal shall be deposited using a qualified WPS. The surface shall be thoroughly cleaned before welding.

3.7.2 The contractor has the option of either repairing an unacceptable weld, or removing and replacing the entire weld or the entire assembly, except as modified by 3.7.4. The repaired or replaced weld shall be reinspected by the method originally used, and the same technique and quality acceptance criteria shall be applied. If the con-

tractor elects to repair the weld, it shall be corrected as follows:

3.7.2.1 Overlap or Excessive Convexity. Excess weld metal shall be removed.

3.7.2.2 Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting. Surfaces shall be prepared (see 3.11) and additional weld metal deposited.

3.7.2.3 Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion. Unacceptable portions shall be removed (see 3.7.1) and rewelded.

3.7.2.4 Cracks in Weld or Base Metal. The extent of the crack shall be ascertained by use of magnetic-particle inspection, dye penetrant inspection, or other equally positive means; the metal shall be removed for the full length of the crack plus 50 mm beyond each end of the crack, and reweld.

3.7.3 Members distorted by welding shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heat as approved by the Engineer. The temperature of the heated areas as measured by approved methods shall not exceed 600°C for quenched and tempered steel nor 650°C (a dull, red color) for other steels. The part to be heated for straightening shall be substantially free of stress and from external forces, except those stresses resulting from the mechanical straightening method used in conjunction with the application of heat.

3.7.4 Prior approval of the Engineer shall be obtained for repairs to base metal (other than those required by 3.2), repair of major or delayed cracks, repairs to ESW and EGW welds with internal defects, or for a revised design to compensate for deficiencies.

3.7.5 The Engineer shall be notified before improperly fitted and welded members are cut apart.

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

3.7.7 Welded Restoration of Material with Mislocated Holes. Except where restoration by welding is necessary for structural or other reasons, punched or drilled mislocated holes may be left open or may be filled with a bolt. When base metal with mislocated holes is restored by welding, the following requirements apply:

3.7.7.1 Base metal not subjected to dynamic tensile stress may be restored by welding, provided the contractor prepares and follows a repair WPS. The repair weld soundness shall be verified by ultrasonic test or radiographic test as approved by the Engineer.

3.7.7.2 Base metal subject to dynamic tensile stress may be restored by welding providing the following apply:

(1) The Engineer approves both repair by welding and the repair WPS.

(2) The repair WPS is followed in the work and the soundness of the restored base metal is verified by UT or RT, as specified in the contract documents for examination of tension groove welds or as approved by the Engineer.

3.7.7.3 In addition to the requirements of 3.7.7.1 and 3.7.7.2, when holes in Q & T steels are restored by welding the following shall apply:

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

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

(3) Radiographic testing of the sample welds shall verify that weld soundness conforms to the requirements of 9.21.2.1.

(4) One reduced section tension test (weld metal), two side-bend tests (weld metal); and three Charpy V-notch (CVN) impact tests of the HAZ (coarse grained area) removed from sample welds shall be used to demonstrate that the mechanical properties of the repaired area conform to the specified requirements of the base metal.

3.7.7.4 Weld surfaces shall be finished as specified in 3.6.3.

3.8 Peening

3.8.1 When approved by the Engineer, peening may be used to prevent cracking and lamellar tears by mechanically reducing residual stresses created by welding. To prevent sharp impressions, peening shall be performed by mechanically striking convex surfaces of intermediate weld beads or layers with a round tool with a 6 mm radius (unless otherwise approved). Root and final passes shall not be peened. When approved by the Engineer, final passes that contain excess weld metal may be peened, provided all of the excess weld metal and all peening marks are removed by grinding.

Peening shall be done when the weld is at a temperature of 65°–260°C. Care shall be taken to avoid striking fusion boundaries or the base metal. Peening energy shall be sufficient to mechanically elongate the surface of the weld without creating overlapping or cracking. Pneumatic tools shall be operated in a manner that prevents contamination of the weld by moisture, oil, or other materials.

3.8.2 The use of manual slag hammers, chisels, and light-weight vibrating tools for the removal of slag and spatter is permitted and is not considered peening.

3.9 Caulking

Caulking of welds shall not be permitted.

3.10 Arc Strikes

Care shall be taken to avoid arc strikes outside the area of permanent welds on any base metal. Cracks or blemishes caused by arc strikes shall be ground to remove all of the defect. On tension and reversal of stress members, magnetic particle tests (preferably the yoke method) shall be used to determine that no cracks are present in the structure (see 6.7.6.2). Hardness tests shall be employed as stated in 3.3.7.4.

3.11 Weld Cleaning

3.11.1 In-Process Cleaning. Before welding over previously deposited metal, all slag shall be removed and the weld and adjacent base metal shall be brushed clean. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption. It shall not, however, restrict the welding of plug and slot welds in accordance with 4.21 and 4.22.

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

3.12 Weld Termination

3.12.1 Welds shall be terminated at the end of a joint in a manner that will ensure sound welds. Whenever possible, this shall be done by use of weld tabs (extension bars and runoff plates) placed in a manner that will duplicate the joint detail being welded.

3.12.2 Weld tabs (extension bars and run off plates) shall be removed upon completion and cooling of the weld, and the ends of the welds shall be made smooth and flush with the edges of the abutting parts.

3.12.3 Ends of welded butt joints required to be flush shall be finished so as not to reduce the width beyond the detailed width or the actual width furnished, whichever is greater, by more than 3 mm or so as not to leave reinforcement at each end that exceeds 3 mm. Ends of welded butt joints shall be faired to adjacent plate or rolled shape edges at a slope not to exceed 1 in 10 unless otherwise shown on the drawings.

3.13 Weld Backing

3.13.1 Groove welds made with the use of steel backing shall have the weld metal thoroughly fused with the backing. Steel backing shall be continuous for the full length of each weld made with backing. A continuous length of backing may be made by welding shorter sections together under the following conditions:

- (1) All welds shall be complete joint penetration groove welds made with the same controls as similar complete joint penetration groove welds in the structure.
- (2) Radiographic or ultrasonic tests shall be used to assure weld soundness.
- (3) All welding and testing of the backing shall be complete before the backing is used to make the structural weld.

3.13.2 Steel backing on welds transverse to the direction of computed stress shall be removed, and the joint shall be ground smooth. Steel backing parallel to the direction of stress or not subject to computed stress need not be removed unless specified in the contract documents or ordered by the Engineer.

3.13.2.1 Steel backing material shall be as specified in 9.2.4.2.

3.13.2.2 For welds in compression in T-joints and columns, steel backing need not be removed, unless required by the contract documents or ordered by the Engineer.

3.13.2.3 Where the steel backing of longitudinal welds is externally attached to the base metal by welding, such welding shall be continuous for the length of the backing.

3.13.3 The suggested minimum nominal thickness of backing, provided that the backing shall be of sufficient thickness to prevent melting through, is shown in the following table:

Process	Min. Nom. Thickness, mm
SMAW	5
GMAW	6
FCAW-S	6
FCAW-G	10
SAW	10

3.13.4 Steel backing shall be placed and held in intimate contact with the base metal. The maximum gap between steel backing and the base metal at the weld root shall be 2 mm, as shown in Figure 3.2(A).

3.13.5 Groove and fillet welds may be backed by copper, flux, glass tape, iron powder, or similar materials to provide an appropriate back-bead shape or to prevent melting through. Roots of welds may also be sealed by means of root passes deposited with SMAW low-hydrogen electrodes or by other approved arc WPSs.

Copper shall not be used as a backing when there is any possibility that the welding arc may strike the copper.

Welds made against backing other than base metal or approved low-hydrogen weld metal shall be subject to WPS qualification testing under the provisions of 5.13 and approval by the Engineer.

Note: Copper melted by the welding arc may produce severe cracking. In SAW, flux that fills gaps not exceeding 5 mm between adjacent parts is not considered to be backing and shall not require WPS qualification testing.

4. Technique

Part A *General Requirements*

4.1 Filler Metal Requirements

At the time of publication of this code, the majority of AWS A5 filler metal specifications did not have metric designations. Users are encouraged to adopt electrode specifications and classifications as these become available.

4.1.1 When matching weld metal is required by the AASHTO design specifications, the electrode or electrode/flux combination shall be in accordance with Table 4.1 or 4.2.

4.1.2 The mechanical properties of filler metals used to produce fillet and groove welds are listed in Tables 4.1 and 4.2. Deliberate undermatching of filler metal mechanical properties is permitted under conditions described in the notes to each table.

4.1.3 After filler metal has been removed from its original package, it shall be protected or stored so that its characteristics and welding properties are not affected (see 4.5.2).

4.1.4 For exposed, bare, unpainted applications of M270M Grade 345W (A709M Grade 345W) steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode or electrode-flux combination shall be in accordance with Table 4.3. In multiple-pass welds, the weld metal may be deposited so that at least two layers on all exposed surfaces and edges are deposited with one of the filler metals listed in Table 4.3, provided the underlying layers are deposited with one of the filler metals specified in Table 4.1 or Table 4.2.

4.1.5 For single-pass welding, other than electroslag welding (ESW) or electrogas welding (EGW), of exposed, bare, unpainted applications of M270M Grade 345W (A709M Grade 345W) steel requiring weld metal

with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the following variations from Table 4.3 may be made.

4.1.5.1 Shielded Metal Arc Welding (SMAW). Single-pass fillet welds up to 6 mm maximum and 6 mm groove welds made with a single pass or a single pass each side may be made using an E70XX low-hydrogen electrode.

4.1.5.2 Submerged Arc Welding (SAW). Single-pass fillet welds up to 8 mm maximum and groove welds made with a single pass electrode-flux combination conforming to Tables 4.1 or 4.2.

4.1.5.3 Gas Metal Arc Welding (GMAW). Single-pass fillet welds up to 8 mm maximum and groove welds made with a single pass or a single pass each side may be made using an ER70S-X electrode conforming to Table 4.2.

4.1.5.4 Flux Cored Arc Welding (FCAW). Single-pass fillet welds up to 8 mm maximum and groove welds made with a single pass or single pass each side, may be made using an E7XT-X electrode conforming to Table 4.1 or 4.2.

4.1.6 For ESW or EGW welding of exposed, bare, unpainted applications of M270M Grade 345W (A709M Grade 345W) steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode or electrode-flux combination shall produce weld metal that conforms to the requirements listed in Table 4.3. The chemical composition of the weld metal deposited on a standard filler metal test pad, where there is minimal dilution of the base metal, shall conform to one of the chemical compositions provided in the list of electrodes described in Table 4.3. The chemical composition of deposited ESW or EGW weld metal will not exactly match either the electrode or the base metal, since there is considerable base-metal dilution. The electrode or electrode/flux combination shall be approved by the Engineer.

Table 4.1
Matching Filler Metal Requirements for WPSs Qualified in Accordance with 5.12^{7,9}

Base Metal ¹	Filler Metal Test Qualification Requirement ²			Qualification, Pretest and Verification Test Requirement ^{5,6}				
AASHTO (ASTM) Designation	AWS Electrode Specification ⁴	Yield Strength, MPa	Tensile Strength, MPa	Min. Yield Strength, MPa	Tensile Strength, MPa	Min. Elongation in 50 mm, Percent	CVN, J AASHTO Temperature Zones	
							I & II	III
M270M (A709M) Gr. 250	SMAW AWS A5.1 E7016, E7018, E7028 A5.5 E7016-X, E7018-X	399 390	482 min 480 min	Prequalified—Exempt from Test (see 5.11)				
	SAW AWS A5.17 F6A0-EXXX F7A0-EXXX	330 400	415–550 480–655	300 370	400–565 470–670	22 22	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	FCAW-G AWS A5.20 E6XT-1,5 E7XT-1,5	345 414	428 min 497 min	315 385	415–600 485–655	22 22	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	Prequalified—Exempt from Test							
	SAW AWS A5.17 F7A0-EXXX	400	485–655	370	470–670	22	27@–20°C	27@–30°C
	FCAW-G AWS A5.20 E7XT-1,5	414	497 min	385	485–655	22	27@–20°C	27@–30°C
M270M (A709M) Gr. 345 Type 1, 2, or 3	SMAW AWS A5.1 E7016, E7018, E7028 A5.5 E7016-X, E7018-X	399 390	482 min 480 min	Prequalified—Exempt from Test				
	SAW AWS A5.17 F7A0-EXXX	400	485–655	370	470–670	22	27@–20°C	27@–30°C
	FCAW-G AWS A5.20 E7XT-1,5	414	497 min	385	485–655	22	27@–20°C	27@–30°C
	Prequalified—Exempt from Test							
	SAW AWS A5.17 or A5.23 F7A0-EXXX F8A0-EXXX ⁸	415 470	485–655 550–690	370 440	470–670 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	FCAW-G AWS A5.20 or A5.29 E7XT-1,5 E8XT-1,5-NiX,W ⁸	415 470	495 min 550–690	385 440	485–655 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C
M270M (A709M) Gr. 345W ³ 100 mm and under	SMAW AWS A5.1 E7016, E7018, E7028 A5.5 E7016-X, E7018-X, E7028-X E7018-W E7015, 16, 18 C1L, C2L E8016, 18 — C1, C2 ⁸ E8016, 18 — C3 ⁸ E8018-W ⁸	399 390 415 399 460 470–550 460	482 min 480 min 480 min 480 min 550 min 550 min 550 min	Prequalified—Exempt from Test				
	SAW AWS A5.17 or A5.23 F7A0-EXXX F8A0-EXXX ⁸	415 470	485–655 550–690	370 440	470–670 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	FCAW-G AWS A5.20 or A5.29 E7XT-1,5 E8XT-1,5-NiX,W ⁸	415 470	495 min 550–690	385 440	485–655 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	Prequalified—Exempt from Test							
	SAW AWS A5.17 or A5.23 F7A0-EXXX F8A0-EXXX ⁸	415 470	485–655 550–690	370 440	470–670 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C
	FCAW-G AWS A5.20 or A5.29 E7XT-1,5 E8XT-1,5-NiX,W ⁸	415 470	495 min 550–690	385 440	485–655 540–705	22 20	27@–20°C 27@–20°C	27@–30°C 27@–30°C

(continued)

Table 4.1 (Continued)

Base Metal ¹	Filler Metal Test Qualification Requirement ²			Qualification, Pretest and Verification Test Requirement ^{5, 6}				
AASHTO (ASTM) Designation	AWS Electrode Specification ⁴	Yield Strength, MPa	Tensile Strength, MPa	Min. Yield Strength, MPa	Tensile Strength, MPa	Min. Elongation in 50 mm, Percent	CVN, J AASHTO Temperature Zones	
							I & II	III
M270M (A709M) Gr. 485W ³	SMAW AWS A5.5 E9018-M	540–620	620 min	Prequalified—Exempt from Test				
	SAW AWS A5.23 F9A0-EXXX-X	540	620–760	510	605–785	17	34@–25°C	34@–30°C
	FCAW-G AWS A5.29 E9XT1-X E9XT5-X	540 540	620–760 620–760	510 510	605–785 605–785	17 17	34@–25°C 34@–25°C	34@–30°C 34@–30°C
M270M (A709M) Gr. 690, 690W Over 60 mm thick	SMAW AWS A5.5 E10018-M	610–690	690 min	Prequalified—Exempt from Test				

Notes:

1. In joints involving base metals of two different yield strengths, filler metal applicable to the lower strength base metal may be used.
2. When welds are to be stress-relieved, the weld metal shall not exceed 0.05% vanadium. The stress-relieved weld shall meet the minimum mechanical properties and impact properties specified in the contract.
3. Special welding materials and procedures may be required to match atmospheric, corrosion, and weathering characteristics. See Table 4.3 for M270M (A709M) Gr.345W steel. Filler metal with suitable weathering characteristics for bare unpainted applications of M270M (A709M) Gr. 690, 690W and M270M (A709M) Gr. 485W steels shall be approved by the Engineer.
4. Electrode specifications with the same yield and tensile properties, but with lower impact test temperature, may be substituted. (e.g., F7A2-EXXX may be substituted for F7A0-EXXX).
5. For base metal thickness or electrode specification not included in this Table, see Table 4.2.
6. The Engineer may accept the results of test that vary from the limits established by this table based upon the following rules:
 - (a) The yield strength of the weld metal shall equal or exceed the yield strength of the base metal, as represented by mill test data, whenever the applied stress normal to the effective area of the weld.
 - (b) The yield strength of the weld metal may be up to 70 MPa less than the minimum specified yield strength of the matching weld metal when stress in the weld is compression normal to the effective area of the weld.
 - (c) Deliberate undermatching of weld metal strength is approved when consistent with design requirements as listed in the contract documents for cases where the stress in the weld is tension or compression parallel to the weld axis and shear on the effective area meets AASHTO design requirements.
 - (d) Ductility and toughness shall be as specified except when otherwise approved for specific projects or applications.
 - (e) Acceptance of modified mechanical properties by one State does not obligate other States to accept the same modifications.
7. All listed values are minimums unless a range is shown.
8. The 550 MPa filler metals are intended for exposed applications of weathering steels. They need not be used on applications of M270M (A709M) Gr.345W that will be painted.
9. The provisions of 5.13 may be used as an option to 5.12.
10. See 5.5.1 for filler metal qualification requirements.

Table 4.2
Matching Filler Metal Requirements for WPSs Qualified in Accordance with of 5.13^{6, 8}

Base Metal ¹	Filler Metal Test Requirements ²			Qualification Test Requirement ⁵				
AASHTO (ASTM)	AWS Electrode Specification ⁴	Yield Strength, MPa	Tensile Strength, MPa	Yield Strength, MPa	Tensile Strength, MPa	Elongation in 50 mm Percent	CVN, J AASHTO Temperature Zones	
							I & II	III
M270M (A709M) Gr. 250	FCAW-S AWS A5.20 E6XT-6, 8	345	428 min	315	425-620	22	27@-20°C	27@-30°C
	E7XT-6, 8	414	497 min	385	485-670	22	27@-20°C	27@-30°C
	AWS A5.29 E6XT8-8	345	410-550	315	400-565			
	E7XT8-X	400	490-620	370	470-635	22	27@-20°C	27@-30°C
	GMAW AWS A5.18 ER 70S- 2, 3, 6, 7	400	480 min	385	485-670	22	27@-20°C	27@-30°C
	ELECTROGAS—not authorized for tension and reversal members							
	AWS A5.25 FES60-XXXX	250	420-550	220	385-565	24	20@-20°C	As Approved by Engr.
	FES70-XXXX	350	490-650	315	470-670	22	20@-20°C	As Approved by Engr.
	FES72-XXXX	350	490-650	315	470-670	22	20@-20°C	As Approved by Engr.
	ELECTROGAS—not authorized for tension and reversal members							
M270M (A709M) Gr. 345	A5.26 EG 60XXXX	250	420-550	220	385-565	24	20@-20°C	As Approved by Engr.
	EG 62XXXX	250	420-550	220	385-565	24	20@-20°C	As Approved by Engr.
	EG 70XXXX	350	490-650	315	470-670	22	20@-20°C	As Approved by Engr.
	EG 72XXXXZ	350	490-650	315	470-670	22	20@-20°C	As Approved by Engr.
	GMAW AWS A5.18 ER 70S- 2, 3, 6, 7	400	480 min	370	470-670	22	27@-20°C	27@-30°C
	FCAW-S AWS A5.20 E7XT-6, 8	414	497 min	385	470-670	22	27@-20°C	27@-30°C
	AWS A5.29 E7XT8-X	400	490-620	370	470-635	22	27@-20°C	27@-30°C
	ELECTROGAS—not authorized for tension and reversal members							
	A5.25 FES 70-XXXX	350	490 to 650	315	470-670	22	20@-20°C	As Approved by Engr.
	FES 72-XXXX	350	490 to 650	315	470-670	22	20@-20°C	As Approved by Engr.
M270M (A709M) Gr. 345W ³ 100 mm and under	ELECTROGAS—not authorized for tension and reversal members							
	AWS A5.26 EG 70XXXX	350	490 to 650	315	470-670	22	20@-20°C	As Approved by Engr.
	EG 72XXXX	350	490 to 650	315	470-670	22	20@-20°C	As Approved by Engr.
	FCAW-S AWS A5.20 E7XT-6, 8	414	497 min	425	485-670	22	27@-20°C	27@-30°C
	AWS A5.29 E7XT8-NiX	400	490-620	370	470-635	22	27@-20°C	27@-30°C

(continued)

Table 4.2 (Continued)

Base Metal ¹	Filler Metal Test Requirements ²			Qualification Test Requirement ⁵				
	AWS Electrode Specification ⁴	Yield Strength, MPa	Tensile Strength, MPa	Yield Strength, MPa	Tensile Strength, MPa	Elongation in 50 mm Percent	CVN, J AASHTO Temperature Zones	
							I & II	III
AASHTO (ASTM) M270M (A709M) Gr. 345W ³ 100 mm and under (cont'd)	GMAW AWS A5.18 ER70S-2, 3, 6, 7 AWS A5.28 ER80S-NiX ⁷	400 470	480 min 550 min	370 370	485-670 455-690	22 20	27@-20°C 27@-20°C	27@-30°C 27@-30°C
	ELECTROGAS—not authorized for tension and reversal members							
	AWS A5.25 FES70-XXXX FES72-XXXX	350 350	490-650 490-650	315 315	485-670 485-670	22 22	20@-20°C 20@-20°C	As Approved by Engr. As Approved by Engr.
	ELECTROGAS—not authorized for tension and reversal members							
	AWS A5.26 EG 70XXXX EG 72XXXX	350 350	490-650 490-650	315 315	485-670 485-670	22 22	20@-20°C 20@-20°C	As Approved by Engr. As Approved by Engr.
	As Approved by Engineer (see Table 4.1)							
M270M (A709M) Gr. 690, 690W ³ Over 60 mm thick	SAW AWS A5.23 F10A4-EM2-M2	610	690-830	580	675-840	16	27@-40°C	As Approved by Engr.
	FCAW-G AWS A5.29 E100 T5-K3 E101 T1-K7	610 610	690-830 690-830	580 580	675-840 675-840	16 16	27@-40°C 27@-40°C	As Approved by Engr. As Approved by Engr.
	GMAW AWS A5.28 ER 100S-1 ER 100S-2	610-700 610-700	690 min 690 min	580-730 580-730	675 min 675 min	16 16	27@-40°C 27@-40°C	As Approved by Engr. As Approved by Engr.
M270M (A709M) Gr. 690, 690W 60 mm thick or less	SMAW AWS A5.5 E11018-M	680-760	760 min	650-114	745 min	20	27@-40°C	As Approved by Engr.
	SAW AWS A5.23 F11A4-EM3-M3	680	760-900	650	745-910	15	27@-40°C	As Approved by Engr.
	FCAW-G AWS A5.29 E110T5-K3, K4 E111T1-K4	680 680	760-900 760-900	650 650	745-910 745-910	15 15	27@-40°C 27@-40°C	As Approved by Engr. As Approved by Engr.
	GMAW AWS A5.28 ER 110S-1	660-740	760 min	625-765	745 min	15	27@-40°C	As Approved by Engr.

(continued)

Table 4.2 (Continued)**Notes:**

1. In joints involving base metals of two different yield strengths, filler metal applicable to the lower strength base metal may be used.
2. When welds are to be stress-relieved, the weld metal shall not exceed 0.05% vanadium. The stress-relieved weld shall meet the minimum mechanical properties and impact properties specified in the contract.
3. Special welding materials and procedures may be required to match atmospheric, corrosion, and weathering characteristics. See Table 4.3 for M270M (A709M) Gr. 345W steel. Filler metal with suitable weathering characteristics for bare unpainted applications of M270M (A709M), Gr. 690, 690W and M270M (A709M) Gr. 485W steels shall be approved by the Engineer.
4. Electrode specifications with the same yield and tensile properties, but with lower impact test temperature, may be substituted. (e.g., F7A2-EXXX may be substituted for F7A0-EXXX).
5. The Engineer may accept the results of tests that vary from the limits established by this table based upon the following rules:
 - (a) The yield strength of the weld metal shall equal or exceed the yield strength of the base metal, as represented by mill test data, whenever the applied stress in the weld is tensile stress normal to the effective area of the weld.
 - (b) The yield strength of the weld metal may be up to 70 MPa less than the minimum specified yield strength of the matching weld metal when stress in the weld is compression normal to the effective area of the weld.
 - (c) Deliberate undermatching of weld metal strength is approved when consistent with design requirements as listed in the contract documents for cases where the stress in the weld is tension or compression parallel to the weld axis and shear on the effective area meets AASHTO design requirements.
 - (d) Ductility and toughness shall be as specified except when otherwise approved for specific projects or applications.
 - (e) Acceptance of modified mechanical properties by one State does not obligate other States to accept the same modifications.
6. All listed values are minimums unless a range is shown.
7. These 550 MPa filler metals are for exposed applications of weathering steels. They need not be used for applications of M270M (A709M), Gr. 345M that will be painted.
8. See 5.5.1 for filler metal qualification requirements.

Table 4.3
Filler Metal Requirements for Exposed
Bare Application of M270M (A709M)
Gr. 345W Steel

Process	Filler Metal Spec.	Approved Electrodes ^{1, 2, 3, 4}
SMAW	A5.5	All electrodes that deposit weld metal meeting a C1, C1L, C2, C2L, C3 or W analysis.
SAW	A5.23	All electrode-flux combinations that deposit weld metal with a Ni1, Ni2, Ni3, Ni4 or W analysis.
FCAW	A5.29	All electrodes that deposit weld metal with a Ni1, Ni2, Ni3, Ni4 or W analysis.
GMAW	A5.28	All electrodes that meet filler metal composition requirements of Ni1, Ni2, Ni3 analysis.

Notes:

1. Filler metals meeting the requirements of this table shall also meet all requirements of Table 4.1 or 4.2 before being approved for bridge welding. These requirements include yield strength, tensile strength, elongation and Charpy properties.
2. The values listed are minimums unless a range is shown.
3. This is a partial listing which does not cover EGW or ESW of M270M (A709M) Gr. 345W steel and makes no provision for other steels with weathering characteristics such as M270M (A709M) Gr. 485W or M270M (A709M) Gr. 690, 690W steels.
 The Engineer shall approve all filler metal to be used in exposed, unpainted applications not covered by this table. The chemical composition of weld metal deposited by the electrodes listed in this table may be used as a guide to weld metal chemistry considered acceptable in weathering applications. There is considerable dilution of base metal in electroslag and electrogas welding; therefore, the weld deposit will not match the electrode or base metal chemistry.
4. See 5.5.1 for filler metal qualification requirements.

4.2 Preheat and Interpass Temperature Requirements

The preheat and interpass temperature must be sufficient to prevent cracking. Experience has shown that the minimum temperatures specified in Table 4.4 are adequate to prevent cracking in most cases. However, increased preheat temperatures may be necessary in situations involving higher restraint, higher hydrogen, lower welding heat input, or steel composition at the upper limits of the specification. Conversely, lower preheat temperatures may be adequate to prevent cracking, depending on restraint, hydrogen level, and actual steel composition or higher welding heat input.

4.2.1 With the exception of stud welding, ESW, EGW and tack welding conforming to 3.3.7.1(1), the minimum preheat and interpass temperatures for redundant members shall be as specified in Table 4.4.

4.2.1.1 Minimum preheat and interpass temperatures may be established on the basis of steel composition, thickness, and restraint using recognized methods of prediction such as those provided in Annex VIII.

Note: These methods are based on laboratory cracking tests and may predict preheat temperatures higher than the minimum temperatures shown in Table 4.4. The guide may be of value in identifying situations where the risk of cracking is increased due to composition, restraint, hydrogen level, or welding heat input where higher heat input may be warranted. Alternatively, the guide may

assist in defining conditions under which hydrogen cracking is unlikely and where the minimum requirements of Table 4.4 may be safely relaxed, based upon WPS qualification testing.

However, should the use of such guidelines result in temperatures lower than required by 4.2.1, the minimum temperature shall be qualified by performing tests acceptable to the Engineer.

4.2.2 The maximum preheat and interpass temperature shall be as specified in the WPS.

4.2.3 Temperature controls shall be based upon the thickness and grades of the base metal. For combinations of base metals, preheat and interpass temperatures shall be based upon the higher of the required temperatures.

4.2.4 Thick material, or highly restrained joints or repair welds, shall be preheated by the contractor above the minimum specified temperatures as required to prevent cracking or minimize lamellar tearing.

4.2.5 The maximum WPS preheat temperature shall be 230°C, unless otherwise approved by the Engineer.

4.2.6 Welding shall not be done when the ambient temperature in the immediate vicinity of the weld is lower than -20°C. The ambient environmental temperature may be lower than -20°C, provided supplemental heat and protection from the elements are sufficient to maintain a temperature adjacent to the weldment at -20°C, or higher.

Table 4.4
Minimum Preheat and Interpass Temperature, °C¹

Group	Welding Process (Base Metal)	Thickness of Thickest Part at Point of Welding, mm			
		To 20 mm Incl.	Over 20 mm to 40 mm Incl.	Over 40 mm to 60 mm Incl.	Over 60 mm Incl.
I/II	Shielded Metal-Arc Welding; Submerged Arc Welding Gas Metal-Arc Welding; or Flux Cored Arc Welding (M270M [A709M] Gr. 250, 345, 345W)	10	20	65	110
IV	Shielded Metal-Arc Welding; Submerged Arc Welding Gas Metal-Arc Welding; or Flux Cored Arc Welding (M270M [A709M] Gr. 485W, 690, 690W) ²	10	50	80	110

Notes:

1. See Annex VIII and Tables 12.3, 12.4, and 12.5 for alternate preheat and interpass temperatures.
2. For M270M (A709M) Gr. 485W, 690, 690W the maximum preheat and interpass temperature shall not exceed 205°C for thicknesses up to 40 mm inclusive, and 230°C for greater thicknesses.

4.2.7 When the base metal is below the temperature listed for the welding process being used and the thickness of material being welded, it shall be preheated (except as otherwise provided) in such a manner that the steel on which weld metal is being deposited is at or above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 75 mm in all directions from the point of welding. To increase the effectiveness of preheat without increasing the temperature, at the contractor's option, the area and depth that is heated may be increased beyond the minimum specified. There is no limit to the maximum area that can be preheated unless stated in the contract documents.

4.2.8 When the base-metal temperature is below 0°C, the base metal shall be heated to at least 20°C, and this minimum temperature shall be maintained during welding.

4.2.9 The minimum preheat and interpass temperature requirements for SAW made with parallel or multiple electrodes may be modified under the provisions of 4.10.6 or 4.11.6.

4.3 Heat Input Control for Grade 690 and 690W

When M270M Grade 690/690W (A709M Grades 690/690W) steels are welded, welding heat input shall be appropriate for the thickness of steel to be joined and the preheat and interpass temperature used. Heat input shall not exceed the manufacturers' recommendations. Table 12.5 may be used for guidance in welding Grade 690/690W steels.

4.4 Stress Relief Heat Treatment

4.4.1 Where required by the contract drawings or specifications, welded assemblies shall be stress-relieved by heat treating. Finish machining shall preferably be done after stress relieving.

Note: Stress relieving of weldments of M270M Grades 690/690W (A709M Grades 690/690W) steels is not generally recommended. Stress relieving may be necessary for those applications where weldments must retain dimensional stability during machining or where stress corrosion may be involved, neither condition being unique to weldments involving M270M Grades 690/690W (A709M Grades 690/690W) steels. However, the results of notch toughness tests have shown that postweld heat treatment may actually impair weld metal and heat-affected zone (HAZ) toughness, and intergranu-

lar cracking may sometimes occur in the grain-coarsened region of the weld HAZ.

4.4.2 The stress relief treatment shall conform to the following requirements:

4.4.2.1 The temperature of the furnace shall not exceed 315°C at the time the welded assembly is placed in it.

4.4.2.2 Above 315°C the rate of heating in °C/hr shall not exceed 5600 divided by the maximum metal thickness in mm, but not more than 220°C/hr. During the heating period, variation in temperature throughout the portion of the part being heated shall be no greater than 140°C within any 5 m interval of length.

Note: The rates of heating and cooling need not be less than 55°C per hour. However, in all cases, consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

4.4.2.3 After a maximum temperature of 600°C is reached on quenched and tempered steels, or a mean temperature range between 600 and 650°C is reached on other steels, the temperature of the assembly shall be held within the specified limits for a time not less than specified in Table 4.5, based on weld thickness. When the specified stress relief is for dimensional stability, the holding time shall not be less than specified in Table 4.5, based on the thickness of the thicker part. During the holding period, the highest and lowest temperature throughout the portion of the assembly being heated shall not vary by greater than 85°C.

4.4.2.4 Above 315°C, cooling shall occur in a closed furnace or cooling chamber at a rate in °C/hr not exceeding 7000 divided by the maximum metal thickness in mm, but not more than 280°C/hr. Below 315°C, the assembly may be cooled in still air.

4.4.3 Alternatively, when it is impractical to postweld heat treat to the temperature limitations stated in 4.4.2, welded assemblies may be stress-relieved at lower temperatures for longer periods of time, as given in Table 4.6.

Table 4.5
Minimum Holding Time (see 4.4.2)

6 mm or Less	Over 6 mm Through 50 mm	Over 50 mm
15 min	5 min./2 mm	2 hrs plus 15 min. for each additional 25 mm over 50 mm

Table 4.6
Alternate Stress-Relief Heat Treatment
(see 4.4.3)

Decrease in Temperature Below Minimum Specified Temperature, Δ °C	Minimum Holding Time at Decreased Temperature, Hours Per 25 mm of Thickness
30	2
60	3
90	5
120	10

Table 4.7
Permissible Atmospheric Exposure
of Low-Hydrogen Electrodes

Electrode	Hours
A5.1	
E70XX	4 max
A5.5	
E70XX-X	4 max
E80XX-X	2 max
E90XX-X	1 max
E100XX-X	1/2 max
E110XX-X	1/2 max

Part B

Shielded Metal Arc Welding (SMAW)

4.5 Electrodes for SMAW

4.5.1 Electrodes for SMAW shall conform to the requirements of the latest edition of ANSI/AWS A5.1, *Specification for Covered Carbon Steel Arc Welding Electrodes*, or to the requirements of ANSI/AWS A5.5, *Specification for Low-Alloy Steel Covered Arc Welding Electrodes*. All electrodes for SMAW shall be of the low-hydrogen classification.

4.5.2 All electrodes having low-hydrogen coverings conforming to ANSI/AWS A5.1 shall be purchased in hermetically sealed containers or shall be dried for at least two hours between 230 and 260°C before they are used. Electrodes having a low-hydrogen covering conforming to ANSI/AWS A5.5 shall be purchased in hermetically sealed containers or shall be dried at least one hour at temperatures between 370 and 425°C before being used. Electrodes shall be dried prior to use if the hermetically sealed container shows evidence of damage. Immediately after opening of the hermetically sealed container or removal of the electrodes from drying ovens, electrodes shall be stored in ovens held at a temperature of at least 120°C. After the opening of hermetically sealed containers or removal from drying or storage ovens, electrode exposure to the atmosphere shall not exceed the requirements of 4.5.2.1.

4.5.2.1 Electrodes exposed to the atmosphere upon removal from drying or storage ovens or hermetically sealed containers shall be used within the time limit shown in Table 4.7 or redried at 230°C to 290°C for two hours minimum.

4.5.2.2 Electrodes exposed to the atmosphere for periods less than those permitted by Table 4.7 may be returned to a holding oven maintained at 120°C minimum and after a minimum period of four hours at that temperature may be reissued. The provisions of 4.5.4 apply.

4.5.3 When used for welding M270M Grades 690/690W (A709M Grades 690/690W) steels, electrodes shall be dried at least one hour at temperatures between 370° and 425°C before being used, whether furnished in hermetically sealed containers or otherwise.

4.5.4 Electrodes that conform to the provisions of 4.5.2 shall be redried no more than one time. Electrodes that have been wet shall not be used.

4.5.5 The contractor shall furnish certified copies of test reports of all pertinent tests required of ANSI/AWS A5.1 or of ANSI/AWS A5.5, whichever is applicable, made on electrodes of the same class, size, and brand, and which were manufactured by the same process and the same materials as the electrodes being used on the project (see 4.12.3). The test shall have been made within one year prior to the manufacture of the electrodes furnished. For sizes of electrodes for which tests are not required by ANSI/AWS A5.1 or ANSI/AWS A5.5, the test reports for electrodes of the size nearest to the size being delivered and of the same classification shall be furnished. The report shall include the manufacturer's certification that the process and material requirements were the same for manufacturing the tested electrodes and the furnished electrodes. A suggested form for the reporting of electrode tests is shown in Annex III, Form Ea.

4.5.6 In lieu of requiring a contractor to furnish copies of manufacturer's test reports for each shipment of electrodes on a project, the contracting authority may maintain a list of approved brands of electrodes for which

satisfactory reports of tests made within one year have been previously submitted. If this alternative is elected, the list shall be available to project engineers and contractors.

4.6 Procedures for SMAW

4.6.1 The work shall be positioned for flat position welding whenever practical.

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

4.6.3 The maximum diameter of electrodes shall be as follows:

- (1) 6.4 mm for all welds made in the flat position, except root passes
- (2) 6.4 mm for horizontal fillet welds
- (3) 6.4 mm for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and with a root opening of 6 mm or more
- (4) 4.0 mm for welds made in the vertical and overhead position
- (5) 5.0 mm for root passes of groove welds and for all other welds not included under 4.6.3(1), (2), (3), and (4)

4.6.4 The minimum size of a root pass shall be sufficient to prevent cracking.

4.6.5 The maximum thickness of root passes in groove welds shall be 6 mm.

4.6.6 The maximum size of single-pass fillet welds and root passes of multiple-pass fillet welds shall be as follows:

- (1) 10 mm in the flat position
- (2) 8 mm in the horizontal or overhead positions
- (3) 12 mm in the vertical position

4.6.7 The maximum thickness of layers subsequent to root passes of groove and fillet welds shall be as follows:

- (1) 3 mm for subsequent layers of welds made in the flat position
- (2) 5 mm for subsequent layers of welds made in the vertical, overhead, or horizontal positions.

4.6.8 The progression for all passes in the vertical position shall be upward, unless a downward progression is qualified by tests approved by the Engineer.

4.6.9 Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound metal before welding is started from the second side.

Part C Submerged Arc Welding (SAW)

4.7 General Requirements

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

4.7.2 The following subsections (4.7.3–4.7.8) govern the use of SAW for any as-rolled or normalized steel approved for welding by this code. When welding quenched and tempered steels, it is necessary to comply with the steel producer's recommendations for maximum permissible combinations of heat input and preheat. Such considerations shall include the additional heat input produced during the simultaneous welding of two sides of a common member.

4.7.3 The diameter of electrodes shall not exceed 6.4 mm.

4.7.4 Surfaces on which submerged arc welds are to be deposited and adjacent faying surfaces shall be clean and free of moisture as specified in 3.2.1.

4.7.5 When the joint to be welded requires specific root penetration and is not backgouged, the contractor shall prepare a sample joint and macroetched cross section to demonstrate that the proposed WPS will attain the required root penetration. The Engineer may accept a radiograph of a test joint or recorded evidence in lieu of the test specified in this paragraph. (The Engineer should accept properly documented evidence of previous qualification tests.)

4.7.6 Roots of groove welds may be made against fused steel backing or approved unfused backing. Roots of fillet welds may be supported by backing to prevent melting-through of the base metal. All backing shall conform to the requirements of 3.13.

4.7.7 Neither the depth nor the maximum width in the cross section of weld metal deposited in each weld pass shall exceed the width at the surface of the weld pass (see Figure 4.1). This requirement may be waived only if the testing of a welding procedure to the satisfaction of the Engineer has demonstrated that such welds exhibit freedom from cracks, and the same WPS and electrode-flux combinations are used in construction.

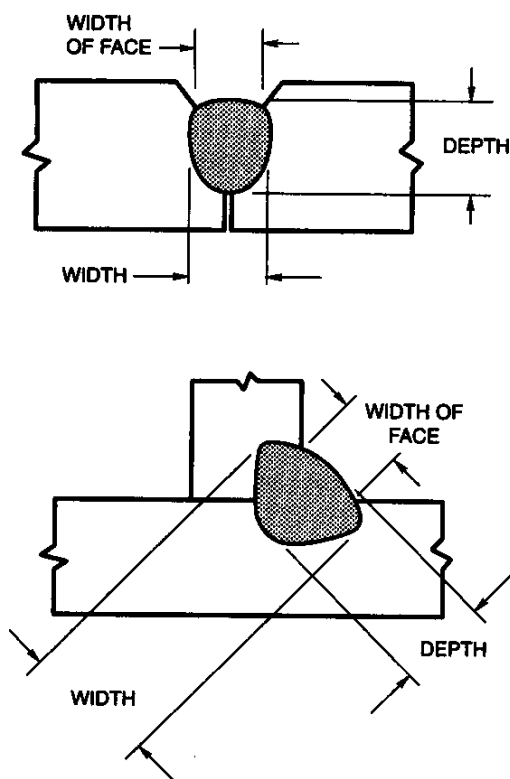


Figure 4.1—Weld Bead in Which Depth and Width Exceed the Width of the Weld Face (see 4.7.7)

4.7.8 Tack welds (in the form of fillet welds) 8 mm or smaller, may remain in the roots of joints requiring specific root penetration, but shall not produce objectionable changes in the appearance of the weld surface nor result in decreased penetration. Tack welds not conforming to the preceding requirements shall be removed or reduced in size by any suitable means before welding. Tack welds in the root of a joint with steel backing less than 8 mm thick shall be removed or made continuous for the full length of the joint, using SMAW with low-hydrogen electrodes.

4.8 Electrodes and Fluxes for SAW

4.8.1 Bare electrodes and flux used in combination for SAW of steels shall conform to the requirements of the latest edition of ANSI/AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, or to the requirements of the latest edition of ANSI/AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*.

4.8.2 Certification

4.8.2.1 The contractor shall furnish certified copies of test reports for all electrode and flux combinations used on a project in accordance with these filler metal specifications (see 4.12.3). The report shall include the result of all pertinent required tests of ANSI/AWS A5.17 or ANSI/AWS A5.23 made on the same classification or grade of electrode/flux combination being used on the project. The test shall have been made on electrodes of the same classification in combination with flux of the same brand and composition, and made with the same manufacturing procedure, as the materials furnished. The test may have been for process qualification or quality control and shall have been made within one year prior to the manufacture of the electrode furnished. The test report form shall be similar to that shown in Annex III, Form Ea, containing all pertinent information concerning the test required by the specification (see 4.5.5).

4.8.2.2 In lieu of requiring a contractor to furnish copies of manufacturer's test reports for each shipment of electrode and flux on a project, the contracting authority may maintain a list of approved brands of electrode/flux combinations for which satisfactory test reports made within one year have been previously submitted. If this alternative is elected, the list shall be available to project engineers and contractors.

4.8.3 Flux used for SAW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage effecting its welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 260°C for one hour before use.

Flux shall be placed in the dispensing system immediately upon opening a package, or, if used from an open package, the flux shall be dried or the top 25 mm shall be discarded. All flux in welding equipment, hoppers, tanks, etc., shall be replaced with new or freshly dried flux whenever welding operations have not been conducted for more than 48 hours. Fluxes shall be protected from moisture and contamination at all times. Flux that has been wet shall not be used.

4.8.4 SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, use of catch pans, sweeping from weldment surfaces or other means. Recovered flux shall be passed through an appropriate screen and over a suitable magnet to remove unwanted particles and materials before being returned to the flux supply system. Flux that is not reclaimed from weldment surfaces within one hour of

being deposited on the weld shall be dried before being used as provided in 4.8.3.

The contractor shall have a system for collecting unmelted flux, mixing with new flux as required, and welding with a mixture of these two such that the flux composition and particle size distribution at the arc are relatively constant. Flux fused in welding shall not be reused.

4.9 Procedures for SAW with a Single Electrode

4.9.1 Single electrode means one electrode connected exclusively to one power source which may consist of one or more power units.

4.9.2 All submerged arc welds except fillet welds shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single pass fillet welds made in the horizontal position shall not exceed 8 mm size.

4.9.3 The thickness of weld layers, except root and surface layers, shall not exceed 6 mm. When the root opening is 12 mm or greater, a multiple-pass, split-layer technique shall be used. The split-layer technique shall also be used in making multiple-pass welds when the width of the layer exceeds 16 mm.

4.9.4 The welding current, arc voltage, and speed of travel shall be such that each pass will have complete fusion with the adjacent base metal and weld metal, and there will be no overlap or undue under-cutting. The maximum welding current to be used in making a groove weld for any pass that has fusion to both faces of the groove shall be 600 A, except that the final layer may be made using a higher current. The maximum current to be used for making fillet welds in the flat position shall be 1000 A.

4.10 Procedures for SAW with Parallel Electrodes

4.10.1 Parallel electrode means two electrodes connected electrically in parallel exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. Welding current, when specified, is the total for the two electrodes.

4.10.2 SAW with parallel electrodes, except fillet welds, shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single-pass parallel electrode fillet welds made in the horizontal position shall not exceed 8 mm size.

4.10.3 The thickness of weld layers is not limited. In making the root pass of a groove weld, single or parallel electrodes may be used. Backing bars or root faces shall be of adequate thickness to prevent melting-through.

When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 12 mm, parallel electrodes shall be displaced laterally or a split-layer technique shall be used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 16 mm, a split-layer technique with electrodes in tandem shall be used.

4.10.4 The welding current, arc voltage, speed of travel, and relative location of electrodes shall be such that each pass will have complete fusion with the adjacent base metal, and such that there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in the roots of joints under restraint.

4.10.4.1 The maximum welding current in making a groove weld shall be the following:

(1) 700 A for parallel electrodes when making the root layer in a groove having no root opening, and which does not fill the groove

(2) 900 A for parallel electrodes when making the root pass in a groove having steel backing or a root face of sufficient thickness to prevent melt-through

(3) 1200 A for parallel electrodes for all passes except the final layer

(4) For the final layer, no restriction on welding current qualified by test under the provisions of 5.12 or 5.13

4.10.4.2 The maximum welding current to be used in making a fillet weld shall be 1200 A for parallel electrodes.

4.10.5 Welds may also be made in the root of groove or fillet welds using gas metal arc welding (GMAW), followed by parallel submerged arcs, provided that the GMAW conforms to the requirements of Part D of this section, and providing the spacing between the gas shielded arc and the following submerged arc does not exceed 400 mm.

4.10.6 Preheat and interpass temperatures for parallel electrode SAW shall be selected in accordance with the provisions of 4.2. For single-pass groove or fillet welds, for combinations of metals being welded and the heat input involved, and with the approval of the Engineer, preheat and interpass temperatures may be established which are sufficient to reduce the hardness in the HAZ of the base metal to less than 225 Vickers hardness number for steel having a minimum specified tensile strength not exceeding 415 MPa, and to less than 280 Vickers hardness number for steel having a minimum specified ten-

tile strength greater than 415 MPa, but not exceeding 485 MPa.

Note: The Vickers hardness number shall be determined in accordance with ASTM E92. If another method of hardness is to be used, the equivalent hardness number shall be determined from ASTM E140, and testing shall be performed according to the applicable ASTM specification.

4.10.6.1 When required by 4.10.6, hardness of the HAZ shall be determined by the following:

(1) On the initial macroetch cross section of a sample test specimen.

(2) On the surface of the member during the progress of the work. The surface shall be ground prior to hardness testing.

(a) The frequency of such HAZ testing shall be at least one test area per weldment of the thicker base metal involved in a joint for each 15 m of groove welds or pair of fillet welds.

(b) These hardness determinations may be discontinued after the procedure has been established to the satisfaction of the Engineer.

4.10.6.2 No reduction of the preheat requirements of 4.2 will be permitted for fillet welds 10 mm and under in size.

4.11 Procedures for SAW with Multiple Electrodes

4.11.1 Multiple electrodes are defined as the combination of two or more single or parallel electrode systems. Each of the component systems has its own independent power source and its own electrode feeder.

4.11.2 Submerged arc welds with multiple electrodes, except fillet welds, shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single-pass multiple electrode fillet welds made in the horizontal position shall not exceed 12 mm.

4.11.3 The thickness of weld layers is not limited. In making the root pass of a groove weld, single or multiple electrodes may be used. Backing bars or root faces shall be of adequate thickness to prevent melt-through. When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 12 mm, a split-layer technique shall be used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 25 mm, and only two electrodes are used, a split-layer technique with electrodes in tandem shall be employed.

4.11.4 The welding current, arc voltage, speed of travel, and relative location of electrodes shall be such that each pass shall have complete fusion with the adjacent base metal and weld metal and such that there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in roots of joints under restraint.

4.11.4.1 The maximum welding current in making a groove weld shall be the following:

(1) 700 A for any single electrode or for parallel electrodes when making the root layer in a groove having no root opening and which does not fill the groove

(2) 750 A for any single electrode or 900 A for parallel electrodes when making the root pass in a groove having steel backing or a root face with sufficient thickness to prevent melt-through

(3) 1000 A for any single electrode or 1200 A for parallel electrodes for all other passes except the final layer

(4) For the final layer there is no restriction on welding current qualified by test under the provisions of 5.12 or 5.13.

4.11.4.2 The maximum welding current to be used in making a fillet weld shall be 1000 A for any single electrode or 1200 A for parallel electrodes.

4.11.5 Multiple electrode welds may also be made in the root of groove or fillet welds using GMAW followed by multiple submerged arcs, provided that the GMAW conforms to the requirements of Part D of this section, and provided the spacing between the gas shielded arc and the first following submerged arc does not exceed 400 mm.

4.11.6 Preheat and interpass temperatures for multiple electrode SAW shall be selected in accordance with 4.2. For single-pass groove or fillet welds, for combinations of metals being welded and the heat input involved, and with the approval of the Engineer, preheat and interpass temperatures may be established which are sufficient to reduce the hardness in the HAZ of the base metal to less than 225 Vickers hardness number for steel having a minimum specified tensile strength not exceeding 415 MPa, and to less than 280 Vickers hardness number for steel having a minimum specified tensile strength greater than 415 MPa but not exceeding 485 MPa.

4.11.6.1 When required by 4.11.6, hardness of the HAZ shall be determined:

(1) On the initial macroetch cross sections of a sample test specimen, and

(2) On the surface of the member during the progress of the work. The surface shall be ground prior to hardness testing.

(a) The frequency of such HAZ testing shall be at least one test area per weldment on the thicker base metal

involved in a joint for each 15 m of groove welds or pair of fillet welds.

(b) These hardness determinations may be discontinued after the procedure has been established to the satisfaction of the Engineer.

4.11.6.2 No reduction of the preheat requirements of 4.2 will be permitted for fillet welds 10 mm and under in size.

Part D

Gas Metal Arc Welding (GMAW) and Flux Cored Arc Welding (FCAW)

4.12 Electrodes

4.12.1 The electrodes and shielding for GMAW or FCAW for producing weld metal with minimum specified yield strengths of 415 MPa, or less, shall conform to the requirements of the latest edition of ANSI/AWS A5.18, *Specification for Carbon Steel Electrodes and Rods*, ANSI/AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, or ANSI/AWS A5.29, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*, as applicable.

4.12.2 Weld metal having a minimum specified yield strength greater than 415 MPa shall conform to the following requirements:

4.12.2.1 The electrodes and shielding gas for GMAW shall conform to the latest edition of ANSI/AWS A5.28, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*.

4.12.2.2 The electrodes and shielding gas (if required) for FCAW shall conform to the latest edition of ANSI/AWS A5.29.

4.12.3 The contractor shall furnish certificates of conformance for all electrodes and combinations of shielding used on a project in accordance with this code. The report shall include the results of all pertinent required tests of ANSI/AWS A5.18, ANSI/AWS A5.28, ANSI/AWS A5.20, or ANSI/AWS A5.29, whichever is applicable, made on electrodes of the same classification or grade, of the same brand, welded with the same shielding gas, and manufactured with the same process and same materials as electrodes being used on this project. Tests may have been for process qualification or quality control and shall have been made within one year prior to manufacture of the electrodes furnished. The report shall include the manufacturer's certification that the process and material requirements were the same for

manufacturing the tested electrodes and the furnished electrodes. The test report shall be similar to that shown in Annex III, Form Ea, containing all pertinent information concerning the test required by the electrode specification.

4.12.4 In lieu of requiring a contractor to furnish copies of manufacturer's test reports for each shipment of electrodes on a project, the contracting authority may maintain a list of approved brands of electrodes for which satisfactory tests made within one year have been previously submitted. If this alternative is elected, the list shall be available to project Engineers and contractors.

4.13 Shielding Gas

A gas or gas mixture used for shielding in GMAW or when required for FCAW shall be of a welding grade having a dew point of -40°C or lower. When requested by the Engineer, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and will meet the dew point requirement.

4.14 Procedures for GMAW and FCAW with a Single Electrode

4.14.1 The following are general requirements:

4.14.1.1 Electrodes shall be dry and in suitable condition for use.

4.14.1.2 The maximum electrode diameter shall be 4.0 mm for the flat and horizontal positions, 2.4 mm for the vertical position, and 2.0 mm for the overhead position.

4.14.1.3 The maximum size of a fillet weld made in one pass shall be 12 mm for the flat and vertical positions, 10 mm for the horizontal position, and 8 mm for the overhead position.

4.14.1.4 GMAW. The thickness of weld layers in groove welds, except root and surface layers, shall not exceed 6 mm. When the root opening is 12 mm or greater, a multiple-pass split-layer technique shall be used. The split-layer technique shall also be used in making all multiple-pass welds when the width of the layer exceeds 16 mm.

4.14.1.5 FCAW. The thickness of the weld layers in groove welds, except root and surface layers, shall not exceed 6 mm. When the root opening is 12 mm or greater, a multiple-pass split-layer technique shall be used. When the width of a layer of a groove weld in the

flat, horizontal, or overhead position is 16 mm or greater, a multiple-pass split-layer technique shall be used. When welding in the vertical position, a split-layer technique shall be used when the width of the layer exceeds 25 mm.

4.14.1.6 The welding current, arc voltage, gas flow, mode of metal transfer, and speed of travel shall be such that each pass will have complete fusion with adjacent base metal and weld metal, and there will be no overlap or excessive porosity or undercutting.

4.14.1.7 The progression for all passes of vertical position welding shall be upwards, unless a downward progression is qualified by tests approved by the Engineer.

4.14.2 Complete joint penetration groove welds made without the use of backing shall have the root of the initial weld gouged, chipped, or otherwise removed to sound weld metal before welding is started from the second side.

4.14.3 GMAW, or FCAW-G, shall not be done in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of 10 km/hr.

4.14.4 GMAW WPSs shielded with a single gas or gas mixture containing less than 80 percent argon shall be considered a short circuiting process and shall not be used in the construction of bridge members without the written approval of the Engineer. See Annex C for non-mandatory guidelines in determining GMAW-S.

Part E

Electroslag Welding (ESW) and Electrogas Welding (EGW)

4.15 Qualification of Process, WPSs, and Joint Details

4.15.1 Prior to use, the contractor shall prepare and qualify each WPS to be used according to the requirements in 5.13. The WPS shall include the joint details, filler metal type and diameter, amperage, voltage (type and polarity), speed of vertical travel if not an automatic function of arc length or deposition rate, oscillation (traverse speed, length, and dwell time), type of shielding including flow rate and dew point of gas (if required), or type of flux, type of molding shoe, postweld heat treatment if used, and other pertinent information.

4.15.2 The ESW and EGW processes shall not be used for welding quenched and tempered steel nor for welding components of members subject to tensile stresses or reversal of stress.

4.16 Mechanical Properties

WPS qualification testing under the provisions of 5.13 shall verify that weld metal mechanical properties meet the requirements of Table 4.2.

4.17 Condition of Electrodes and Guide Tubes

Electrodes and consumable guide tubes shall be dry, clean, and in suitable condition for use.

4.18 Shielding Gas

A gas or gas mixture when required for shielding of EGW shall be of a welding grade and have a dew point of -40°C or lower. When requested by the Engineer, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and will meet the dew point requirements.

4.19 Condition of Flux

Flux used for ESW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from packages damaged in transit or in handling shall be discarded or shall be dried at a minimum temperature of 260°C for one hour before use. Flux that has been wet shall not be used.

4.20 Procedures for ESW and EGW

4.20.1 Gas to be used for shielding shall be of a welding grade and shall meet all requirements of the WPS. When mixed at the welding site, suitable meters shall be used for proportioning the gases. Percentage of gases shall conform to the requirements of the WPS.

4.20.2 EGW that requires external gas shielding shall not be done in a draft or wind of a velocity greater than 10 km/hr unless the weld is protected by a shelter. This shelter shall be of a material and shape appropriate to

reduce wind velocity in the vicinity of the weld surface to a maximum of 10 km/hr.

4.20.3 The type and diameter of the electrodes used shall meet the requirements of the WPS. Electrodes shall conform to the requirements of Table 4.2.

4.20.4 Welds shall be started in such a manner as to permit sufficient heat buildup for complete fusion of the weld metal to the groove faces of the joint before the weld leaves the sump. Welds which have been stopped at any point in the weld joint for a sufficient amount of time for the slag or weld pool to begin to solidify may be restarted and completed, provided the completed weld is proven satisfactory after examination by ultrasonic testing for a minimum of 150 mm on either side of the restart and, unless prohibited by joint geometry, the weld soundness is also confirmed by radiographic testing. All such restart locations shall be recorded and reported to the Engineer.

4.20.5 Because of the high heat input characteristic of these processes, preheating is not normally required. However, no welding shall be performed when the temperature of the base metal at the point of welding is below 0°C. Preheating may be required by the WPS to improve the quality of the weld at the starting sump.

4.20.6 All groove welds in butt joints in main members shall be radiographed in accordance with the provisions of section 6, Part B and shall conform to the requirements of 9.21 and Figure 9.4.

4.20.7 Welds having defects prohibited by 9.21 shall be repaired as permitted by 3.7 using a qualified welding process or the entire weld shall be removed and replaced.

Part F

Plug and Slot Welds

4.21 Plug Welds

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

4.21.1 For welds to be made in the flat position, each shall be deposited around the root of the joint and then deposited along a spiral path to the center of the hole, fusing and depositing a layer of weld metal in the root and bottom of the joint. The arc is then carried to the periphery of the hole and the procedure repeated, fusing and depositing successive layers to fill the hole to the required depth. The slag covering the weld metal should

be kept molten until the weld is finished. If the arc is broken or the slag is allowed to cool, the slag must be completely removed before restarting the weld.

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

4.21.3 For welds to be made in the overhead position, a spiral procedure is followed as for the flat position, except that the slag should be allowed to cool and should be completely removed after depositing each successive layer until the hole is filled to the required depth.

4.22 Slot Welds

Slot welds shall be made using techniques similar to those specified in 4.21 for plug welds, except that if the length of the slot exceeds three times the width, or if the slot extends to the edge of the part, the technique requirements of 4.21.3 shall apply.

4.23 Plug and Slot Welds

When plug and slot welds are made by continuous welding over previously deposited weld beads and through molten slag, the welder shall observe the arc and slag cover for signs of conditions that are present during the formation of fusion defects, such as intermittent arc, excessive spatter, and slag boiling with excessive gas. When these signs are observed, the welding shall be discontinued. After the slag has cooled, all slag and fusion defects shall be removed before welding is resumed.

Part G

Control of Production Welding Variables

4.24 Tests

Control of welding variables shall be based upon the results of WPS qualification tests performed as described in section 5.

4.25 Control of Variables

Welders and welding operators shall set welding controls, weld, and operate welding equipment within the limitations on current, voltage, travel speed, and shielding gas flow rates listed in the approved WPS.

4.26 Calibration of Equipment

4.26.1 Equipment used to measure variables shall be accurately calibrated. The contractor shall verify, at least every 3 months, the accuracy of meters and other devices used to record or display welding variables. The equipment used for verifying meters and other devices shall be certified annually.

4.26.2 Correction charts or similar methods may be used to compensate for meter error when approved by the Engineer.

4.27 Current Control

4.27.1 The welding current may be controlled by controlling the wire feed speed, provided correlation between amperage and wire feed speed is known for specific electrode types and diameters.

4.27.2 The Inspector shall have access to accurate amperage versus wire feed speed tables or charts whenever wire feed speed is used as a method of current control.

5. Qualification

5.0 Scope

Qualification of a Welding Procedure Specification (WPS) is covered in Part A. Qualification of welding personnel (i.e., welders, welding operators and tack welders) is covered by Part B.

Part A **Welding Procedure Specification (WPS) Qualification**

5.1 Approval

Approval of WPSs shall be based upon the results of mechanical tests that demonstrate that the process and WPS used will produce sound weld metal with required strength, ductility, and toughness.

The mechanical properties of fillet and groove welds shall be determined using standard groove weld tests. The soundness of fillet and groove test welds shall be determined by radiographic tests, mechanical tests, and etching of test welds. The soundness of production welds shall be established by visual and nondestructive tests as required by this code.

5.1.1 Purpose of WPS Qualification Tests. The WPS qualification tests required by this code are designed to provide assurance that the weld metal produced by welding in accordance with the provisions of this code will produce weld metal strength, ductility, and toughness conforming to the provisions of Tables 4.1 and 4.2, as appropriate.

5.2 Qualification Responsibility

Each contractor shall conduct tests to qualify or verify WPSs as required by this code. See 5.13 for WPS qualification requirements.

5.2.1 Acceptance Requirements. Acceptance of WPS qualification tests shall be as stated in 5.2.3 and 5.3.

5.2.2 Contractor. The contractor shall prepare WPSs, based upon the heat input and electrical controls imposed by this WPS, and, within these limits, shall specify welding variables that will produce the welding conditions, characteristics, weld sizes, and contours required in the work.

5.2.3 Engineer. The Engineer should accept properly documented evidence of previous qualification of welders, welding operators, and tack welders. The Engineer shall accept evidence of previous WPS, pretest or verification qualification testing, provided (1) the PQR is complete and shows compliance with the mechanical test requirements of these specifications, and (2) testing was witnessed within the last 60 months and the results of the tests certified as accurate by a state representative or an independent third party acceptable to the state.

5.2.4 Excess Testing. Testing in excess of that required by this code shall be paid for by the owner at prices established by agreement with the contractor unless otherwise provided in the contract documents. Irrespective of this requirement, the Engineer may order tests of welders, welding operators, or WPSs whenever there is evidence that unacceptable welds are being or have been produced.

5.2.5 Records. Records of the test results shall be kept by the contractor/ fabricator/erector and shall be made available to those authorized to examine them.

5.3 Duration

All WPSs, except as provided in 1.3.6, 5.11, and 12.7, shall be based upon tests which have been performed not more than 60 months in advance of production welding. This requirement applies to WPS qualification tests, pretests, and verification tests.

5.4 Base Metal

The following provisions cover the base metal to be used for WPS qualification, pretest, and verification tests.

5.4.1 Base-Metal Qualification Requirements. The production base metals qualified by the PQR base metal shall conform to the following:

PQR Test Plate Specification and Grade (See Note)	Qualified Production Base Metal Specification and Grade
M270M (A709M) Gr. 250	M270M (A709M) Gr. 250
M270M (A709M) Gr. 345	M270M (A709M) Gr. 250, 345
M270M (A709M) Gr. 345W (meeting requirements of 5.4.2)	M270M (A709M) Gr. 250, 345, 345W
Any steel with minimum specified yield strength >345 MPa	PQR Test Plate Specification and Grade

Note: All test plate material should have a minimum Charpy-V notch value of 27J at 4°C.

5.4.2 M270M Grade 345W Test Plate Chemistry Requirements. When M270M Grade 345W (A709M Grade 345W) test plate and backing steel is used to qualify all AASHTO steels having a specified minimum yield strength of 345 MPa, or less, the M270M Gr. 345W (A709M Grade 345W) steel shall have the following chemical composition:

Element	Composition, min, %
Carbon	0.15
Manganese	1.00
Silicon	0.25
Chromium	0.50
Vanadium	0.03

Test plate and backing steel that does not have a chemical composition that conforms to the above limits may be used, provided the steel has equivalent hardenability determined by one of the following:

(1) The Carbon Equivalent shall be 0.45 percent minimum as determined by the formula

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

Carbon shall be 0.12 percent minimum.

or

(2) The hardenability shall be equivalent to steel meeting the requirements of 5.4.2(1) when computed based upon an ideal critical diameter, whether calculated or experimental.

5.4.3 Unlisted Steels with $F_y \geq 485$ MPa. WPSs used to produce matching weld metal to join steels, with a minimum specified yield strength of 485 MPa or greater that are not listed in 9.2, shall be qualified by the contractor as specified in the contract documents or ordered by the Engineer in accordance with 9.2.3. Weldability testing shall be as determined by the Engineer, or approved by AASHTO.

5.4.3.1 Charpy V-Notch Requirements. WPS qualification tests for welds on steels with minimum specified yield strength of 485 MPa or greater shall measure strength, ductility, toughness, and soundness of the weld metal. When specified in the contract documents, qualification tests for steels shall also measure the Charpy V-notch toughness of the coarse grained area of the HAZ. The minimum Charpy V-notch energy, test temperature, orientation of the notch, and other necessary details shall be specified in the contract documents when HAZ testing is required.

5.4.4 CMTRs. Copies of certified mill test reports (CMTRs) shall be furnished for all plates and backing used in testing.

5.4.5 WPS Backing. Steel backing used in weld tests shall be of the same specification and grade as the weld test plates, but Charpy-V notch (CVN) tests are not required.

5.5 Welding Consumables

Welding consumables shall conform to the provisions of the appropriate filler metal specifications listed in Tables 4.1, 4.2, or other specification approved by the Engineer. Filler metal tests of conformance shall be conducted by the manufacturers of welding consumables, as required by the specifications. The tests shall conform to the requirements for the electrode, electrode-flux combination, or electrode-shielding gas(es), as specified to match the base metal to be welded, unless otherwise specified in the contract documents. Tests shall be conducted annually unless otherwise specified, and certification shall be as specified in section 4.

5.5.1 WPS Requirements for Consumables. See Table 5.1 for the WPS qualification requirements for consumables.

5.5.2 Active Flux. WPSs that use active fluxes shall be limited to single- and two-pass applications, unless the

Table 5.1
WPS Qualification Requirements¹ for Consumables (see 5.5.1)

Consumables	Process					
	FCAW	SAW	GMAW	SMAW	ESW	EGW
Each AWS filler metal classification	X	X	X	X	X	X
Each manufacturer's brand and type of cored electrode	X	X			X	X
Each manufacturer's brand and type of flux		X			X	
Each shielding gas or combination of shielding gases (Note 2)	X		X			X

Notes:

1. An "X" indicates applicability for the process; a shaded block indicates non-applicability.
2. Differences of 25% or less in the minor element of the mixture proportions shall not require separate tests.

WPS is qualified under the provisions of 5.13 and approved by the Engineer. Tests of WPSs that employ active fluxes shall be conducted using the 20 mm test plates.

5.6 Test Plate Thickness

See Table 5.2 for the production welding thicknesses qualified by the PQR test plate thicknesses.

5.7 General Requirements for WPS Qualification

5.7.1 WPS Qualification Test. A WPS qualification test is a test performed by the contractor in accordance with the provisions of 5.12 or 5.13. Figure 5.1 shall be used for all WPS qualification testing. Prequalified WPSs in accordance with 5.11, or qualified WPSs in accordance with 5.12 or 5.13, may be used with joint details described in Figures 2.4 or 2.5 without further testing.

5.7.2 Pretest. A WPS pretest is a WPS qualification test performed in accordance with the provisions of 5.12 by someone other than the contractor, but used by the contractor as a basis for preparing WPSs. Figure 5.1 shall be used for all pretesting qualification.

5.7.3 Verification of Pretest PQRs. A WPS verification test is a simplified version of a WPS qualification test that shall be performed by the contractor when verifying a Procedure Qualification Record (PQR) which was obtained from a third party that had performed a pretest. Qualification tests performed under the provisions of 5.12 or 5.13 do not require verification testing. Figure 5.2 shall be used for all verification testing.

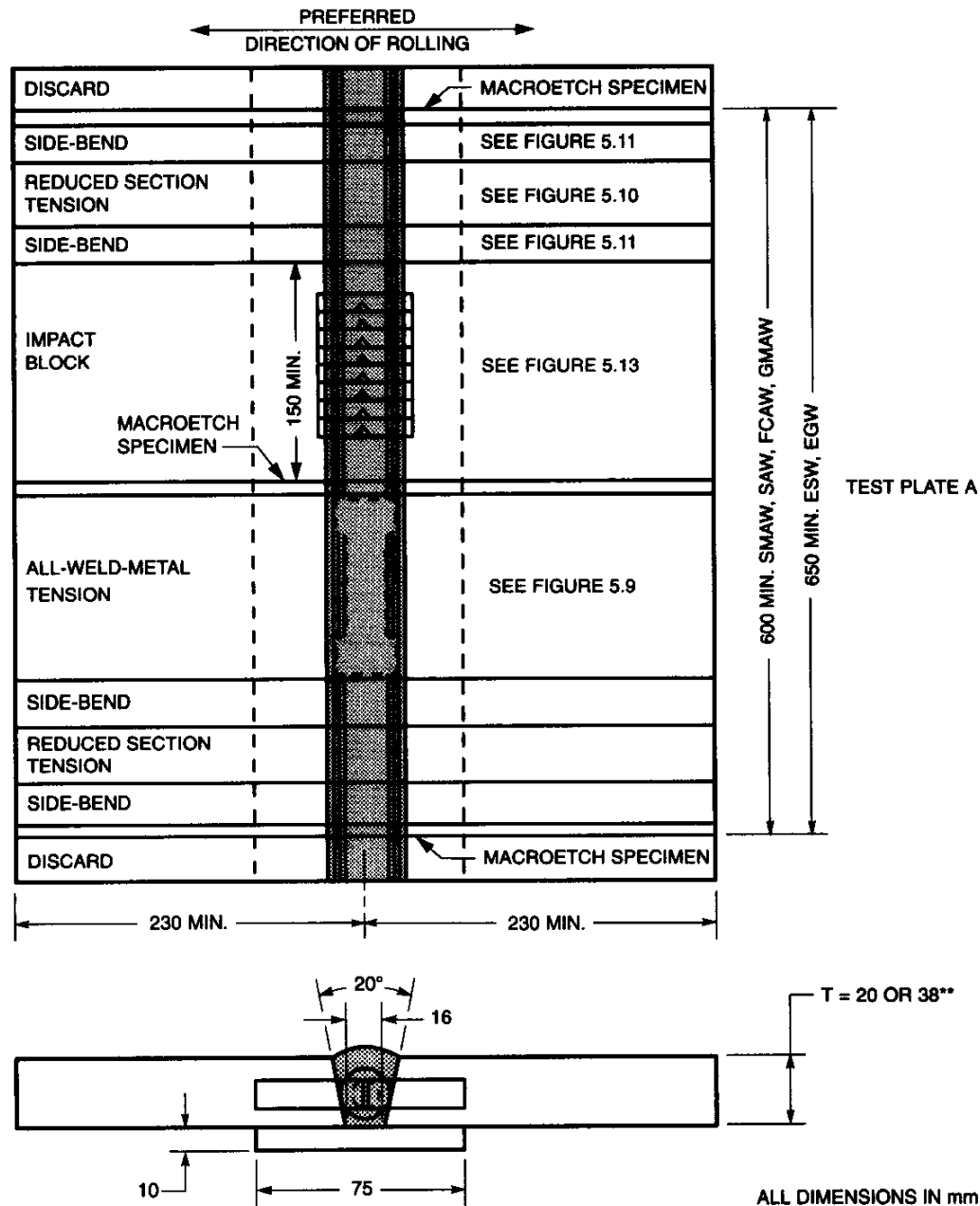
Table 5.2
Production Welding Thickness Qualified¹ by PQR Test Plate Thickness (see 5.6)

Complete Joint Penetration Groove Weld PQR Test Plate Thickness (mm) [T]	Qualified Thicknesses (mm) (Groove and Fillets)	
	Min.	Max.
20	3	38
Notes: 2, 4		
$38 \leq T \leq 50$	38	Unlimited
Notes: 3, 4		

Notes:

1. This table applies to the SMAW, SAW, GMAW and FCAW processes. See Table 5.4 for ESW or EGW.
2. The 20 mm test plate shall be used for all WPS qualification. A maximum heat input test per 5.12.1 shall always be required for the 20 mm test plate. For the option of the minimum heat input test on the 20 mm test plate, see 5.12.2.
3. Minimum heat input WPS tests per 5.12.2.2 are required on the thickness T tested.
4. For unlimited thickness qualification per 5.12, the following option is available:
 - a) A maximum heat input test on 20 mm plate and
 - b) A minimum heat input test on T thick plate ($38 \text{ mm} \leq T \leq 50 \text{ mm}$)

5.7.4 Table 4.1 Processes. WPSs using submerged arc welding (SAW) and gas shielded flux cored arc welding (FCAW-G), with electrode-flux and electrode-shielding gas combinations listed in Table 4.1 shall be approved, based upon qualification testing or pretesting and verification testing, as provided in 5.12 or 5.13.



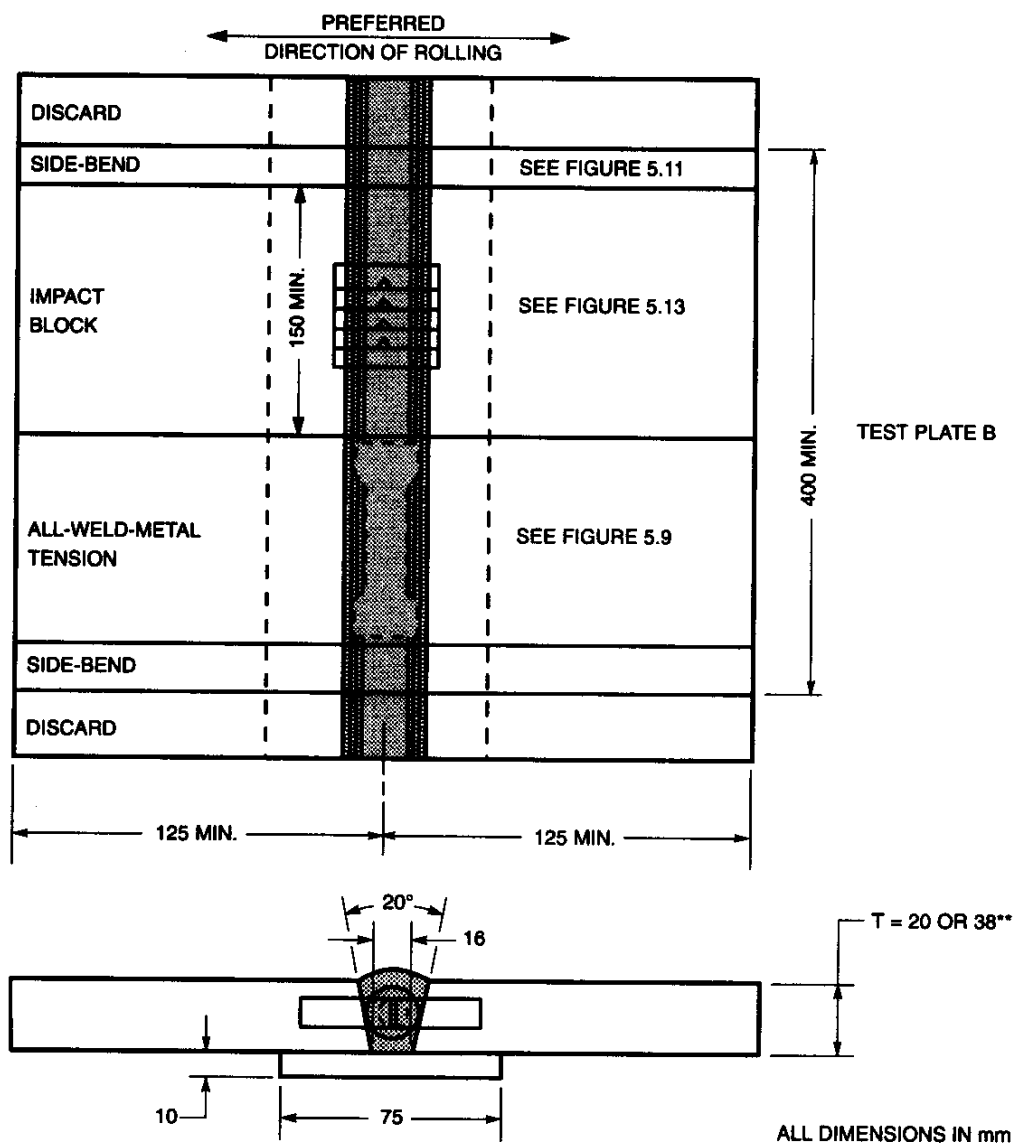
Notes:

1. Welding and machining shall be witnessed by a state representative or an independent third party acceptable to the state.
2. Test specimens and the Procedure Qualification Record* showing all welding parameters used for the test shall be available to the Engineer.

*Test specimens need only be retained for examination by the original approving authority.

**or larger, see Table 5.2

Figure 5.1—WPS Qualification or Pretest—Test Plate A (see 5.7.1)



Notes:

1. Welding and machining shall be witnessed by a state representative or an independent third party acceptable to the state.
2. Test specimens and the Procedure Qualification Record* showing all welding parameters used for the test shall be available to the Engineer.
3. Testing shall be done on by approved testing laboratory. Such testing need not be witnessed by another agency.

*Test specimens need only be retained for examination by the original approving authority.

**or larger, see Table 5.2

Figure 5.2—WPS Qualification or Pretest—Test Plate B (see 5.7.3)

5.7.4.1 Consumables. WPSs employing consumables listed in Table 4.1 may be pretested or qualified for a specific project or application at the option of the contractor. Pretesting, as described in 5.7.2, may be performed by manufacturers of welding consumables, contractors, or independent agencies. Qualification testing under the provision of 5.12 or 5.13 may be performed only by the contractor doing the production welding.

5.7.5 Table 4.2 Processes. WPSs using submerged arc welding (SAW), flux cored arc welding-gas shielded (FCAW-G), flux cored arc welding-self shielded (FCAW-S), gas metal arc welding (GMAW), electrogas welding (EGW), electroslog welding (ESW), and processes with electrode-flux and electrode-shielding gas combinations listed in Table 4.2 shall be approved based upon qualification testing in accordance with the provisions of 5.13.

5.7.6 Exemption from Further Testing. WPSs for groove and fillet welds that have been qualified by test, or pretested and verified as described in this section, which conform to the requirements of section 2, section 3, section 4, and applicable provisions of section 9, Welded Steel Bridges, are exempt from further qualification testing, unless otherwise specified in the contract documents.

5.7.7 Joints Not Conforming to Figures 2.4 or 2.5. When the contractor elects to use groove weld details that do not conform to the details of Figure 2.4 or 2.5, the WPSs using these details may be qualified by test as described in 5.13 using Figure 5.3. Bend and tensile tests are used to evaluate soundness. The mechanical properties of the weld metal shall be determined by the WPS testing described in 5.12 or 5.13, using Figure 5.1.

5.7.8 Aging. No test plate or specimen produced by the testing described in 5.12 or 5.13 shall be heat treated, stress relieved, aged at temperatures above room temperature, or modified in any way after welding except by approved machining and testing procedures, unless the treatment is stated as a requirement of the WPS and is a requirement for similar welds in the structure.

5.7.9 Combination of WPSs. A combination of prequalified SMAW and qualified or pretested and verified WPSs may be used to complete a single welded joint without additional testing, provided the limitations of essential variables and limitations of maximum and minimum heat input applicable to each WPS are observed.

5.7.10 Previous Code Editions. WPSs qualified to previous editions of this code shall be acceptable provided the WPS is soft converted to metric (SI) units of measure. PQR data shall not be required to be converted if

the tests were performed to a previous edition of the code.

5.8 Position of Test Welds

5.8.1 Qualification Requirements. All welds that will be encountered in actual construction shall be classified as (1) flat, (2) horizontal, (3) vertical, or (4) overhead in accordance with the definitions of welding positions described in Figures 5.4 and 5.5. Each WPS shall be tested in the position in which welding will be performed in the work, except that test welds made in the flat positions qualify for flat and horizontal welding.

5.8.2 Groove Weld Test Positions. Plates shall be welded in the following positions:

5.8.2.1 Position 1G (Flat). The test plates shall be placed in an approximately horizontal plane and the weld metal shall be deposited from the upper side. See Figure 5.6 (Detail A).

5.8.2.2 Position 2G (Horizontal). The test plates shall be placed in an approximately vertical plane with the groove approximately horizontal. See Figure 5.6 (Detail B).

5.8.2.3 Position 3G (Vertical). The test plates shall be placed in an approximately vertical plane with the groove approximately vertical. See Figure 5.6 (Detail C).

5.8.2.4 Position 4G (Overhead). The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the underside. See Figure 5.6 (Detail D).

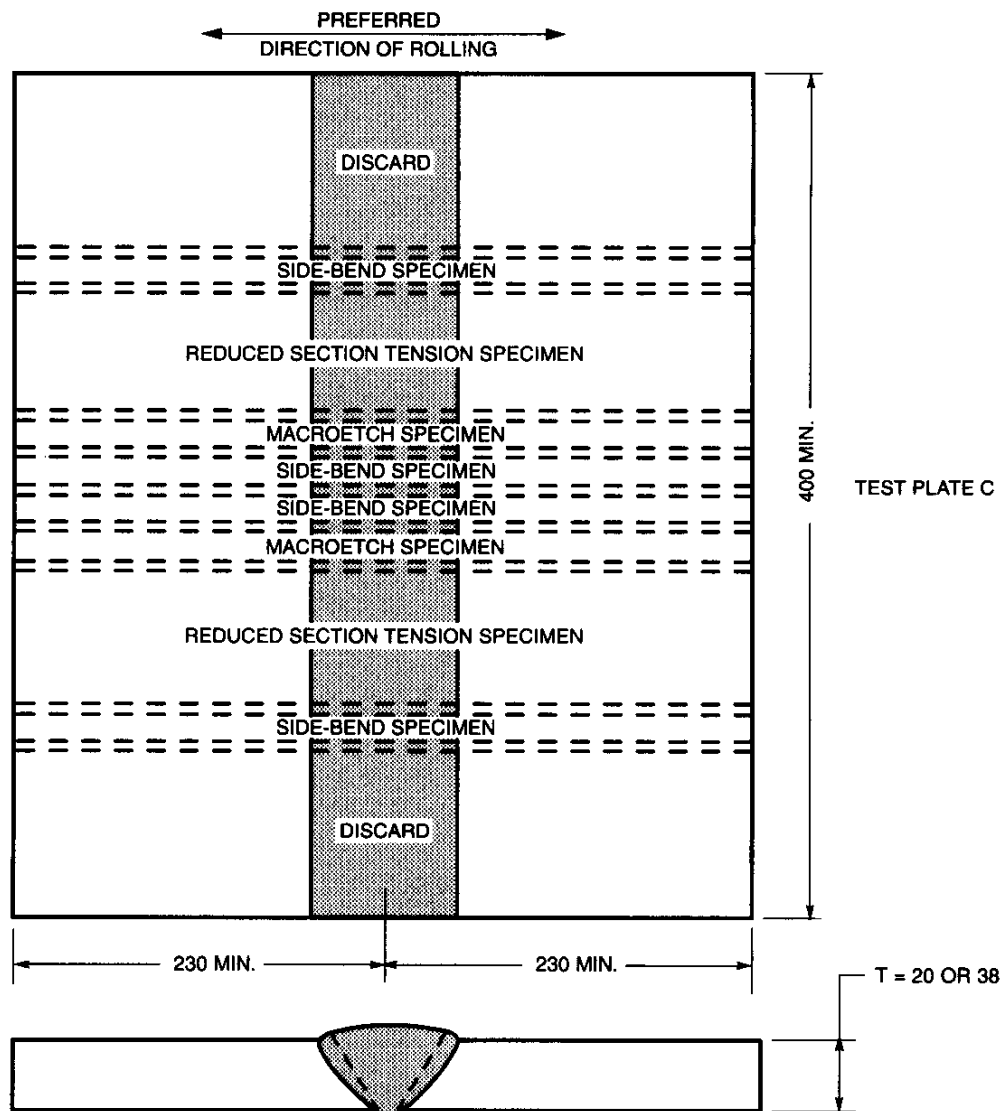
5.8.3 Fillet Weld Test Positions. When making fillet weld macroetch soundness tests for procedure qualification, test plates shall be welded in the following positions:

5.8.3.1 Position 1F (Flat). The test plates shall be so placed that each fillet weld is deposited from the upper side with its axis approximately horizontal and its throat approximately vertical. See Figure 5.7 (Detail A).

5.8.3.2 Position 2F (Horizontal). The test plates shall be so placed that each fillet weld is deposited on the upper side of the horizontal surface and against the vertical surface. See Figure 5.7 (Detail B).

5.8.3.3 Position 3F (Vertical). The test plates shall be placed in approximately vertical planes, and each fillet weld shall be deposited on the vertical surfaces. See Figure 5.7 (Detail C).

5.8.3.4 Position 4F (Overhead). The test plates shall be so placed that each fillet weld is deposited on the underside of the horizontal surface and against the vertical surface. See Figure 5.7 (Detail D).



THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY.
THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.

ALL DIMENSIONS
IN mm

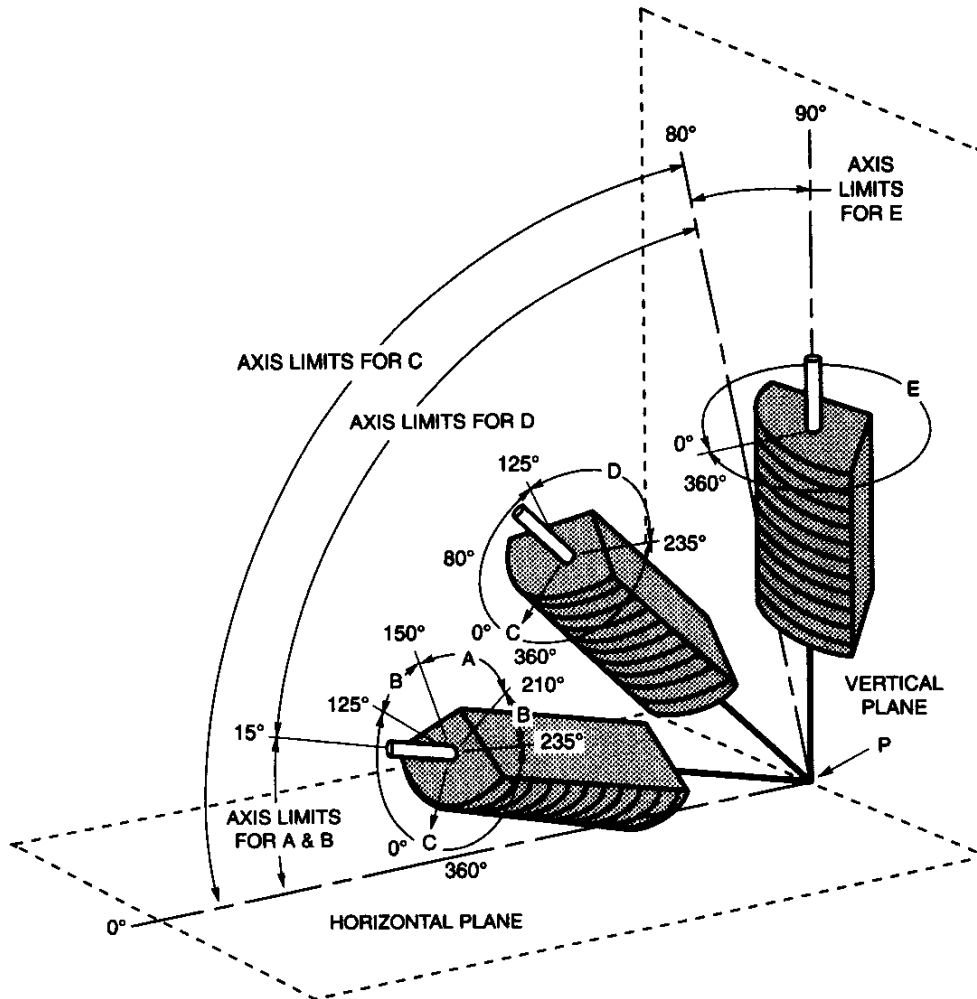
Notes:

1. Welding and machining shall be witnessed by a state representative or an independent third party acceptable to the state.
2. Test specimens and the Procedure Qualification Record* showing all welding parameters used for the test shall be available to the Engineer.
3. Macroetch specimens 10 mm thick and "T" wide* shall be polished and etched for macroscopic examination by the Engineer.
4. Testing shall be done by an approved testing laboratory. Such testing need not be witnessed by another agency.

*Test specimens need only be retained for examination by the original approving authority.

**Figure 5.3—Weld Soundness Test Plate for Details Not Conforming to
Figure 2.4 or Figure 2.5—Test Plate C (see 5.7.7)**

Tabulation of positions of fillet welds			
Position	Diagram reference	Inclination of axis	Rotation of face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D	15° to 80°	125° to 235°
	E	80° to 90°	0° to 360°

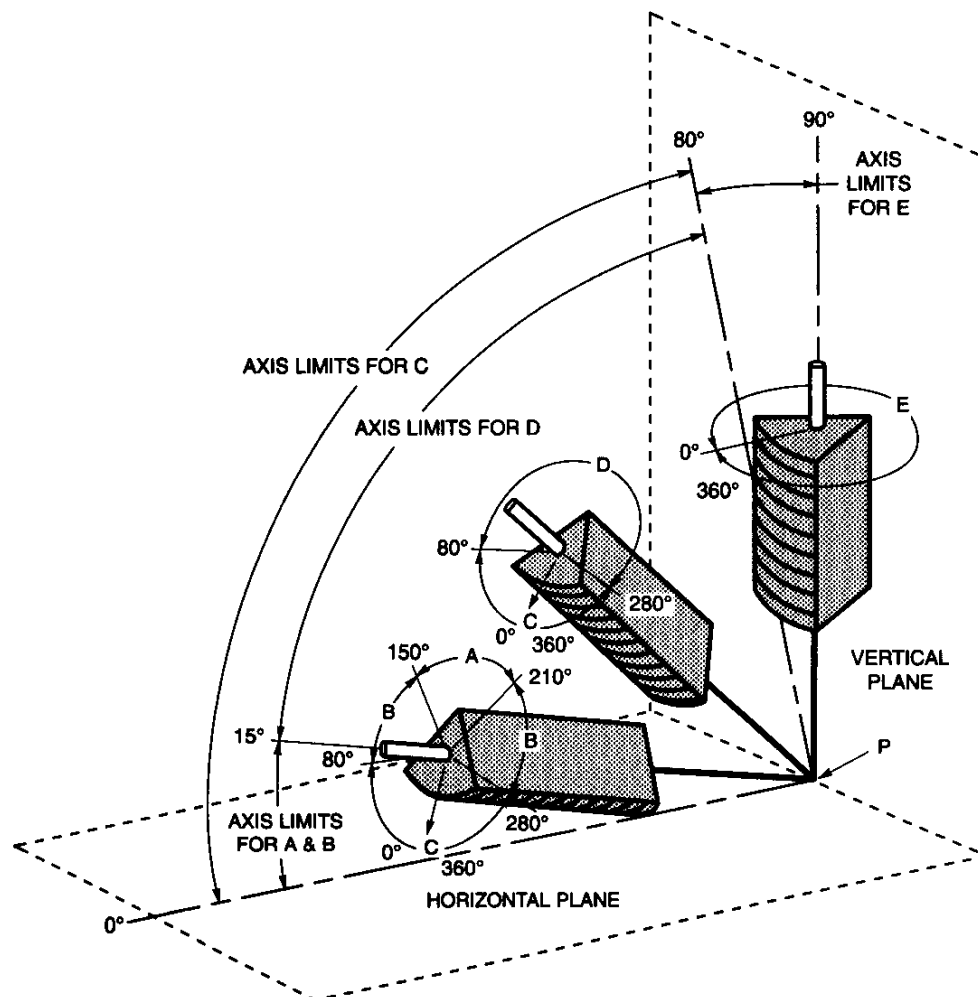


Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 5.4—Positions of Fillet Welds (see 5.8.1)

Tabulation of positions of groove welds			
Position	Diagram reference	Inclination of axis	Rotation of face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°



Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 5.5—Positions of Groove Welds (see 5.8.1)

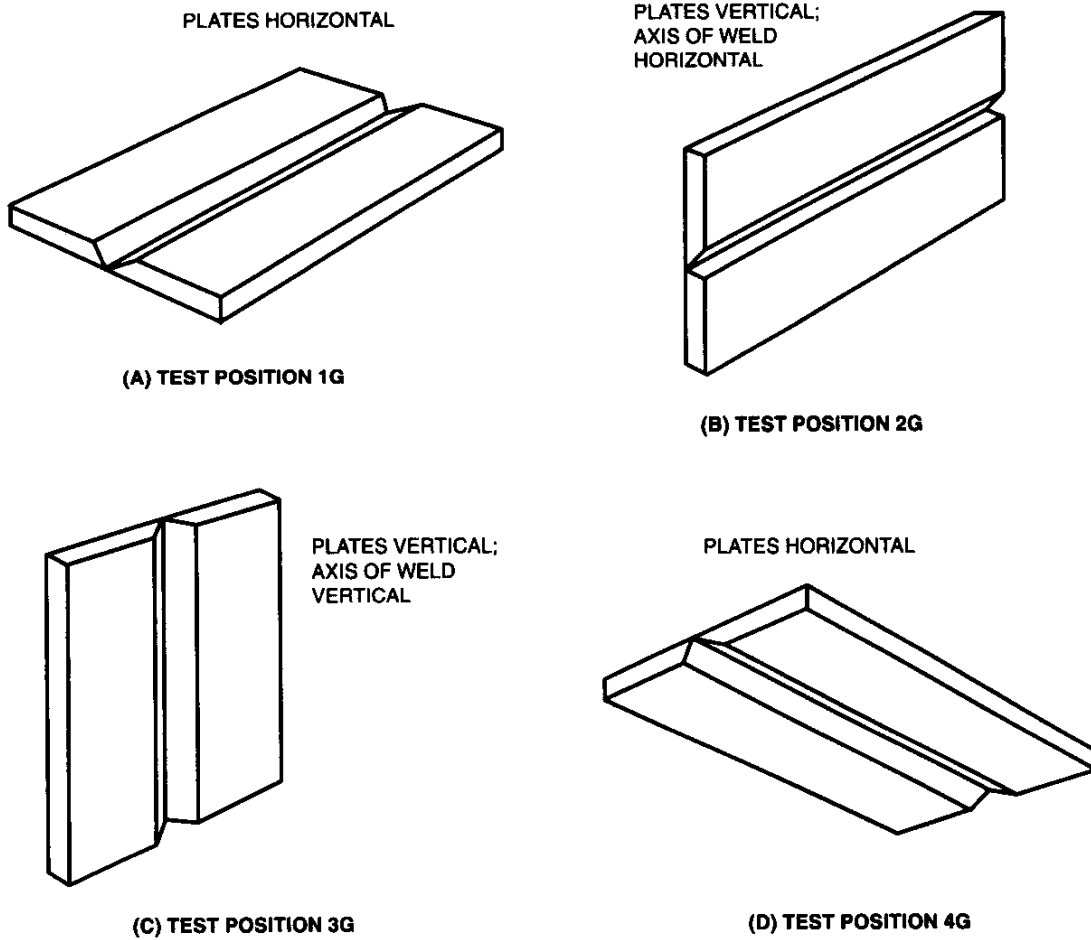
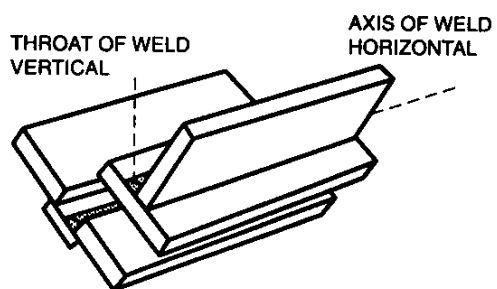
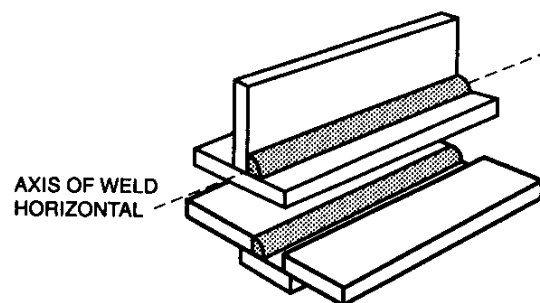


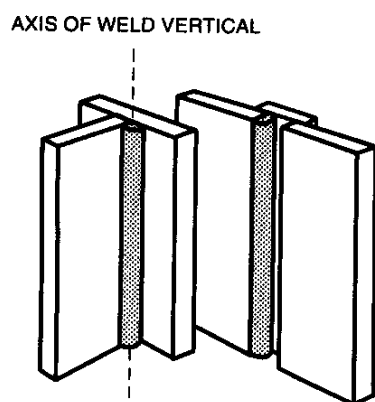
Figure 5.6—Position of Test Plates for Groove Welds (see 5.8.2)



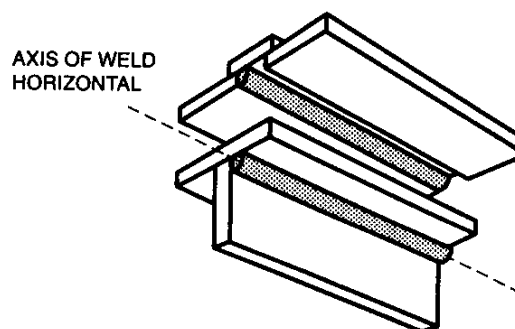
(A) FLAT POSITION 1F



(B) HORIZONTAL POSITION 2F



(C) VERTICAL POSITION 3F



(D) OVERHEAD POSITION 4F

Figure 5.7—Position of Test Plates for Fillet Welds (see 5.8.3)

5.9 Options for WPS Qualification or Prequalification

The following table lists options available for prequalification or qualification of a WPS:

Joint Detail(s)	Process(es)	Filler Metals Listed in Table(s):	Qualification Options per Subsection(s):
Groove detail conforming to Figure 2.4 or 2.5	SMAW	4.1	5.11
		4.2	5.13
	FCAW-G, SAW	4.1	5.12.1, or 5.12.2, or 5.13
		4.2	5.13
	FCAW-S, GMAW, EGW, ESW	4.2	5.13
Any groove detail not conforming to Figure 2.4 or 2.5	SMAW, SAW, FCAW (-G & -S), GMAW, EGW, ESW	4.1 or 4.2	5.13
Fillet Welds	SMAW, SAW, FCAW (-G & -S), GMAW, EGW, ESW	4.1 or 4.2	5.10

5.9.1 Partial Joint Penetration Groove Welds. WPSs qualified for use as complete joint penetration groove welds may be used to make partial joint penetration groove welds without additional testing. The Engineer may require the contractor to provide three macroetch test specimens to evaluate weld soundness and to verify that the required weld size is produced.

5.10 Fillet Weld WPS Qualification

5.10.1 Groove Weld PQRs. Fillet WPSs may be written based upon appropriate groove welding PQRs.

5.10.2 Fillet Weld Properties. The mechanical properties of fillet welds shall be determined by mechanical testing of groove welds. A separate fillet weld property test is not required unless specified in the contract documents.

5.10.3 Fillet Weld Soundness Test. Fillet WPSs shall be subject to fillet weld soundness macroetch qualification as shown in Figure 5.8. The test shall be conducted using WPS polarity, mean current and mean voltage.

(1) A fillet weld macroetch test shall be made for each WPS and position to be used in construction. One test weld shall be the maximum size single-pass fillet weld and one test weld shall be the minimum size multiple-pass fillet weld used in construction. The two fillet weld tests may be combined in a single test weldment or assembly.

(2) The weldment shall be cut perpendicular to the direction of welding at three locations as shown in Figure 5.8. Specimens representing one face of each of the three cuts shall be polished and etched to constitute a macroetch test specimen and shall be tested in accordance with the provisions of 5.19.3.

5.11 Prequalified WPS

SMAW WPSs using electrodes listed in Table 4.1 and that conform to the requirements of this code are considered prequalified and exempt from WPS testing.

5.11.1 Prequalified Tack Weld WPS. WPSs for tack welds which are completely remelted by subsequent SAW shall be exempt from WPS qualification testing as otherwise required by this code.

5.12 Heat Input WPS

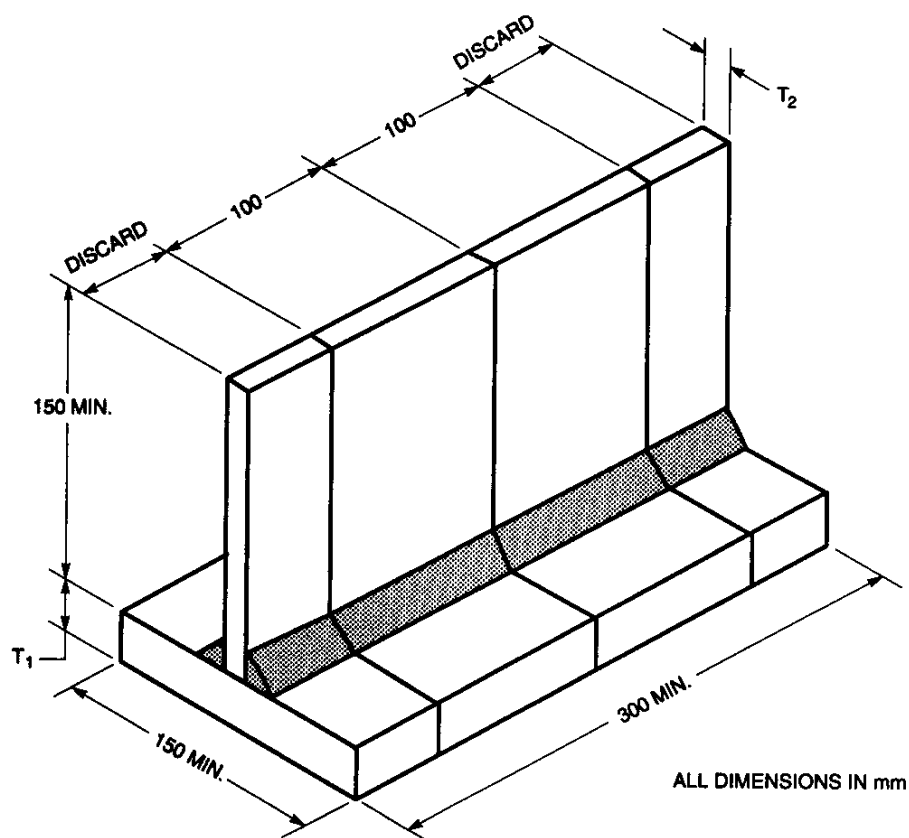
This covers WPS qualification or pretesting and verification using filler metal meeting the requirements of Table 4.1, and the details of Figures 2.4 and 2.5. Either 5.12.1 or 5.12.2 may be selected for WPS qualification. See 5.12.3.1 and 5.12.3.3 to determine production heat input limitations.

Heat input shall be determined using the formula:

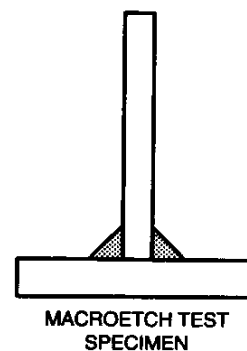
$$\text{Heat Input (kilojoules/mm)} = \frac{\text{Amperage} \times \text{Voltage} \times .06}{\text{Travel Speed (mm/minute)}}$$

5.12.1 Maximum Heat Input. To qualify SAW or FCAW-G WPSs for filler metals listed in Table 4.1, tests shall be conducted using Figure 5.1, with a WPS that produces the highest calculated welding heat input and, therefore, the slowest cooling rate of the weld and base metal HAZ. Tests to verify a WPS shall use Figure 5.1 or Figure 5.2.

Note: Care should be taken to prevent the build-up of interpass temperature beyond the maximum expected in the work since this may adversely effect the weld metal toughness measured in the test. The interpass temperature may be controlled by waiting for the test plate to cool between weld passes or by directing a jet of compressed air against the back of the test assembly between passes as necessary.



WELD SIZE	T ₁ MIN.	T ₂ MIN.
6	20	6
8	25	8
10	25	10
12	25	12
16	25	16
20	25	20
>20	25	25



Notes:

1. Where the maximum plate thickness used in production is less than the value shown in the table, the maximum thickness of the production pieces may be substituted for T₁ and T₂.
2. At the contractor's option, the maximum single pass fillet welds may be welded on one side of the joint, and the minimum multiple pass fillet weld may be welded on the other side.

**Figure 5.8—Fillet Weld Soundness Test (Macroetch) for WPS Qualification—
Test Plate D (see 5.10.3)**

The following are WPS parameters:

5.12.1.1 Electrodes. The number of electrodes shall be as described in the WPS. (Size of the electrode is not an essential variable in this method.)

5.12.1.2 Electrical Parameters. Current type, polarity, and specified electrical electrode extension (electrical stickout) shall be as described in the WPS. A change in electrode extension of 20 mm or more for SAW, or 6 mm or more for FCAW-G, shall require requalification.

5.12.1.3 Maximum Current. Current shall be WPS maximum.

5.12.1.4 Maximum Voltage. Voltage shall be WPS maximum.

5.12.1.5 Minimum Gas Flow. Shielding gas flow rate shall be WPS minimum.

5.12.1.6 Maximum Preheat/Interpass Temperature. Preheat and interpass temperature shall be the maximum expected to be encountered in production welding.

5.12.2 Maximum-Minimum Heat Input. Testing to establish the maximum-minimum heat input envelope for approval of SAW, and FCAW-G WPSs for filler metals listed in Table 4.1 shall be done using Figure 5.1 for qualification, and Figures 5.1 or 5.2 for verification. A group of WPSs that use the same basic welding process, i.e., same electrode type, manufacturer, or classification, same current type and polarity, same electrode-flux/shielding-gas combination, same electrode extension, but possibly different electrode diameters and operating variables, may be qualified using the WPS, modified to produce both the maximum and minimum heat input as follows:

5.12.2.1 Maximum Heat Input. Conduct the maximum heat input test as described in 5.12.1.

5.12.2.2 Minimum Heat Input. Conduct the minimum heat input test. Welding variables shall be selected to produce the lowest heat input and therefore, the fastest cooling rates in the weld and HAZ as follows:

(1) Number of electrodes shall be as described in the WPS. (Size of electrodes is not an essential variable in this method.)

(2) Current type, polarity, and specified electrical electrode extension shall be as described in the WPS. A change in electrode extension of 20 mm or more for SAW, or 6 mm or more for FCAW-G, shall require requalification.

(3) Current shall be WPS minimum.

(4) Voltage shall be WPS minimum.

(5) Shielding gas shall be WPS maximum.

(6) Preheat and interpass temperature shall be the minimum permitted by the code for the thickness of the

test plate used. The test plate may be cooled artificially between weld passes. See 5.12.1.

5.12.3 Production Welding Limitations

5.12.3.1 Maximum Heat Input Envelope. SAW and FCAW-G WPSs, qualified or pretested and verified in accordance with the provisions of 5.12.1, shall be operated between 60 percent and 100 percent of the qualified maximum PQR heat input.

5.12.3.2 Maximum Heat Input PQR Current, Voltage, and Travel Speed. When WPS qualification is based upon maximum heat input testing under the provisions of 5.12.1, current and voltage shall not exceed the maximum values recorded in the Procedure Qualification Record (PQR). After current and voltage have been selected, the travel speed shall be adjusted so that the heat input conforms to the requirements of 5.12.3.1. Current and voltage shall not be reduced by more than 20 percent and 14 percent, respectively, from the maximum values recorded in the PQR.

5.12.3.3 Maximum-Minimum Heat Input Envelope. SAW and FCAW-G WPSs qualified or pretested and verified in accordance with the provisions of 5.12.2, shall be operated at any calculated welding heat input between the qualified maximum and minimum PQR heat input.

5.12.3.4 Maximum-Minimum Heat Input Current, Voltage, and Travel Speed. When WPS qualification is based upon maximum-minimum heat input testing under the provisions of 5.12.2, the current and voltage shall not be more than the maximums or less than the minimums recorded in the PQR. Travel speed shall be adjusted so that the heat input conforms to the requirements of 5.12.3.3.

5.13 Production Procedure WPS

The provisions of this subsection shall apply to WPSs with filler metals in Table 4.1 or 4.2, and standard or nonstandard joints.

5.13.1 Filler Metals Not Listed in Table 4.1. WPSs qualified with filler metals not listed in Table 4.1, and if the WPS is not qualified (as described in 5.12), the WPS shall be qualified observing the limitation of variables listed in Table 5.3.

5.13.2 Non-Prequalified SMAW WPS. SMAW WPSs using electrodes listed in Table 4.2 shall be subject to WPS qualification testing as described in 5.13.

5.13.3 Limitations. When a WPS is qualified under the provisions of 5.13, the contractor shall conduct the required tests and record the specific values for essential variables listed in Table 5.3. A suggested form listing the information required in the WPS is given in Annex III.

Table 5.3
PQR Essential Variable Changes for WPSs Qualified per 5.13.3

Essential Variable Changes to PQR Requiring Requalification	Process ¹					
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Electroslag Welding (ESW)	Electrogas Welding (EGW)
Filler Metal						
1) Increase in filler metal classification strength	X	X	X	X	X	X
2) Addition or deletion of supplemental powdered or granular filler metal or cut wire		X				
3) Increase or decrease in the amount of supplemental powdered or granular filler metal or wire		X				
4) If the alloy content of the weld metal is largely dependent on supplemental powdered filler metal, any WPS change that results in a weld deposit with the important alloying elements not meeting the WPS chemical composition requirements		X				
Electrode						
6) Increase or decrease in electrode diameter by more than one standard size	X	X	X	X	X	X
7) Change in electrode classification	X	X	X	X	X	X
8) Change in electrode-flux combination		X			X	
9) Change in electrode-shielding gas combination (Note 4)			X	X		X
10) Change in number of electrodes	X	X	X	X	X	X
11) A change in the amperage by:	To a value not recommended by the electrode manufacturer	>10% increase or decrease	>10% increase or decrease	>10% increase or decrease	>20% increase or decrease	>20% increase or decrease

(continued)

Table 5.3 (Continued)

Essential Variable Changes to PQR Requiring Requalification	Process ¹					
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Electroslag Welding (ESW)	Electrogas Welding (EGW)
12) A change in type of current (AC or DC) or polarity	X	X	X	X	X	X
13) A change in mode transfer (see 5.12 and Annex C)			X			
14) A change in the voltage by:		> 7% increase or decrease	> 7% increase or decrease	> 7% increase or decrease		
15) For WPSs using alloy or active fluxes, any increase in the maximum voltage		X				
16) A change in the travel speed by:		>15% increase or decrease	>10% increase or decrease	>10% increase or decrease	>20% increase or decrease (Note 6)	>20% increase or decrease (Note 6)
17) An increase in heat input by more than 10% or decrease of more than 30% (Note 6)	X	X	X	X	X	X

Gas Shielding

18) A change in shielding gas from a single gas to any other single gas or mixture of gases, or a change of more than 25% in any of the minor elements of the gas mixture, or change from a gas mixture to a single gas			X	X		X
19) A change from external shielding to self shielding				X		
20) Any increase of 25% or more or decrease of 10% or more in total gas flow			X	X		X

Multiple Electrode SAW

21) A change > 10%, or 3 mm whichever is greater, in the longitudinal spacing of the arcs		X				
---	--	---	--	--	--	--

(continued)

Table 5.3 (Continued)

Essential Variable Changes to PQR Requiring Requalification	Process ¹					
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Electroslag Welding (ESW)	Electrode Gas Welding (EGW)
22) A change of > 10%, or 2 mm, whichever is greater, in the lateral spacing of the acrs		X				
23) An increase or decrease of more than 10° in the angular orientation of any parallel electrode		X				
24) For machine or automatic SAW; an increase or decrease of more than 3° in the direction of travel		X				
25) For machine or automatic SAW, an increase or decrease of more than 5° normal to the direction of travel		X				

General

26) For the PQR groove area, an increase or decrease > 25% in the number of passes (Note 7)	X	X	X	X	X	X
27) Vertical welding shall be vertical-up unless qualified by tests approved by the Engineer	X		X	X		
28) A change from a U-groove to a V-groove (but not vice versa)	X	X	X	X		
29) A change in the type of groove to a square groove and vice versa	X	X	X	X		
30) A change exceeding the tolerances of 2.9, 2.10, or 3.3.4 in the shape of any type of groove involving: a) A decrease in the groove angle b) A decrease in the root opening c) An increase in the root face which will not be subsequently removed by backgouging	X	X	X	X		

(continued)

Table 5.3 (Continued)

Essential Variable Changes to PQR Requiring Requalification	Process ¹					
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Electroslag Welding (ESW)	Electrogas Welding (EGW)
31) The omission, but not inclusion, of backing or backgouging	X	X	X	X		
32) A decrease from the preheat temperature by more than 15°C (Note 3)	X	X	X	X		
33) Increase in interpass temperature >55°C	X	X	X	X	X	X
34) Addition or deletion of PWHT	X	X	X	X	X	X
35) For M270M (A709M), Gr. 690, 690W, increase in plate thickness greater than 12 mm or decrease of 25 mm or more	X	X	X	X		

Notes:

1. An "X" indicates applicability for the process; a shaded block indicates non-applicability.
2. If the production weld groove area differs from that of the PQR groove area, it is permissible to change the number PQR passes in proportion to the area without requiring WPS requalification.
3. The production welding preheat or interpass temperature may be less than the PQR preheat or interpass temperature provided that the provisions of Table 4.4 or Annex VIII are met, and the base metal temperature shall not be less than the PQR temperature at the time of subsequent welding.
4. Solid wire electrodes conforming to the same AWS filler metal classification may be interchanged without requalification (see Table 5.1).
5. These limitations apply for travel speed changes that are not an automatic function of arc length or deposition rate, and are not applicable when it necessary to compensate for variation in joint opening as approved by the Engineer.
6. For M270M, (A709M) Gr. 690, 690W, allowable heat input increase or decrease shall be limited to 10%.
7. For M270M (A709M) Gr. 690, 690W, passes any change in the number of groove weld passes requires requalification, except proportional changes to accommodate a change in weld cross-sectional area. For fillet welds in these steels, any change in the number of passes requires a fillet weld T-test per Figure 5.8 to be performed.

Changes to the PQR variables in Table 5.3 shall require WPS requalification. When a combination of WPSs is used, the variables applicable to each WPS shall apply.

5.14 Electroslag and Electrogas Welding

ESW and EGW WPSs shall be qualified as specified in 5.13, using Figure 5.1, modified as described in 5.14.1.

5.14.1 Figure 5.1. Test plates used to qualify ESW, or EGW WPS shall conform to Figure 5.1. Test plates shall have sufficient length of weld to permit the machining and testing of eight Charpy V-notch impact test specimens, except the plates shall have a square butt preparation without steel backing, unless otherwise required by the WPS.

5.14.2 Limitations. Supplementing the variables of Table 5.3, the additional essential variables of Table 5.4 apply to ESW or EGW WPSs. Changes beyond these additional variable limits shall also require WPS requalification.

5.15 Type of Tests and Purpose

Mechanical testing shall verify that the WPS produces the strength, ductility, and toughness required by Tables 4.1, 4.2, or as approved by the Engineer for the filler metal tested. Soundness tests shall meet the requirements of 5.19.2 and 5.19.3. The tests described below are used to determine the mechanical properties and the soundness of welds deposited following a given WPS. The tests are as follows:

5.15.1 Groove Welds. The following are tests for groove welds:

- (1) Reduced Section Tension Tests, to measure tensile strength
- (2) Side-Bend Tests, to evaluate soundness
- (3) All-Weld-Metal Tension Tests, to measure tensile strength, yield strength, and ductility
- (4) Charpy V-Notch Impact Tests, to measure relative fracture toughness
- (5) Macroetch Tests, to evaluate soundness and to measure effective throat or weld size; also, used to gage the size and distribution of weld layers and passes
- (6) Radiographic Tests, to evaluate weld soundness.

5.15.2 Fillet Welds. Tests for fillet welds are the following:

5.15.2.1 Mechanical Properties. The mechanical properties of fillet welds are measured by testing groove welds unless otherwise specified in the contract documents.

5.15.2.2 Macroetch. The fillet weld soundness macroetch test, to evaluate weld soundness and to gage the size, shape, and distribution of individual weld passes.

5.16 Weld Specimens—Number, Type, and Preparation

5.16.1 Configuration. The type and number of the specimens that must be tested to qualify a WPS are shown in Figure 5.1.

5.16.2 Corner and T-Joints. Test plates for groove welds in corner or T-joints shall be butt joints having the same groove configuration as the corner or T-joint to be used in construction, except the depth of groove need not exceed 25 mm.

5.16.3 Mechanical Testing. Test specimens shall be removed from the test plate by thermal cutting or machining. Specimens removed by thermal cutting shall have sufficient material in the initial test blank to permit all thermal cutting HAZ material to be removed by subsequent machining. Care shall be taken not to overheat small specimens.

Each test shall include specimens described in Table 5.5.

Mechanical test specimens, except Charpy V-notch specimens, shall be prepared as follows:

- (1) All-weld-metal tension test specimens, prepared for testing in conformance with Figure 5.9
- (2) Reduced section tension test specimens, prepared for testing in conformance with Figure 5.10.
- (3) Side bend specimens, prepared for testing in conformance with Figure 5.11.
- (4) Root and face bend specimens prepared for testing in conformance with Figure 5.12. (Used only for special applications of welder qualification.)

5.16.4 Charpy V-Notch Tests. The Charpy V-notch specimens shall be prepared for testing in conformance with Figure 5.13 as follows:

- (1) Five specimens shall be machined from each test weld made by SMAW, SAW, FCAW, or GMAW and tested at the specified temperature.
- (2) Eight specimens shall be machined from each test weld made by ESW or EGW and tested at the specified temperature.

Table 5.4
Additional PQR Essential Variable Changes Requiring WPS Requalification for Electroslag
or Electrode Gas Welding (sec. 5.14.2)

Essential Variable Changes to PQR Requiring Requalification	Requalification ¹ by WPS Test	Requalification ¹ by Radiographic or Ultrasonic Test ²
Molding Shoes (fixed or movable)		
1) A change from metallic to nonmetallic or vice versa	X	
2) A change from fusing to nonfusing or vice versa	X	
3) A reduction in any cross-sectional dimension or area of a solid nonfusing shoe > 25%	X	
4) A change in design from nonfusing solid to water cooled or vice versa	X	
Filler Metal Oscillation		
5) A change in oscillation traverse speed > 4 mm/s		X
6) A change in oscillation traverse dwell time > 2 seconds (except as necessary to compensate for joint operating variations—as approved by the Engineer)		X
7) A change in oscillation traverse length which affects by more than 3 mm, the proximity of filler metal to the molding shoes		X
Filler Metal Supplements		
8) A change in consumable guide metal core cross-sectional area > 30%	X	
9) A change in the flux system, i.e., cored, magnetic electrode, external, etc.	X	
10) A change in flux composition including consumable guide coating	X	
11) An increase or decrease in flux burden exceeding 30%	X	
Process Characteristics		
12) A change to a combination with any other welding process	X	
13) A change from single pass to multi-pass and vice versa	X	
14) A change from constant current to constant voltage and vice versa		X
Wire Feed Speed		
15) An increase or decrease in the wire feed speed > 40%	X	
Groove Type		
16) A change in groove design, reducing cross-sectional area (for non-square grooves)	X	
17) A change in WPS joint thickness, outside limits of 0.5T – 1.1T (T = qualification thickness)	X	
18) An increase or decrease > 6 mm in square groove root opening	X	

Notes:

1. An "x" indicates applicability for the requalification method; a shaded block indicates non-applicability.
2. Testing to be performed in accordance with section 6, Parts E or F, as applicable.

Table 5.5
Required Number of Test Specimens
WPS Qualification (see 5.16.3)

Test Plate Figure	All Weld Metal Tension Test	Reduced Section Tension Test	Side Bend Test	Charpy V-Notch Impact Test	Groove Weld Macroetch Test	Fillet Weld Macroetch Test
5.1	1	2	4	5*	**	—
5.2	1	—	2	5	—	—
5.3	—	2	4	—	2	—
5.8	—	—	—	—	—	3

*Eight Charpy V-Notch Impact Test Required for ESW and EGW

**When Ordered by the Engineer

5.17 Nondestructive Testing

Before preparing mechanical test specimens, the qualification test plate shall be radiographed in accordance with the provisions of section 6. Weld quality shall meet the requirements of 9.21.1 and 9.21.2, except that for the WPS test for M270M (A709M) Grades 690 and 690W steels, there shall be no discontinuities other than allowable porosity in the test weld. Portions of weld test plates marked "discard" are not subject to inspection or test.

5.18 Method of Testing Specimens

5.18.1 Reduced Section Tension Specimens. Before testing, the least width and corresponding thickness of the reduced section shall be measured in millimeters. The specimen shall be ruptured under tensile load, and the maximum load in newtons shall be determined. The cross-sectional area shall be obtained by multiplying the width by the thickness. The tensile strength shall be obtained by dividing the maximum load by the area of the cross section.

5.18.2 Macroetch Test. Macroetch soundness tests are required for WPS qualification testing done on test plates described in Figure 5.3 and Figure 5.8. The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used for etching to give a clear definition of the welds showing the fusion line (weld-metal/base-metal interface), individual weld passes, and the HAZ.

5.18.3 Root, Face, and Side Bend Specimens. Each specimen shall be bent in a bend test jig that meets the requirements shown in Figures 5.14, 5.15, or 5.16 or is substantially in accordance with these figures, provided the maximum bend radius is not exceeded. Any conve-

nient means may be used to move the plunger member with relation to the die member.

5.18.3.1 Specimen Placement. The specimen shall be placed on the die member of the jig with the weld at mid-span. Face bend specimens shall be placed with the face of the weld directed toward the gap. Root bend and fillet weld soundness specimens shall be placed with the root of the weld directed toward the gap. Side bend specimens shall be placed with that side showing the greater discontinuity, if any, directed toward the gap.

5.18.3.2 Weld and HAZ Placement. The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and HAZ shall be centered and completely within the bent portion of the specimen after testing.

5.18.3.3 Wraparound Jig. When using the wrap-around jig, the specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation. The weld and HAZ shall be completely in the bent portion of the specimen after testing. Test specimens shall be removed from the jig when the outer roll has been moved 180 degrees from the starting point.

5.18.4 All-Weld-Metal Tension Test. The test specimen shall be tested in accordance with ASTM A370, *Mechanical Testing of Steel Products* or the latest edition of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

5.18.5 Charpy V-Notch Impact Test. Toughness testing shall be performed as described for V-notch test specimens under the heading "Charpy Impact Testing" of ASTM A370 (AASHTO T244). Only full size (10 mm × 10 mm) specimens shall be used. See Figure 5.13.

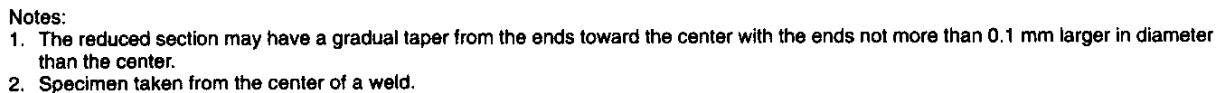
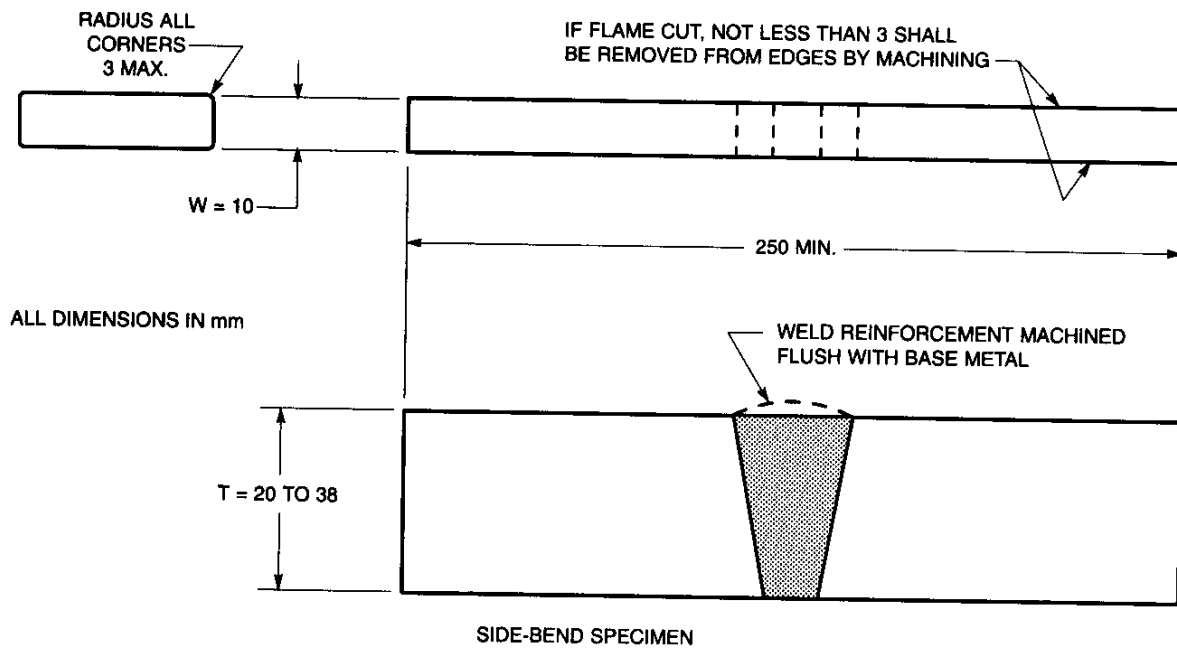


Figure 5.9—Standard Round All-Weld-Metal Tension Specimen (see 5.16.3)



Figure 5.10—Reduced Section Tension Specimen (see 5.16.3)



Note: T depends on the thickness of test plate shown in Figures 5.1, 5.2, and 5.3

Figure 5.11—Side Bend Specimen (see 5.16.3)

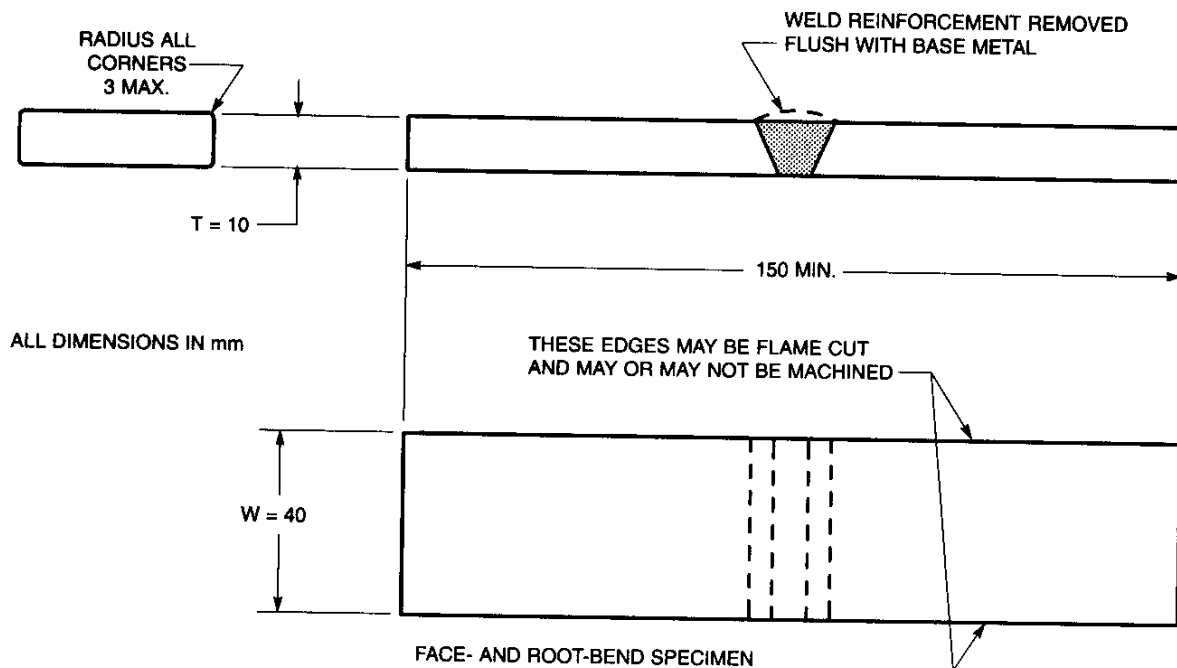
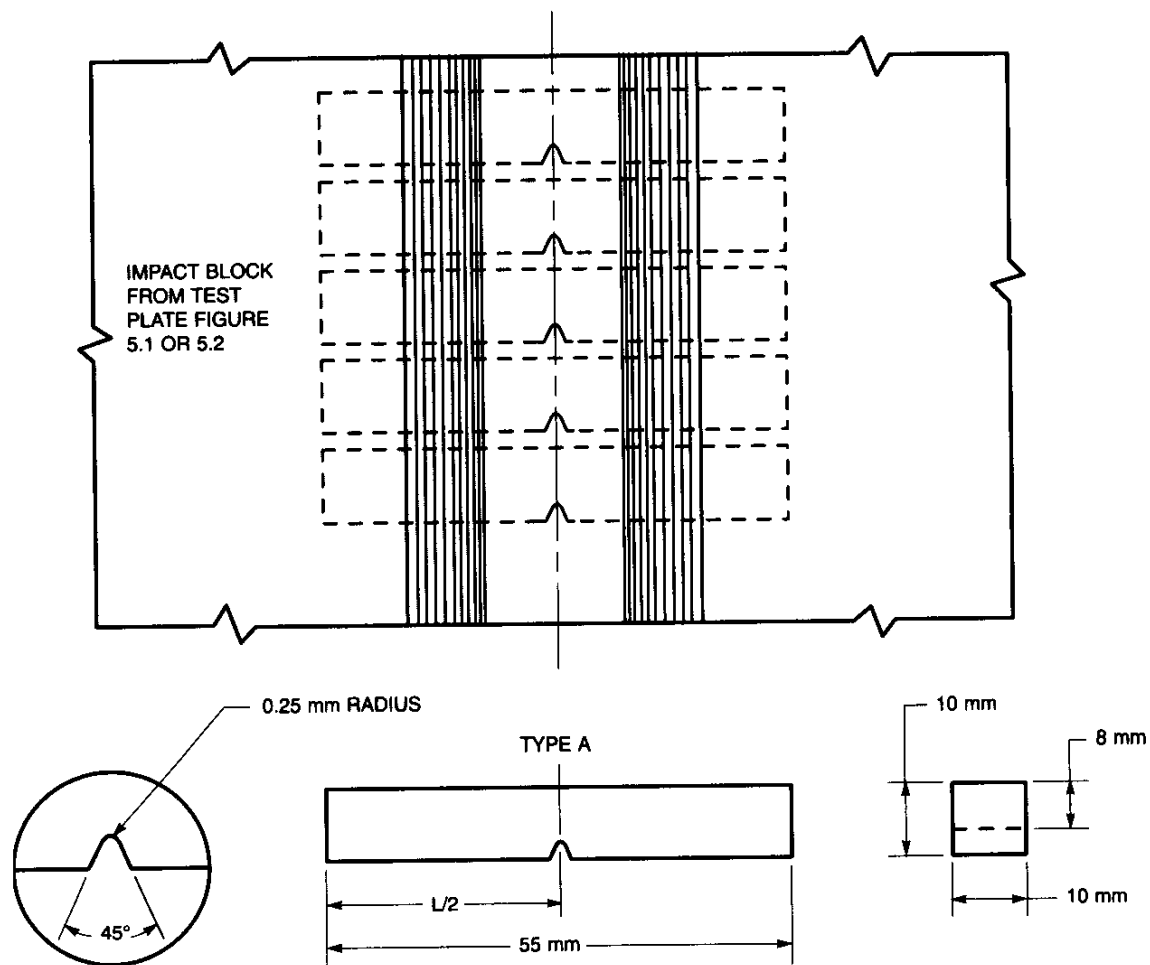


Figure 5.12—Face and Root Bend Specimen (see 5.16.3)



Note—Permissible variations shall be as follows:

Adjacent sides shall be at
Cross section dimensions
Length of specimen (L)
Centering of notch (L/2)

Angle of notch

Radius of notch

Dimensions to bottom of notch: Type A specimen

Finish requirements

90° ± 10 Min.

±0.025 mm

±0, -2.5 mm

±1 mm: When an end-centering device is necessary to center the specimen in the anvil, see 11.2.2**, it is necessary that the notch be accurately centered to ensure compliance with 4.3.1**.

±1°

±0.025 mm

2 ± 0.025 mm

2 μm on notched surface and opposite face;

4 μm on other two surfaces

*Five test specimens shown, eight required for electroslag and electrogas welds.

**ASTM E23, *Standard Methods for Notched Bar Impact Testing of Metallic Materials*.

Figure 5.13—Charpy V-Notch Impact Test Specimen—Type A (see 5.16.4)



Note: Plunger and interior die surfaces shall be machine-finished.

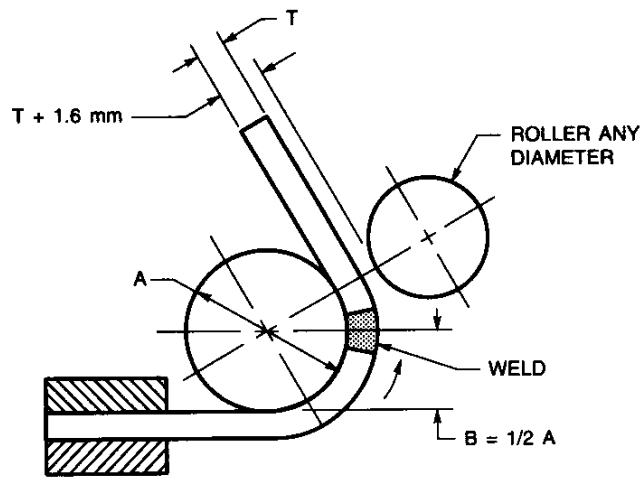
(3) 6 mm—the maximum corner crack, except:

(a) When the corner crack resulted from a visual slag inclusion or other fusion-type discontinuity, the 3 mm maximum shall apply.

(b) Specimens with corner cracks exceeding 6 mm with no evidence of slag inclusions or other fusion-type discontinuities shall be disregarded and a replacement test specimen from the original weldment shall be tested.

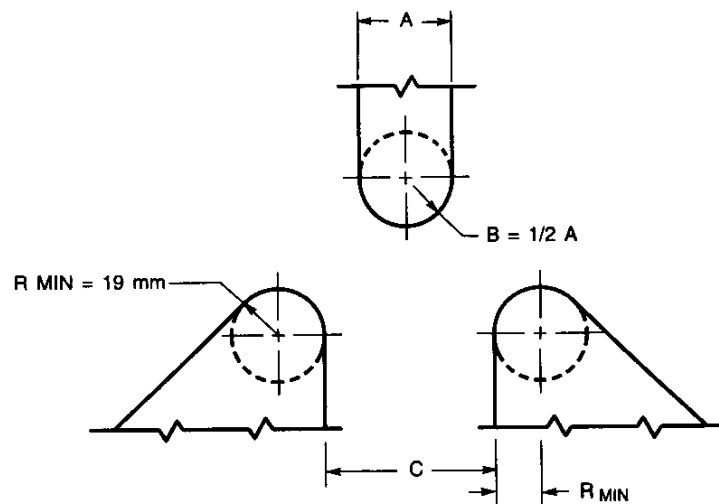
- 5.19.3 Macroetch Tests.** For acceptable qualification, the macroetch test specimen, when inspected visually, shall conform to the following requirements:

5.19.3.1 PJP Groove Welds and Fillet Welds. All welds subject to the macroetch test shall have the following:



Minimum specified base metal yield strength, MPa	A mm	B mm
345 & under	38.1	19.0
Over 345 to 620	50.8	25.4
620 & over	63.5	31.8

Figure 5.15—Alternate Wraparound Guided Bend Test Jig (see 5.18.3)



Minimum specified base metal yield strength, MPa	A mm	B mm	C mm
345 & under	38.1	19.0	60.3
Over 345 to 620	50.8	25.4	73.0
620 & over	63.5	31.8	85.7

Figure 5.16—Alternate Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen (see 5.18.3)

- (1) No cracks
- (2) Thorough fusion between adjacent layers of weld metal and between weld metal and base metal
- (3) Weld profiles conforming to design details but with none of the variations prohibited in 3.6
- (4) No undercut exceeding 1 mm
- (5) The designated weld size (PJP groove welds)

5.19.3.2 Fillet Weld Size and Fusion

- (1) Minimum fillet weld leg size shall meet the specified fillet weld size.
- (2) Fillet welds shall have fusion to the root of the joint, but not necessarily beyond.

5.19.4 All-Weld-Metal Tension Tests. The mechanical properties shall conform to the values specified in Table 4.1 or 4.2, or as listed in contract documents.

5.19.5 Charpy V-Notch Tests. Charpy V-notch impact test results shall meet or exceed the values specified in Table 4.1 or 4.2, or unless otherwise specified in the contract documents. Acceptance shall be based on the following criteria:

5.19.5.1 SMAW, SAW, FCAW, GMAW Specimens. For SMAW, SAW, FCAW, or GMAW specimens, the highest and lowest Charpy V-notch test values shall be disregarded, and the remaining three values shall be averaged. For tests to be successful, the average of the three remaining Charpy V-notch test specimens energy values shall meet or exceed the minimum specified Charpy V-notch impact energy value. No more than one specimen may have an impact energy value less than the minimum specified and no specimen shall have a value less than 2/3 of the minimum specified value.

5.19.5.2 ESW and EGW Specimens. For ESW or EGW welded specimens, the highest and lowest values shall be disregarded and the remaining six values shall be averaged. For tests to be successful, the average of the remaining six Charpy V-notch test values shall meet or exceed the specified minimum Charpy V-notch energy value. No more than two specimens may have an impact energy value less than the minimum specified and no specimen shall have a value less than 2/3 of the minimum specified value.

5.19.6 Visual Inspection. For acceptable qualification, the welded test plate when inspected visually shall conform to the requirements for visual inspection in 9.21.1, except that undercut shall not exceed 1 mm.

5.20 Retests

5.20.1 Tension and Bend. If any one specimen of all those tested fails to meet the test requirements, two re-

tests for that particular type of test specimen may be performed with specimens cut from the same WPS qualification test plate or a new plate conforming to the same specification. The results of both test specimens must meet the test requirements. For material over 38 mm thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material.

5.20.2 Charpy V-Notch. When Charpy V-notch test results do not meet the requirements of 5.19.5, a retest may be made. The impact energy value of each of the required test specimens, after disregarding the highest and the lowest test values, shall equal or exceed the minimum specified Charpy V-notch energy average.

Part B **Welder, Welding Operator, and Tack Welder Qualification**

5.21 General Requirements

Welders, welding operators, and tack welders using SMAW, SAW, GMAW, FCAW, ESW, and EGW welding processes shall be qualified by the tests described in Part B.

5.21.1 Purpose. The qualification tests described in Part B are specially devised tests to determine the welder's, welding operator's, or tack welder's ability to produce sound welds.

The qualification tests are not intended to be used as a guide for welding during actual construction. Construction welding shall be performed in accordance with the requirements of the WPS.

5.21.2 WPS Compliance. The welder, or welding operator, shall follow a WPS applicable to the joint details given in 5.23.1.2, 5.23.1.3, 5.23.1.4, or 5.23.1.5, whichever is applicable.

5.21.3 Base Metal. The base metal used shall be an AASHTO approved steel as described in 9.2.1 or the WPS. (See 5.24.1.1)

5.21.4 Period of Effectiveness. The welder's, welding operator's, or tack welder's qualification as specified in this code shall be considered as remaining in effect indefinitely unless (1) the welder, welding operator, or tack welder is not engaged in a given process of welding for which the welder, welding operator, or tack welder is qualified for a period exceeding six months, or unless (2) there is some specific reason to question a welder's, welding operator's or tack welder's ability. In case of (1),

the requalification test need be made only in the 10 mm thickness.

5.21.5 Weld Cleaning

5.21.5.1 Chipping and Brushing. Cleaning between weld passes shall be limited to hand chipping and hand-wire brushing. Power chippers or grinders shall not be used during the weld test.

5.21.5.2 Root and Fill Pass Cleaning. Root or intermediate weld bead contours shall not be modified by chipping, grinding, cutting, or other means before depositing subsequent weld passes.

5.21.5.3 Cleaning Position. Weld cleaning shall be done with the test weld in the same position as the welding position being qualified.

5.21.6 Responsibility

5.21.6.1 Contractor. Each contractor shall conduct tests or verify that the welders, welding operators, and tack welders are qualified as required by this code.

5.21.7 Records. Records of the test results shall be kept by the manufacturer or contractor and shall be available to those authorized to examine them.

5.21.8 Previous Code Editions. Welders, welding operators and tack welders qualified to previous editions of this code shall be considered qualified to this code. Qualification test records shall not be required to be converted to metric (SI) units of measure if the tests were performed to a previous edition of this code.

5.22 Production Welding Positions Qualified

5.22.1 Welder Qualification (Groove Welds). See Table 5.6.

5.22.1.1 1G (Flat). Qualification in the 1G (flat) position qualifies for flat position groove welding of plate and structural shapes, and flat and horizontal position fillet welding of plate and structural shapes.

5.22.1.2 2G (Horizontal). Qualification in the 2G (horizontal) position qualifies for flat and horizontal position groove welding of plate and structural shapes, and flat and horizontal position fillet welding of plate and structural shapes.

5.22.1.3 3G (Vertical). Qualification in the 3G (vertical) position qualifies for flat, horizontal, and vertical position groove welding of plate and structural shapes; and flat, horizontal, and vertical position fillet welding of plate and structural shapes.

Table 5.6
Welder Qualification—Type and Position
Limitations (see 5.22)

Qualification Test		Type of Weld and Position of Welding Qualified*	
		Plate	
Weld	Positions**	Groove	Fillet
Plate-groove	1G	F	F,H
	2G	F,H	F,H
	3G	F,H,V	F,H,V
	4G	F,OH	F,H,OH
	3G & 4G	All	All
Plate-fillet (Note 1)	1F	F	
	2F	F,H	
	3F	F,H,V	
	4F	F,H,OH	
	3F & 4F	All	
Plate-Plug (Note 2)	1F	F	
	3F	V	
	4F	OH	

Notes:

1. Not applicable for fillet welds between parts having a dihedral angle (Ψ) of 60° or less (see 5.23.1.4)
2. Applicable only to qualification of plug welds (See 5.23.1.5)

* Position of welding: F = flat, H = horizontal, V = vertical, OH = overhead

** See Figs. 5.4 and 5.5

5.22.1.4 4G (Overhead). Qualification in the 4G (overhead) position qualifies for flat and overhead position groove welding of plate and structural shapes and flat, horizontal, and overhead position fillet welding of plate and structural shapes.

5.22.2 Welder Qualification (Fillet Welds)

5.22.2.1 1F (Flat). Qualification in the 1F (flat) position qualifies for flat position fillet welding of plate and structural shapes.

5.22.2.2 2F (Horizontal). Qualification in the 2F (horizontal) position qualifies for flat and horizontal position fillet welding of plate and structural shapes.

5.22.2.3 3F (Vertical). Qualification in the 3F (vertical) position qualifies for flat, horizontal, and vertical position fillet welding of plate and structural shapes.

5.22.2.4 4F (Overhead). Qualification in the 4F (overhead) position qualifies for flat, horizontal, and overhead position fillet welding of plate and structural shapes.

5.22.3 Welding Operator Qualification. Welding operators shall qualify for each position of production welding.

5.22.4 Tack Welder Qualification. A tack welder who passes the fillet weld break test shall be eligible to tack weld all types of groove joints and fillets using the process and the welding position tested.

5.23 Qualification Tests Required

5.23.1 Welder Qualification. The welder qualification test for manual and semiautomatic welding shall be as follows:

- (1) Groove weld qualification tests for plate of unlimited thickness in accordance with 5.23.1.2
- (2) Groove weld qualification tests for plate of limited thickness in accordance with 5.23.1.3
- (3) Fillet weld qualification tests (for fillet welding only) in accordance with 5.23.1.4
- (4) Plug weld qualification tests (for plug welds only) in accordance with 5.23.1.5

5.23.1.1 WPS Qualification. A welder may also be qualified by welding a satisfactory WPS qualification test plate, as specified in 5.12 or 5.13, that meets the requirements of 5.19. That welder is thereby qualified to weld plate with the process and in the test position used for WPS qualification. That welder is also qualified for slot welding for the process and position tested. The thickness range qualified for is specified in Table 5.7.

5.23.1.2 Groove Weld Qualification Test for Plate of Unlimited Thickness. The joint details shall be as follows: 25 mm plate, single-V-groove, 45 degree included angle, 6 mm root opening with backing (see Figure 5.17). For horizontal position qualification, the joint detail may, at the contractor's option, be as follows: single-bevel-groove, 45 degree groove angle, 6 mm root opening with backing (see Figure 5.18). If radiographic testing is used, backing shall be 6 mm min to 10 mm by 75 mm. For mechanical testing, backing may be 6 mm to 10 mm by 25 mm min. The minimum length of the welded groove shall be 125 mm.

5.23.1.3 Groove Weld Qualification Test for Plate of Limited Thickness. The groove detail shall be as follows: 10 mm plate, single-V-groove, 45 degree included angle 6 mm root opening with backing (see Figure 5.19). For horizontal position qualification, the joint detail may, at the contractor's option, be as follows: single-bevel-groove 45 degree groove angle, 6 mm root opening with backing (see Figure 5.20). Backing shall be 6 mm min to 10 mm max by 75 mm min, if radiographic testing is used. For mechanical testing after the backing is re-

moved, it shall be 6 mm min to 10 mm max by 25 mm. The minimum length of welding groove shall be 180 mm.

5.23.1.4 Qualification Tests for Fillet Welds Only. Requirements for fillet weld qualification only, on plate and rolled structural shapes, are as follows:

(1) For fillet welds between parts having a dihedral angle (Ψ) of less than 60°, the welder shall weld a groove weld test plate as required by 5.23.1.2 or 5.23.1.3. This qualification shall also be valid for joints having a dihedral angle (Ψ) of 60 degrees and greater.

(2) For joints having a dihedral angle (Ψ) of 60 degrees or greater, but not exceeding 135 degrees, the welder shall weld a test plate according to Option 1 or Option 2, depending upon the contractor's choice, as follows:

(a) Option 1: Weld a T-test plate in accordance with Figure 5.21.

(b) Option 2: Weld a soundness test plate in accordance with Figure 5.22.

5.23.1.5 Plug Weld Qualification Tests for Plug Welds Only. The joint shall consist of a 20 mm diameter hole in a 10 mm plate with a 10 mm minimum thickness backing plate. (See Figure 5.23.)

5.23.2 Welding Operator Qualification

5.23.2.1 Joint Requirements for Processes Other Than ESW or EGW. The welding operator qualification test for other than plug welds and ESW or EGW welding shall have a joint detail as follows: 25 mm plate, single-V-groove, 20 degrees included groove angle, 16 mm root opening with backing. Backing shall be 10 mm to 12 mm by 75 mm min if radiography is used without removal of backing. If backing is to be removed, at least 40 mm width of backing is required. The minimum length of welding groove shall be 400 mm (see Figure 5.24).

This test will qualify the welding operator for groove and fillet welding in materials of unlimited thickness for the process and position tested.

Alternatively, the welding operator may be qualified by radiography of the initial 400 mm of a production groove weld. The material thickness range qualified shall be that shown in Table 5.7.

5.23.2.2 Joint Requirements for ESW or EGW. The qualification test for an ESW or EGW welding operator shall consist of welding a joint of the maximum thickness of material to be used in construction, but the thickness of the material of the test weld need not exceed 38 mm (see Figure 5.25). If a 38 mm thick test weld is made, no test need be made for lesser thicknesses. This test shall qualify the welding operator for groove and fil-

Table 5.7
Number and Type of Specimens and Range of Thickness Qualified—
Welder and Welding Operator Qualification (see 5.25.1)

1. Test on Plate

Type of Weld	Thickness of Test Plate (T) as Welded, mm	Visual Inspection	Number of Specimens					Plate Thickness Qualified, mm
			Bend Tests*			T-Joint Break	Macro-Etch Test	
			Face	Root	Side			
Groove**	10	Yes	1	1	—	—	—	20 max ^{1,3}
Groove	10 <T <25	Yes	—	—	2	—	—	2T ^{3,4} max
Groove	25 or over	Yes	—	—	2	—	—	Unlimited ³
Fillet Option No. 1 ¹	12	Yes	—	—	—	1	1	Unlimited
Fillet Option No. 2 ²	10	Yes	—	2	—	—	—	Unlimited
Plug	10	Yes	—	—	—	—	2	Unlimited

Notes:

1. See Figure 5.21

2. See Figure 5.22

3. Also qualifies for fillet welding on material of unlimited thickness.

4. T max for welding operator qualification.

*Radiographic examination of the welder or welding operator test plate may be made in lieu of the bend test. Not permitted for GMAW-S.

**Not applicable for welding operator qualification.

2. Tests on Electroslag and Electrode Gas Welding

Plate Thickness Tested, mm	Test Specimens Required			Plate Thickness Qualified, mm
	Number of Sample Welds	Visual Inspection	Side Bend ⁵ (see Figure 5.23)	
38 max	1	Yes	2	Unlimited for 38 Max tested for <38

5. Radiographic examination of test plate may be made in lieu of the bend test.

let welds in material of unlimited thickness for this process and test position.

5.23.2.3 WPS Qualification. The welding operator who makes a complete joint penetration groove weld WPS qualification test that meets the requirements of this code is thereby qualified to weld by that process in the positions qualified by the test position. The maximum thickness qualified is based upon test plate thickness as listed in Table 5.7. The welding operator is also qualified for fillet welding and slot welding of plate and shapes for the process and position tested.

5.23.2.4 Qualification Tests for Fillet Welds Only. Requirements for fillet weld qualification only, on plate and rolled structural shapes, are as follows:

(1) For fillet welds between parts having a dihedral angle (Ψ) of 60 degrees or less, the welding operator shall weld a groove weld test plate as required by 5.23.2.

This qualification shall also be valid for joints having a dihedral angle (Ψ) of 60 degrees and greater.

(2) For joints having a dihedral angle (Ψ) greater than 60 degrees, but not exceeding 135 degrees, the welding operator shall weld a test plate in accordance with Option 1 or Option 2, depending upon the contractor's choice, as follows:

(a) Option 1. Weld a T-test plate in accordance with Figure 5.26.

(b) Option 2. Weld a soundness test plate in accordance with Figure 5.27.

5.23.3 Tack Welder Qualification. A tack welder shall be qualified by one fillet weld break specimen made in each position in which tack welds are to be made. The tack welder shall make a 6 mm maximum size tack weld approximately 50 mm long on the fillet weld break specimen, as shown in Figure 5.28.

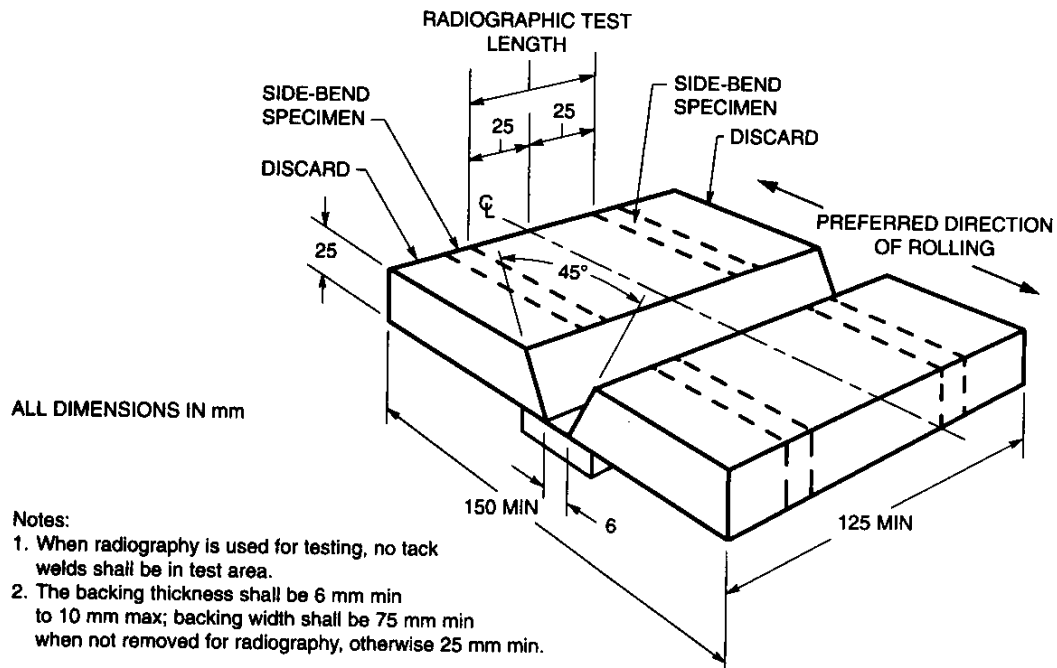


Figure 5.17—Test Plate for Unlimited Thickness—Welder Qualification (see 5.23.1.2)

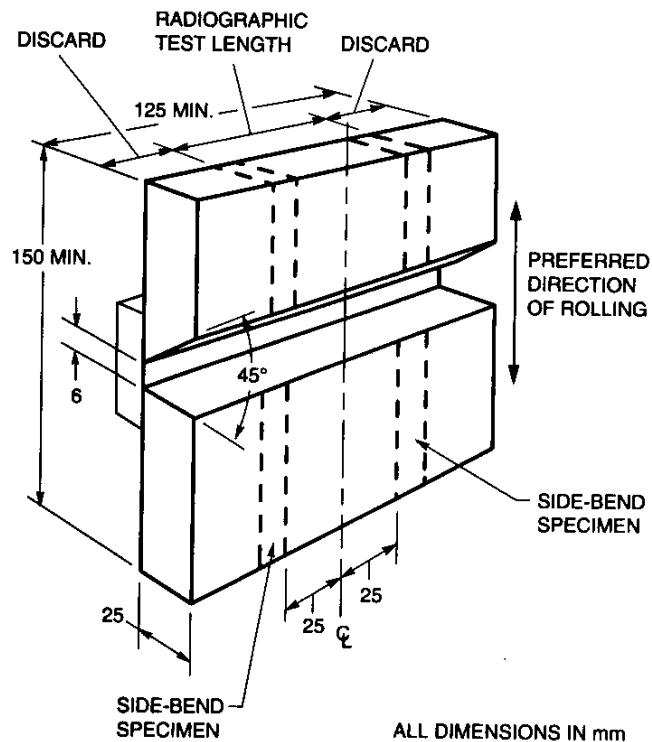


Figure 5.18—Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification (see 5.23.1.2)

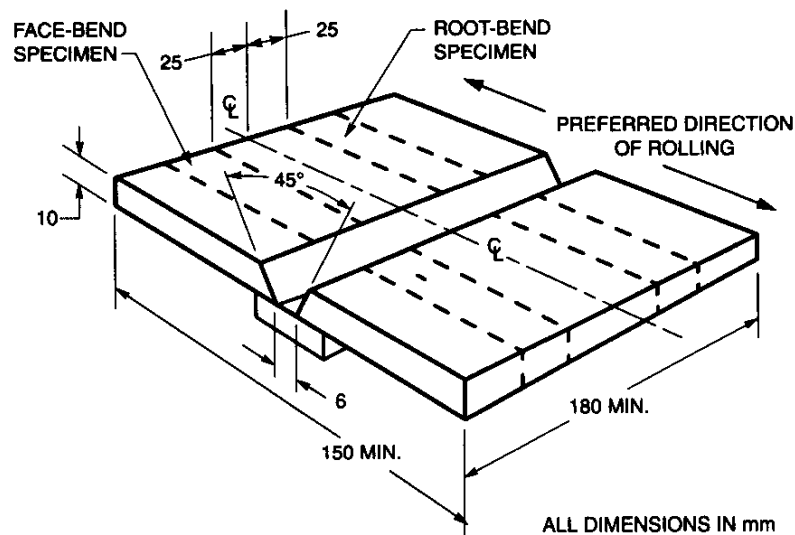
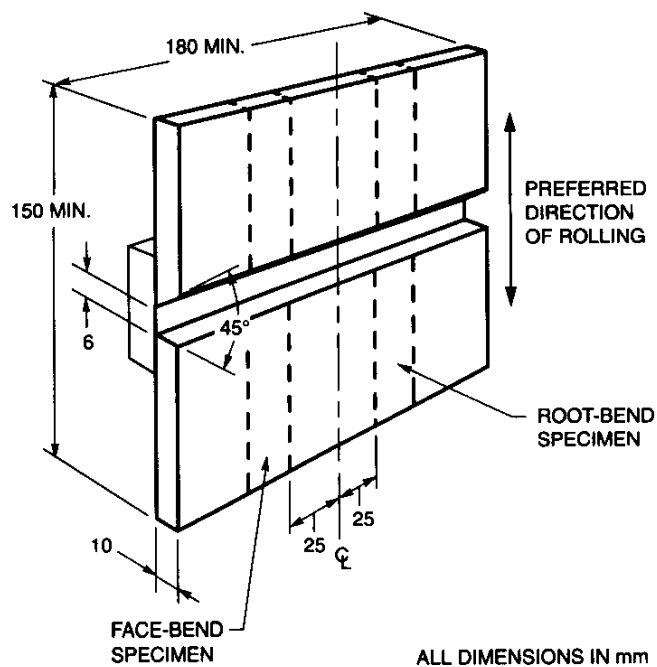


Figure 5.19—Test Plate for Limited Thickness—All Positions—Welder Qualification (see 5.23.1.3)



Notes:

1. When radiography is used for testing, no tack welds shall be in test area. Weld backing shall not be removed.
2. Then backing bar thickness shall be between 6 mm min and 10 mm max; backing bar width shall be 75 mm max for radiography and 25 mm min for mechanical testing.

Figure 5.20—Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification (see 5.23.1.3)



5.24 Limitation of Variables

combination shall be considered qualified to weld or tack weld with any other approved electrode and shielding medium combination for the process used in the qualification test.

5.24.1.1 Base Metal. Qualification established with any one of the steels permitted by this code shall be considered as qualification to weld or tack weld any of the other steels with the following exception:

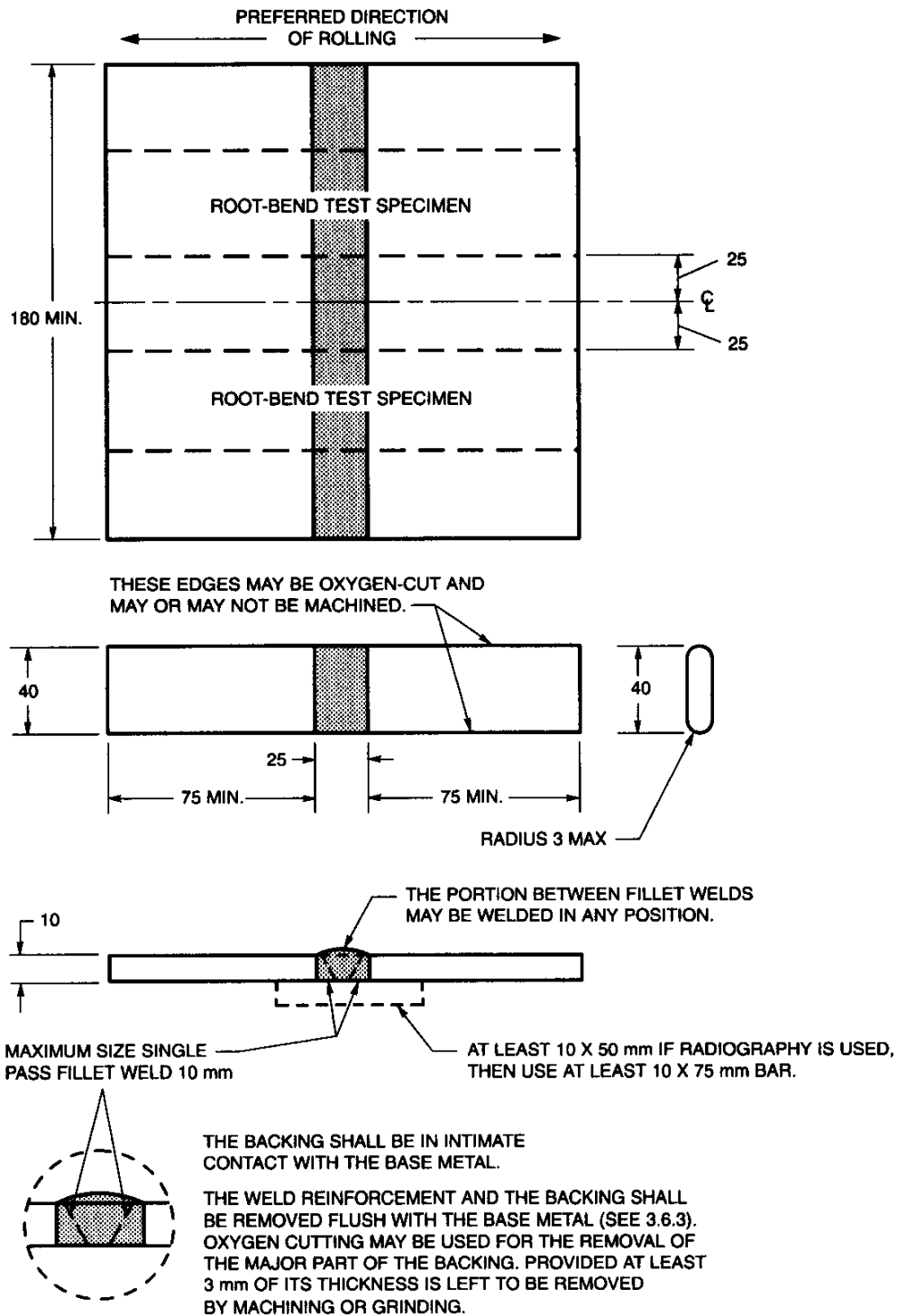
Qualification to weld or tack weld steel with a minimum yield strength of 620 MPa or greater shall be established with steel meeting the same specification as steel for the project.

5.24.1.2 Process. A welder, welding operator, or tack welder shall be qualified for each process used.

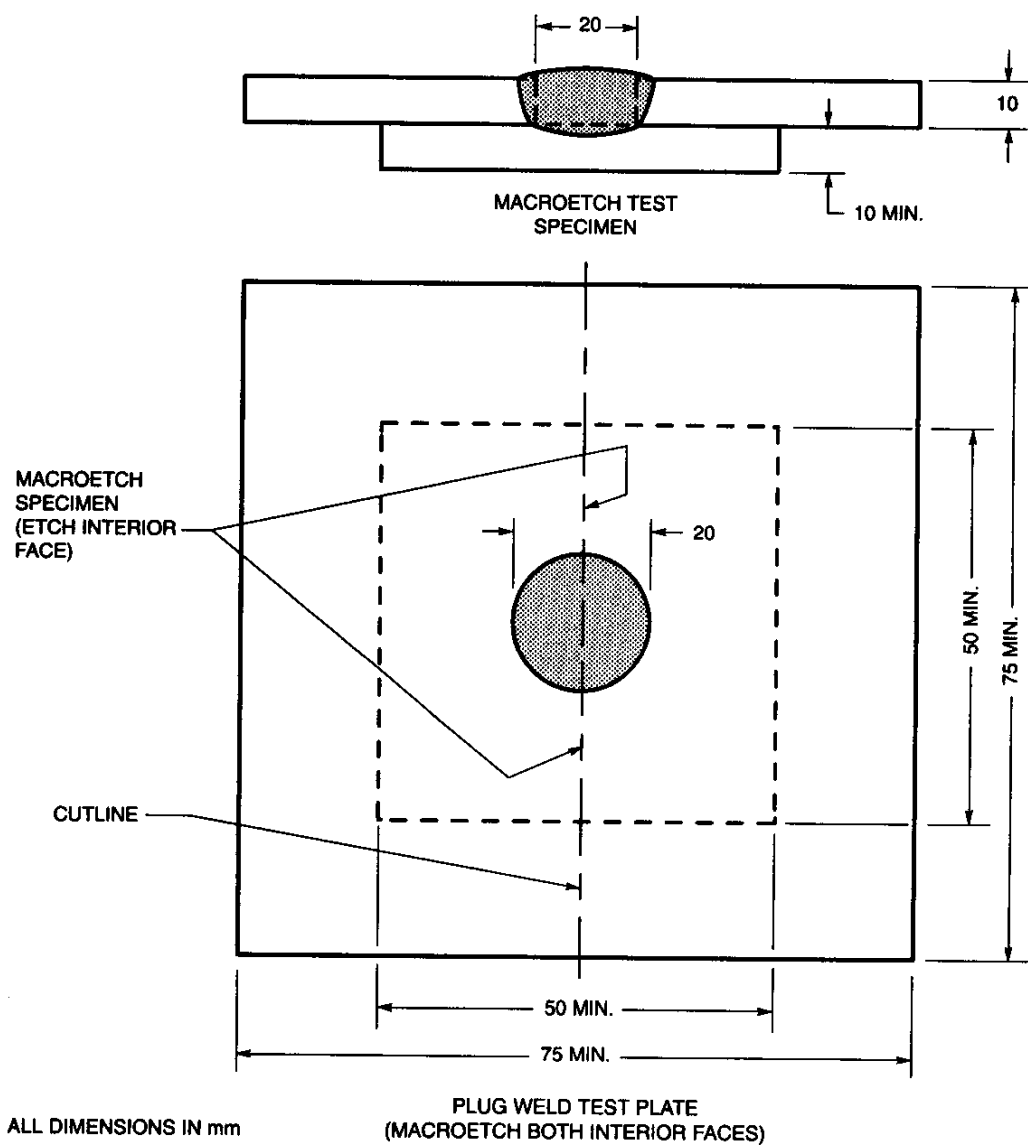
5.24.1.3 Approved Electrode and Shielding Medium. A welder, welding operator, or tack welder qualified with an approved electrode and shielding medium

5.24.2.1 SMAW Restrictions. A welder qualified for SMAW using EXX18 electrodes shall be qualified to weld with all SMAW electrodes permitted under this code, except welders required to use an electrode classification of E100XX-X or higher to join metals with a minimum specified yield strength of 620 MPa or greater shall be tested using E10018-X or E11018-X electrodes as necessary to match the yield strength of the base metal to be used in the work.

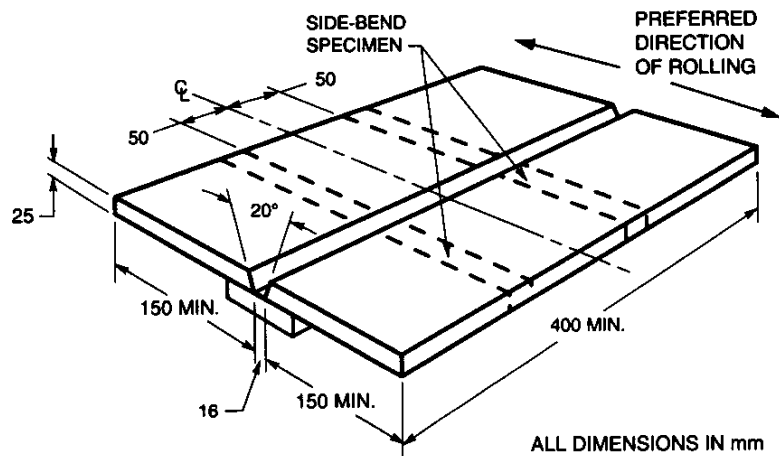
5.24.2.2 Position. A change in the position of welding to one for which the welder is not already qualified shall require requalification. When the plate is in the vertical position, change in the direction of welding shall require requalification. See Table 5.6.



**Figure 5.22—Fillet Weld Root-Bend Test Plate—Welder Qualification—
Option 2 (see 5.23.1.4)**



**Figure 5.23—Plug Weld Macroetch Test Plate—
Welder Qualification (see 5.23.1.5)**



Notes:

1. When radiography is used for testing, no tack welds shall be in test area.
2. The joint configuration of a qualified groove weld procedure may be used in lieu of the groove configuration shown here.
3. The backing bar thickness shall be 10 mm min to 12 mm max; backing bar width shall be 75 mm min when not removed for radiography, otherwise 40 mm.

**Figure 5.24—Test Plate for Unlimited Thickness—
Welding Operator Qualification (see 5.23.2.1)**

5.24.2.3 Backing. Omission of backing material (if the welder was qualified using backing) in complete joint penetration welds welded from one side shall require requalification.

5.24.3 Welding Operator Qualification Variables Only. The following requirements shall only apply to welding operator qualification.

5.24.3.1 ESW/EGW. An ESW or EGW welding operator qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with any other approved electrode and shielding medium combination for the process used in the qualification test.

5.24.3.2 Processes Other than ESW/EGW. For other than ESW or EGW welding, a welding operator qualified to weld with multiple electrodes shall be qualified to weld with a single electrode, but not vice versa.

5.24.3.3 Position. A change in the position in which welding of plate is done shall require requalification.

5.24.3.4 Semiautomatic Welder Qualification. Welders qualified for SAW shall be considered qualified for single-electrode machine welding in the same process(es) subject to the limitations of 5.24, provided the

welding operators receive training and demonstrate their ability to make satisfactory production welds.

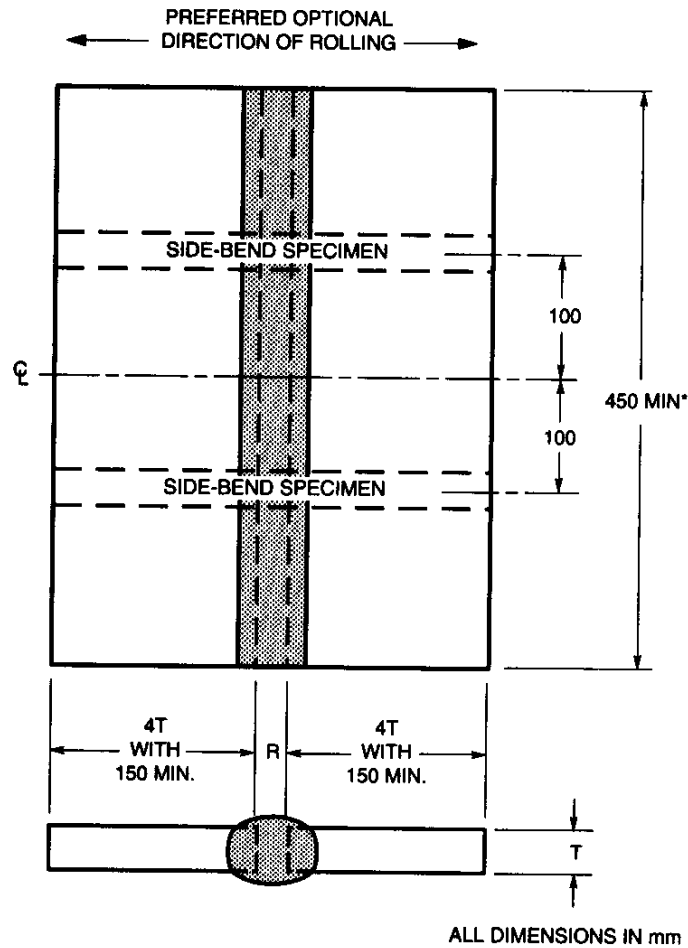
5.24.4 Tack Welder Qualification Variables Only. The following requirements shall apply only to tack welder qualification.

5.24.4.1 SMAW Restrictions. A tack welder qualified for SMAW using EXX18 electrodes shall be qualified to tack weld with all SMAW electrodes permitted under this code. Tack welding shall be performed using E7018 electrodes, unless the contract documents require tack welding with electrodes classified E10018-X, E11018-X, or E12018-X. Tack welders shall be qualified for the particular electrode used.

5.24.4.2 Position. A change in the position in which tack welding is done shall require requalification.

5.25 Test Specimens: Number, Type, and Preparation

5.25.1 Welder Requirements. The type and number of test specimens that shall be tested to qualify a welder by mechanical testing are shown in Table 5.7, together with



Notes:

1. Root opening "R" established by procedure specification.
 2. T = maximum to be welded in construction but need not exceed 38 mm.
- *Extensions need not be used in joint is of sufficient length to provide 450 mm of sound weld.

**Figure 5.25—Butt Joint for Welding Operator Qualification—
Electroslag and Electro gas Welding (see 5.23.2.2)**



the range of thickness that is qualified for use in construction by the thickness of the test plate used in making the qualification. Radiographic testing of the test weld may be used, at the contractor's option in lieu of mechanical testing. Radiographic testing is not an option for GMAW-S. Weld backing shall not be removed from welds subject to radiographic test.

5.25.2 Welding Operator Requirements. For mechanical testing, guided bend test specimens shall be prepared by cutting the test plate as shown in Figure 5.24, 5.25, or 5.27, whichever is applicable, to form specimens approximately rectangular in cross section. The specimens shall be prepared for testing in accordance with Figure 5.11 or 5.12, as applicable.

5.25.3 Tack Welder Requirements. One test specimen shall be welded as shown in Figure 5.28 with the entire welded assembly as the test specimen.

5.26 Method of Testing Specimens

5.26.1 Radiographic Testing. Except for joints welded by GMAW-S [short-circuiting], radiographic examination of welder and welding operator qualification test plates may be made in lieu of guided bend tests described in Parts B of this section. See 4.14.4 for clarification of short-circuiting transfer.

5.26.1.1 Weld Reinforcement. If radiographic testing is used in lieu of the prescribed bend test, the weld reinforcement shall be ground flush or finished with slight reinforcement so that there are no lines or surface irregularities that may obscure discontinuities in the radiograph. Weld backing shall not be removed from welds subject to radiographic test.

5.26.1.2 RT Procedure for Welder Qualification. The radiographic procedure and technique shall be in accordance with the requirements of section 6, Part B.

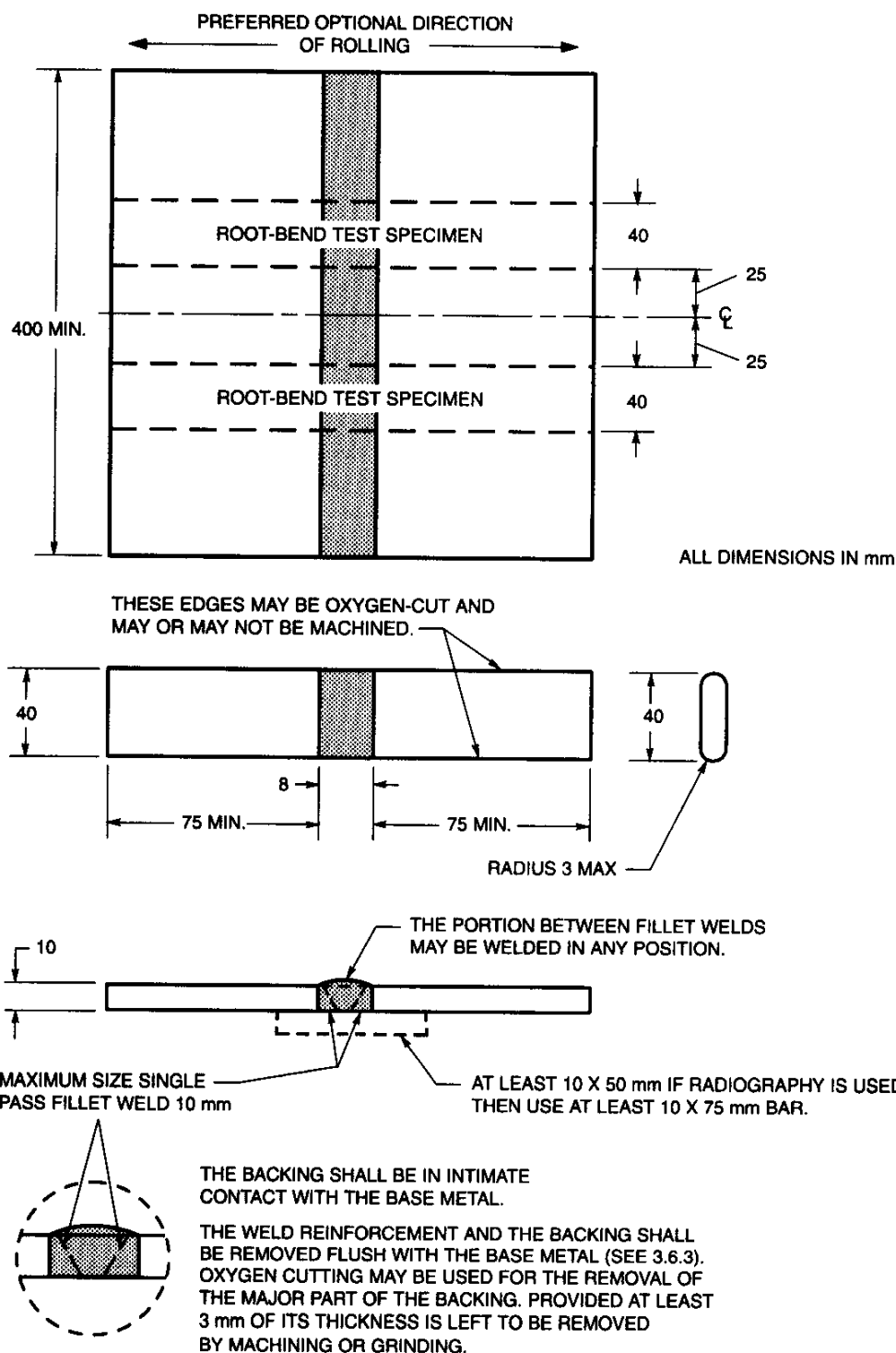
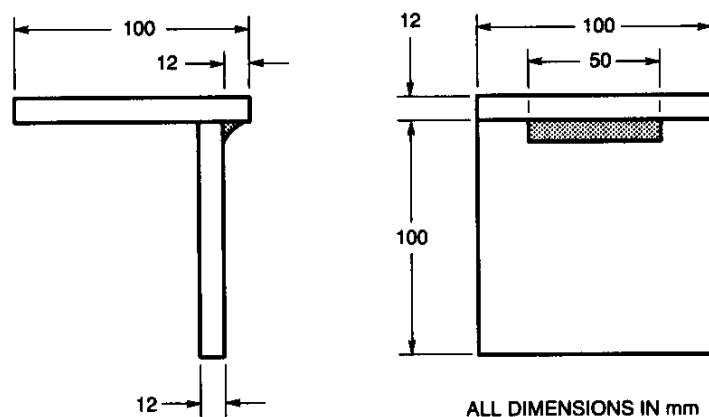


Figure 5.27—Fillet Weld Root Bend Test Plate—Welding Operator Qualification—Option 2 (see 5.23.2.4)



**Figure 5.28—Fillet-Weld-Break Specimen—
Tack Welder Qualification (see 5.25.3)**

Exclude 30 mm at each end of the weld from evaluation in the plate test.

5.26.1.3 RT Procedure for Welding Operator Qualification. The radiographic procedure and technique shall be in accordance with the requirements of section 6, Part B. At each end of the length of the test plate, 75 mm shall be excluded from evaluation.

5.26.2 Guided Bend Test for Welder Qualification. Guided bend test specimens shall be prepared by cutting the test plate as shown in Figures 5.17, 5.18, 5.19, 5.20, whichever are applicable, to form specimens approximately rectangular in cross section. The specimens shall be prepared for testing in accordance with Figures 5.11 or 5.12, as applicable.

5.26.2.1 Root, Face, and Side Bend Specimens. See 5.18.3 for specimen requirements.

5.26.3 Fillet Weld Break and Macroetch Test Requirements

5.26.3.1 Welder Qualification. The fillet weld break and macroetch test specimens shall be cut from the test joint, as shown in Figure 5.21. The end of the macroetch test specimen shall be smooth for etching. The entire length of the fillet weld shall be examined visually and then the 150 mm specimen shall be loaded in such a way that the root of the weld is in tension. The load shall be steadily increased or repeated until the specimen fractures or bends flat upon itself.

5.26.3.2 Welding Operator Qualification. The fillet weld break and macroetch test specimens shall be cut from the test joint as shown in Figure 5.26. The end of the macroetch test specimen shall be smooth for etching.

The entire length of the fillet weld shall be examined visually and then a 150 mm long specimen shall be loaded in such a way that the root of the weld is in tension. The load shall be steadily increased or repeated until the specimen fractures or bends flat upon itself.

5.26.3.3 Tack Welder Qualification. A force shall be applied to the specimen as shown in Figure 5.29, until rupture occurs. The force may be applied by any convenient means. The surface of the weld and of the fracture shall be examined visually for defects.

5.26.3.4 Macroetch Test. The test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used to give a clear definition of the weld.

5.27 Test Results Required

5.27.1 Visual Inspection of Welder and Welding Operator Test Plates. For acceptable qualification, the welded test plates, when inspected visually, shall conform to the requirements for visual inspection in 9.21.1, except that undercut shall not exceed 1 mm.

5.27.2 Radiographic Test. For acceptable qualification, the weld, as revealed by the radiograph, shall conform to the requirements of 9.21.2, except that 9.21.2.2 shall not apply.

5.27.3 Root or Side Bend Tests. The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

- (1) 3 mm measured in any direction on the surface

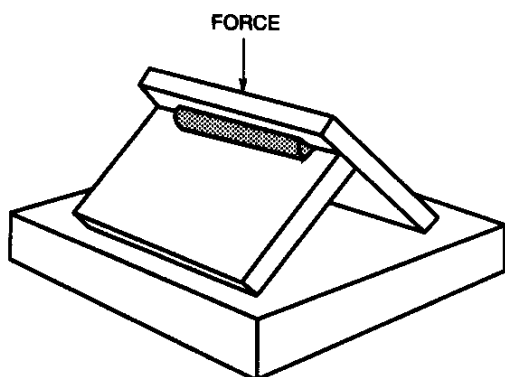


Figure 5.29—Method of Rupturing Specimen—Tack Welder Qualification (see 5.26.3.3)

(2) 10 mm for the sum of the greatest dimensions of all discontinuities exceeding 1 mm, but less than or equal to 3 mm

(3) 6 mm — the maximum corner crack, except when that corner crack resulted from visible slag inclusion or other fusion-type discontinuities, then the 3 mm maximum shall apply

Specimens with corner cracks exceeding 6 mm with no evidence of slag inclusions or other fusion-type discontinuities may be disregarded, and a replacement test specimen from the original weldment shall be tested.

5.27.4 Fillet Weld Break Test (Welder and Welding Operator)

5.27.4.1 Visual Examination. To pass the visual examination, the fillet weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and excessive undercut. There shall be no porosity visible on the surface of the weld.

5.27.4.2 Fracture Surface. The specimen shall pass the test if it bends flat upon itself. If the fillet weld fractures, the fractured surface shall show complete fusion into the root of the joint and shall exhibit no inclusion or porosity larger than 2 mm in the greatest dimension. The sum of the greatest dimensions of all inclusions and porosity shall not exceed 10 mm in the 150 mm specimen.

5.27.5 Fillet Weld Break Test (Tack Welder)

5.27.5.1 Visual Examination. The tack weld shall present a uniform appearance and shall be free of overlap, cracks, and excessive undercut exceeding 1 mm. There shall be no porosity visible on the surface of the tack weld.

5.27.5.2 Fracture Surface. The fracture surface of the tack weld shall show fusion to the root but not necessarily beyond and shall exhibit no incomplete fusion to the base metal nor any inclusion or porosity larger than 2 mm in greatest dimension.

5.27.6 Macroetch Test. For acceptable qualification, the test specimen, when inspected visually, shall conform to the following requirements:

5.27.6.1 Fillet Welds. Fillet welds shall have the following:

- (1) No cracks
- (2) Thorough fusion between adjacent layers of weld metals and between weld metal and base metal
- (3) Weld profiles conforming to intended detail, but with none of the variations prohibited in 3.6
- (4) No undercut exceeding 1 mm.
- (5) Fusion to the root of the joint but not necessarily beyond.
- (6) Leg sizes equal to or greater than the specified leg size.

5.27.6.2 Plug Welds. Plug welds shall have the following:

- (1) No cracks
- (2) Thorough fusion to backing plate and to sides of the hole
- (3) No visible slag in excess of 6 mm total accumulated length

5.28 Retests

5.28.1 Welder and Welding Operator. If a welder or welding operator fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions.

5.28.1.1 Immediate Retest. An immediate retest may be made consisting of two test welds of each type and position that the welder or welding operator failed. All retest specimens shall meet all the specified requirements.

5.28.1.2 Retest After Further Training or Practice. A retest may be made provided there is evidence that the welder or welding operator has had further training or practice. A complete retest of the types and positions failed shall be made.

5.28.2 Tack Welder. In case of failure to pass the fillet weld break test, the tack welder may make one retest without additional training.

6. Inspection

Part A **General Requirements**

6.1 General

6.1.1 For the purpose of this code, quality control inspection and testing and quality assurance inspection and testing are separate functions.

6.1.1.1 Quality control (QC) is the responsibility of the contractor. As a minimum, the contractor shall perform inspection and testing prior to assembly, during assembly, during welding and after welding as specified in this section and additionally as necessary to assure that materials and workmanship conform to the requirements of the contract documents.

6.1.1.2 Quality assurance (QA) is the prerogative of the Engineer. The Engineer should perform inspection and testing necessary to verify that an acceptable product is being furnished as specified in the contract documents. QA inspection and testing should be performed and reported in a manner that will minimize interference with production.

6.1.2 Inspector—Definition

6.1.2.1 The Quality Control (QC) Inspector is the duly designated person who acts for and in behalf of the contractor on inspection, testing, and quality matters within the scope of the contract documents.

6.1.2.2 The Quality Assurance (QA) Inspector is the duly designated person who acts for and on behalf of the Engineer and owner on all matters within the scope of the contract documents and the limit of authority delegated by the Engineer.

6.1.2.3 When the term *Inspector* is used without further qualification, it applies equally to QC and QA as defined in 6.1.2.1 and 6.1.2.2.

6.1.3 Inspection Personnel Qualification

6.1.3.1 All Inspectors responsible for QC and QA acceptance or rejection of materials and workmanship shall be qualified as follows:

(1) The Inspector shall be an AWS Certified Welding Inspector (CWI) qualified and certified in accordance with the provisions of AWS QC1, *Standard for Qualification and Certification of Welding Inspectors*.

(2) The Inspector shall be qualified by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) standard W178.2, *Certification of Welding Inspectors*.

Note: Welding inspectors qualified by the Canadian Welding Bureau (to the Level II or the Level III requirements of the Canadian Standards Association standard W178.2, Certification of Welding Inspectors), are acknowledged by AWS as being qualified under the provisions of AWS QC1. It is the policy of the Structural Welding Committee to recognize welding inspector certification programs that are substantially the same as offered by AWS and CWB. Such programs, public or private, must be competently administered, be reasonably specified, and be open to the public. When so constituted, such certification programs will be considered equivalent to AWS and CWB programs.

(3) The Inspector shall be an engineer or technician who, by training and experience in metals fabrication, inspection and testing, is acceptable to the Engineer as an equivalent to (1) or (2).

6.1.3.2 An Inspector, previously certified as a welding inspector under the provisions of AWS QC1 or CSA standard W178.2, Level II or III, may serve as an Inspector for this work, provided there is acceptable documentation that the Inspector has remained active as an Inspector of welded structural steel fabrication since last being certified and there is no reason to question the inspector's ability.

6.1.3.3 The Inspector may be supported by assistant inspectors who may perform specific inspection functions under the supervision of the Inspector. Assistant inspectors shall be qualified by training and experience to perform the specific functions to which they are assigned. The work of assistant inspectors shall be regularly monitored, generally on a daily basis, by the Inspector.

6.1.3.4 Personnel Qualification. Personnel performing nondestructive testing shall be qualified in accordance with the American Society for Nondestructive Testing's (ASNT) *Recommended Practice No. SNT-TC-1A*, or equivalent. Certification of Level I and Level II individuals shall be performed by a Level III individual who has been certified by (1) ASNT, or (2) has the education, training, experience, and has successfully passed the written examination prescribed in *ASNT SNT-TC-1A*. Only individuals qualified for NDT Level II or individuals qualified for NDT Level I and working under the direct supervision of an individual qualified for NDT Level II may perform nondestructive testing.

6.1.3.5 The Engineer shall have the authority to verify the qualifications of Quality Control Inspectors and NDT personnel to specified levels by retests or other means.

6.1.3.6 Personnel performing nondestructive tests under the provisions of 6.1.3.4 need not be qualified under the provisions of 6.1.3.1 but shall have adequate vision as required by 6.1.3.7.

6.1.3.7 Inspectors, assistant inspectors and personnel performing nondestructive testing shall have passed an eye examination, with or without corrective lenses, to prove (1) near vision acuity of Snellen English, or equivalent, at 300 mm, and (2) far vision acuity of 20/40 or better. Vision tests are required every three years, or less if necessary, to demonstrate adequacy.

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

6.1.5 The Inspector shall be notified in advance of the start of fabrication/erection operations subject to inspection and verification.

6.2 Inspection of Materials

The Inspector shall make certain that only materials conforming to the requirements of the contract documents are used.

6.3 Inspection of WPS Qualification and Equipment

6.3.1 The Inspector shall make certain that all welding procedures are qualified in accordance with section 5 of this code. The Inspector shall make certain that each welding procedure is covered by a written WPS and that such WPSs are available to the welders and inspectors for reference.

6.3.2 The Inspector shall inspect the welding and cutting equipment to be used in the work to verify that it conforms to the requirements of 3.1.2.

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

6.4.1 The Inspector shall permit welding to be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements of section 5, and shall verify that their qualifications authorize them to use the welding procedures specified for the work, or shall make certain that each welder, welding operator, or tack welder has previously demonstrated such qualification under supervision acceptable to the Engineer.

6.4.2 When the quality of work by a welder, welding operator, or tack welder appears to be below the requirements of this code, the Inspector may require that the welder, welding operator, or tack welder demonstrate an ability to produce sound welds by means of a simple test, such as the fillet weld break test, or by requiring complete requalification in accordance with section 5.

6.4.3 The Inspector shall require requalification of any welder, welding operator, or tack welder whose qualification is not current by the requirements of this code.

6.4.4 When qualifying welders, welding operators, and tack welders, the Inspector shall observe the qualification tests.

6.5 Inspection of Work and Records

6.5.1 The Inspector shall make certain that the size, length, and location of all welds conform to the requirements of this code and to the detail drawings and that no unspecified welds have been added without approval.

6.5.2 The Inspector shall make certain only WPSs are employed which meet the provisions of section 5.

6.5.3 The Inspector shall make certain that electrodes are used only in the positions and with the type of welding current and polarity for which they are classified.

6.5.4 The Inspector shall, at suitable intervals, observe the joint preparation, assembly practice, welding techniques, and performance of each welder, welding operator, and tack welder to make certain that applicable requirements of this code are met. The Inspector shall examine the work to make certain that it meets the requirements of section 3 and 9.21. The size and contour of welds shall be measured using suitable gages. Visual inspection for cracks in welds and base metal, and for other discontinuities should be aided by strong light magnifiers, or such other devices as may be helpful. Acceptance criteria different from those specified in this code may be used when approved by the Engineer.

6.5.5 The Inspector shall identify with a distinguishing mark or adequate document control as approved by the Engineer all parts or joints that the Inspector has inspected and approved.

6.5.6 The Inspector shall keep a record of qualifications of all welders, welding operators, and tack welders; all WPS qualifications or other tests that are made; the control of welding materials and equipment; and such other information as may be required.

6.5.7 For nondestructive testing, the Inspector shall ascertain that equipment, procedures, and techniques are in accordance with 6.7. The QA Inspector may view the making of nondestructive tests, examine and evaluate the test results, approve satisfactory welds, or reject unsatisfactory welds, approve satisfactory methods proposed by the contractor for repairing unacceptable welds, and inspect the preparation and rewelding of unacceptable welds.

6.5.8 The Inspector shall record the locations of inspected areas and the findings of all nondestructive tests, together with detailed descriptions of all repairs made.

6.6 Obligations of the Contractor

6.6.1 The contractor shall allow access to the project fabrication facility by QA personnel. The contractor shall cooperate with QA personnel and provide ready access to QC inspection records.

6.6.2 The contractor shall be responsible for visual inspection and nondestructive testing specified in 6.7 and necessary correction of all deficiencies in materials and workmanship in accordance with the requirements of section 3 and 9.21 and as provided elsewhere in contract documents.

6.6.3 The contractor shall comply with all requests of the QA Inspector to correct deficiencies in materials and workmanship, as provided in the contract documents.

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

6.6.5 If nondestructive testing, not specified in the original contract agreement, is subsequently requested by the Engineer, the contractor shall perform any requested testing or shall permit any requested testing to be performed. Costs shall be negotiated by the owner and the contractor. Responsibility for the cost of extra work shall lie with the owner. However, if such testing should disclose an attempt to defraud or reveal gross nonconformance to this code, repair work shall be done at the contractor's expense.

6.6.6 The contractor shall schedule nondestructive testing to facilitate attendance by the QA Inspector. The QA Inspector shall be advised by the contractor of operational and nondestructive testing schedules and scheduled changes.

6.7 Nondestructive Testing

Nondestructive testing in addition to visual inspection shall be performed by the contractor to comply with this specification. Testing of base metals in accordance with 3.2; preparation of base metal; production welds; weld repairs; WPS qualification test weldments; and welder, welding operator, and tack welder qualification test weldments are included. Costs of this nondestructive testing shall be considered incidental to the structural steel fabrication or erection or both, and no separate payment will be made.

6.7.1 Complete joint penetration groove welds in main members shall be QC tested by nondestructive testing. Unless otherwise provided, radiographic testing shall be used for examination of complete joint penetration groove welds in butt joints subject to calculated tension or reversal of stress. All complete joint penetration groove welds in T- and corner joints shall be tested by ultrasonic testing. When required, testing of complete joint penetration groove welds in butt joints in compression or shear may be done by RT or UT.

6.7.1.1 Welds made by either the electroslag welding (ESW) or electrogas (EGW) processes shall be tested by both radiographic and ultrasonic testing.

6.7.1.2 Radiographic or ultrasonic testing of welds shall be performed in accordance with the following frequency requirements:

(1) One hundred percent of each joint subject to calculated tension or reversal of stress, except on welds in vertical butt joints in beams or girder webs, as follows:

(a) 1/6 of the web depth beginning at the point, or points, of maximum tension, and

(b) 25 percent of the remainder of the web depth need be tested.

(c) If unacceptable discontinuities are found in (a) or (b) above the remainder of the weld shall be tested.

(2) Twenty-five percent of each joint subject to compression or shear, or, at the Contractor's option, 25 percent of the total joints subject to compression or shear. When the latter is selected, the tested joints shall be distributed throughout the work and shall total at least 25 percent of the compression or shear weld length.

(a) If unacceptable discontinuities are found in spot testing, the entire length shall be tested.

(b) If unacceptable discontinuities are found in 20 percent or more of the compression or shear joints in a "lot," all compression and shear joints in that "lot" shall be tested for their full length.

(c) A lot is defined as those tension or compression/shear joints, or both, which were welded in accordance with the same approved WPS and non-destructively tested as a group.

(d) Unless otherwise specified in the contract documents, the above requirements do not apply to longitudinal butt joints in beam or girder webs. These welds shall be subject to the inspection criteria of 6.7.2.

(3) The requirements for radiographic and ultrasonic testing shall apply equally to shop and field welds.

6.7.2 Unless otherwise specified, fillet welds and partial penetration groove welds joining primary components of main members shall be QC tested by the magnetic-particle method in accordance with the following:

6.7.2.1 At least 300 mm shall be tested in every 3 m length including longitudinal welds in butt joints in beam or girder webs, and 300 mm of such welds less than 3 m in length of each size of weld and type of joint in main members including the end connections for such members. Typical welds which require testing are web to flange, diaphragm connection plates to web or flange; diaphragm sealing plate or gussets to web or flange in box members; cross frame and diaphragm welds on curved bridges, etc. If unacceptable discontinuities are found in any test length of weld, the full length of the weld, or 1.5 m on both sides of the test length, whichever is less, shall be tested.

6.7.2.2 For Grade 690/690W steels, all main member fillet and partial penetration groove welds shall be tested full-length by the magnetic-particle method.

6.7.2.3 Magnetic-particle inspection of fillet welds is not required for secondary members.

6.7.3 After repairs of defects have been made, additional NDT inspection shall be performed to ensure that the repairs are satisfactory. This testing shall include the repaired area plus at least 50 mm on each side of the repaired area.

6.7.4 Welds tested nondestructively that do not meet the requirements of this code shall be repaired by the methods permitted by 3.7.

6.7.5 When radiographic testing is used, the procedure and technique shall be in accordance with Part B of this section.

6.7.6 When magnetic-particle testing is used, the procedure and techniques shall be in accordance with the dry powder magnetic-particle examination of welds using the prod method or the yoke method.

6.7.6.1 The prod method shall be performed in accordance with ASTM E709, *Practices for Magnetic Particle Examination*, and the standards of acceptance shall be in accordance with 9.21 of this code.

(1) When the prod method is used to test steels with a minimum specified yield strength of 345 MPa or greater, aluminum prods shall be used on the test equipment. Copper prods shall not be used on such steels.

(2) Arcing shall be minimized by following the proper testing procedures.

6.7.6.2 The yoke method shall be performed in accordance with ASTM E709, and the standard of acceptance shall be in accordance with 9.21 of this code.

(1) Testing by the yoke method shall be performed using half-wave rectified direct current or alternating current.

(2) Electromagnetic yokes shall have lifting forces conforming to the following:

Current Type	Yoke Pole Leg Spacing (YPS)	
	$50 \leq \text{YPS} < 100 \text{ mm}$	$100 \leq \text{YPS} \leq 150 \text{ mm}$
AC	45 N	Not Applicable
DC	135 N	225 N

6.7.6.3 Prior to magnetic-particle testing, the surface shall be examined, and any adjacent area within at least 25 mm of the surface to be tested, shall be dry and free of contaminants such as oil, grease, loose rust, loose sand, loose scale, lint, thick paint, welding flux, and weld

spatter. Thin nonconductive coatings such as paint in the order of 25 to 50 μm that do not interfere with the formation of indications may remain, but they must be removed at all points where electrical contact is to be made.

Cleaning may be accomplished by detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, and ultrasonic cleaning methods.

6.7.6.4 The prod or poles shall be oriented in two directions approximately 90 degrees apart at each inspection point, to detect both longitudinal and transverse discontinuities. The prod or pole position shall overlap as testing progresses to ensure 100 percent inspection of the areas to be tested. Discontinuities are best detected when their axis is normal to the magnetic lines of force. Therefore, the prod technique is most sensitive to discontinuities whose major axis is parallel to a line drawn between the two prods, whereas the yoke technique is most sensitive to discontinuities whose major access is normal to a line drawn between the two poles.

6.7.6.5 A report of magnetic-particle examination shall be prepared and furnished to the Engineer.

(1) The report shall include the following minimum information:

- (a) Part identification
- (b) Examination procedure number (if applicable)
- (c) Date of examination
- (d) Technician's name, certification level, and signature
- (e) Name and signature of contractor's or owner's Inspectors, or both, who witnessed the examination
- (f) Examination results
- (g) Equipment make and model
- (h) Yoke or prod spacing used
- (i) Particles (manufacturer's name) and color

(2) One copy shall be furnished to the contractor for the owner.

6.7.7 For detecting discontinuities that are open to the surface, liquid penetrant inspection may be used. The standard methods set forth in ASTM E165 shall be used for liquid penetrant inspection, and the standards of acceptance shall be in accordance with 9.21 of this code.

Part B

Radiographic Testing of Groove Welds in Butt Joints

6.8 Extent of Testing

The provisions of 6.7 identify the minimum extent of radiographic testing.

6.9 General

6.9.1 The procedures and standards set forth in Part B govern radiographic testing of welds. The requirements listed herein are specifically for testing groove welds in butt joints in plate, shapes, and bars by x-ray or gamma ray sources. The methodology shall conform to ASTM E94, *Standard Recommended Practice for Radiographic Testing*; ASTM E142, *Standard Method for Controlling Quality of Radiographic Testing*; ASTM E747, *Controlling Quality of Radiographic Testing Using Wire Penetrators [Image Quality Indicators (IQIs)]*; and ASTM E1032, *Radiographic Examination of Weldments*.

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

- (1) Radiographic testing of fillet, T, and corner welds
- (2) Changes in source-to-film distance
- (3) Unusual application of film
- (4) Unusual Image Quality Indicator applications (including film side IQIs)
- (5) Radiographic testing of thicknesses greater than 150 mm
- (6) Film types, densities, and variations in exposure, development, and viewing techniques

6.10 Radiographic Procedure

6.10.1 Radiographs shall be made using a single source of either x- or gamma radiation. The radiographic sensitivity shall be judged based on hole-type IQI image or wire image quality indicators (IQI). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required IQIs and the essential holes or wire sizes as described in 6.10.7, Tables 6.1 and 6.1A, and Figures 6.1E and 6.1F. Identifying letters and numbers shall show clearly in the radiograph. For more detailed information see ASTM E747, *Standard Method for Controlling Quality of Radiographic Testing Using Wire Penetrators*.

6.10.2 Radiography shall be performed in accordance with all applicable safety requirements.

6.10.3 When the contract documents require the removal of weld reinforcement, the welds shall be prepared for radiography by grinding as described in 3.6.3. Other weld surfaces need not be ground or otherwise smoothed for purposes of radiographic testing unless surface irregularities or the junction between weld and base metal may cause unacceptable weld discontinuities to be obscured in the radiograph.

Table 6.1
Hole-Type Image Quality Indicator (IQI)
Requirements (see 6.10.7)

Nominal Material Thickness Range, mm	Source Side	
	Designation	Essential Hole
Up to 6 incl.	10	4T
Over 6 to 10	12	4T
Over 10 to 12	15	4T
Over 12 to 16	15	4T
Over 16 to 20	17	4T
Over 20 to 22	20	4T
Over 22 to 25	20	4T
Over 25 to 32	25	4T
Over 32 to 38	30	2T
Over 38 to 50	35	2T
Over 50 to 60	40	2T
Over 60 to 80	45	2T
Over 80 to 100	50	2T
Over 100 to 150	60	2T
Over 150 to 200	80	2T

Table 6.1A
Wire Image Quality Indicators (IQI)
Requirements (see 6.10.7)

Nominal Material Thickness Range, mm	Source Side Maximum Wire Diameter, mm
Up to 6 incl.	0.25
Over 6 to 10	0.33
Over 10 to 16	0.41
Over 16 to 20	0.51
Over 20 to 38	0.63
Over 38 to 50	0.81
Over 50 to 60	1.02
Over 60 to 100	1.27
Over 100 to 150	1.60
Over 150 to 200	2.54

6.10.3.1 Weld tabs (extension bars and run-off plates) shall be removed prior to radiographic inspection, unless otherwise approved by the Engineer.

6.10.3.2 When required by 3.13 or other provisions of the contract documents, steel backing shall be removed and the surface shall be finished flush by grinding prior to radiography. Grinding shall be as described in 3.6.3.

6.10.3.3 When weld reinforcement or backing, or both, are not removed and hole-type or wire IQI alternate placement is not used, steel shims which extend at least 3 mm beyond three sides of the required hole-type or wire IQI shall be placed under the IQI so that the total

thickness of steel between the IQI and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

6.10.4 Radiographic film shall be Type 1 or Type 2 as described in ASTM E94. Lead foil screens shall be used as described in ASTM E94. Fluorescent screens shall not be permitted.

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

6.10.5.1 Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of ASME *Boiler and Pressure Vessel Code*, Section V, Article 2.

6.10.5.2 The source-to-subject distance shall not be less than the total length of film being exposed in a single plane. This provision does not apply to panoramic exposures made under the provisions of 6.9.

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

6.10.6 X-ray units, 600 kV potential maximum, and Iridium 192 may be used as a source for all radiographic inspection, provided they have adequate penetrating ability. Cobalt 60 shall be used as a radiographic source only when the steel being radiographed exceeds 75 mm in thickness. Other radiographic sources shall be subject to the approval of the Engineer.

6.10.7 Hole-type or wire IQIs shall show clearly on each radiograph. The minimum number and their required locations shall be as follows:

For welds joining nominally equal thicknesses, where a radiograph represents 250 mm or greater of weld length, two IQIs placed, as shown in Figure 6.1A; where a radiograph represents less than 250 mm of weld, one hole-type or wire IQI placed as shown in Figure 6.1B.

For welds at a transition in thickness, where a radiograph represents 250 mm or greater of weld length, two hole-type or wire IQIs on the thinner plate and one hole-type or wire IQI on the thicker plate, or two wire IQIs at the alternate wire IQI placement locations each as shown in Figure 6.1C; when a radiograph represents less than 250 mm of weld length, one hole-type or wire IQI on each plate or one wire IQI at the alternate wire IQI placement location shown in Figure 6.1D.

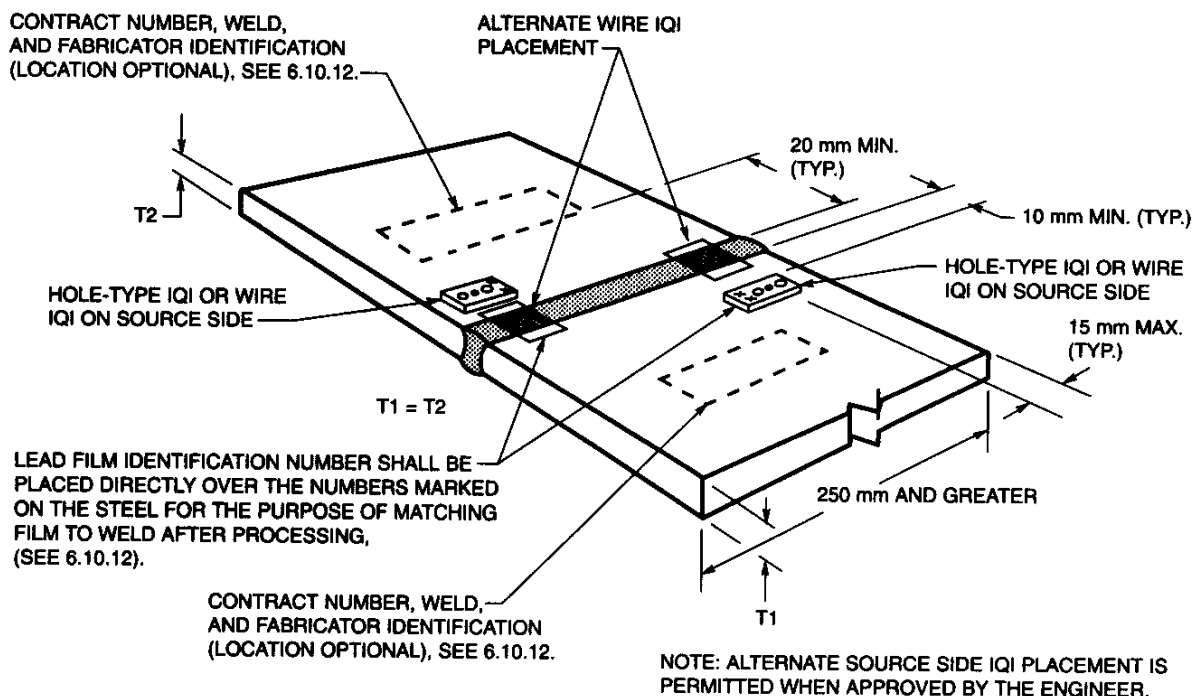


Figure 6.1A—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 250 mm and Greater in Length (see 6.10.7)

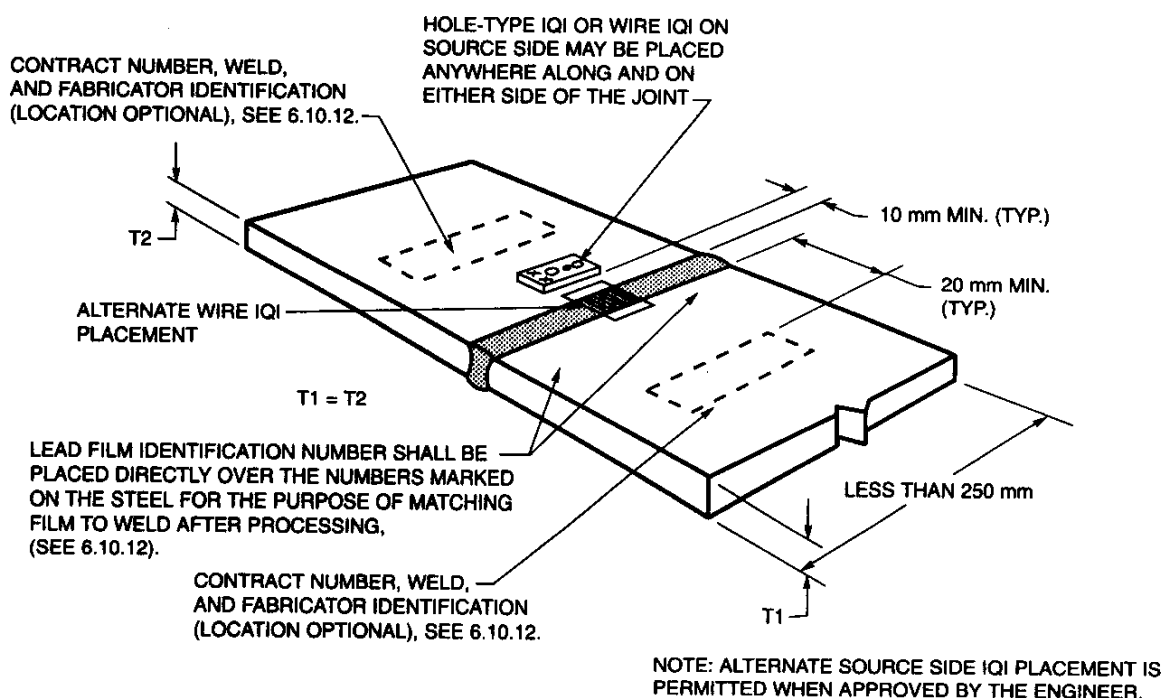


Figure 6.1B—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 250 mm in Length (see 6.10.7)

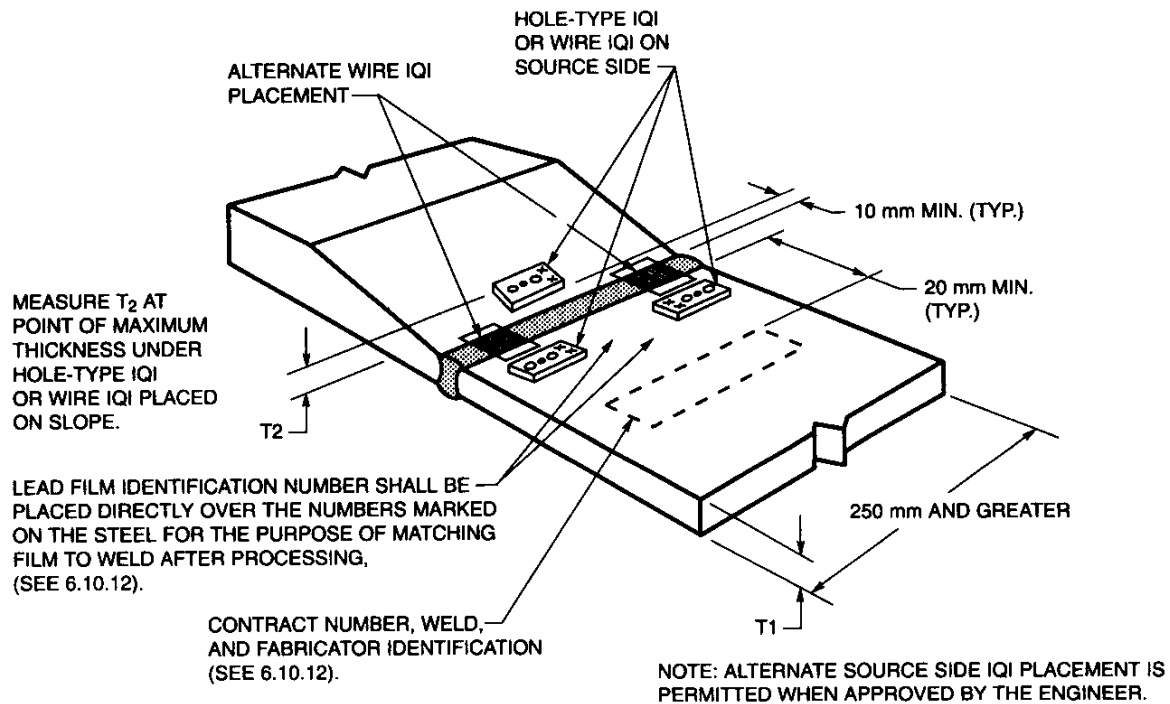


Figure 6.1C—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 250 mm and Greater in Length (see 6.10.7)

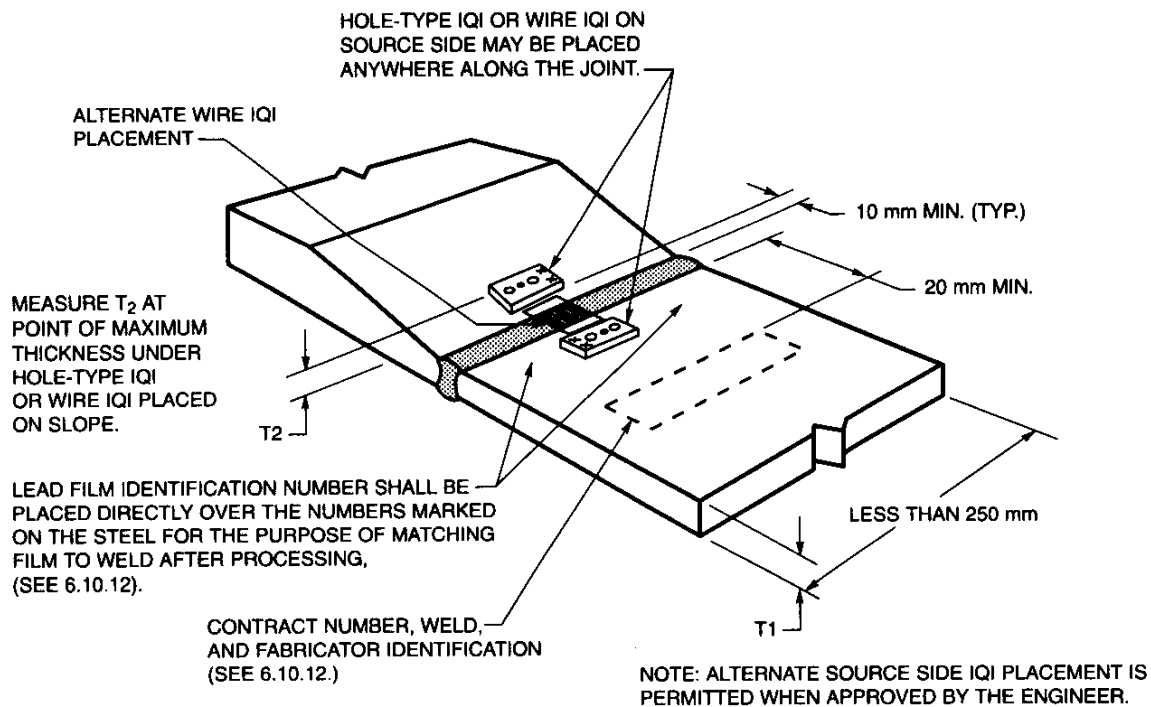


Figure 6.1D—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less Than 250 mm in Length (see 6.10.7)

6.10.7.1 Hole-type IQIs or wire IQI shall be placed on the source side with hole-type IQI parallel to the weld joint and holes at the outer edge of the area being radiographed. IQI wires shall be perpendicular to the joint with the smallest wire on the outer edge of the area being radiographed.

6.10.7.2 The thickness of hole-type IQIs or wire IQI set and the essential hole or wire shall be as specified in Tables 6.1 and 6.1A. A smaller essential hole or wire or a thinner hole-type IQI, or a wire IQI using smaller wires may be selected by the contractor, provided all other provisions for radiography are met.

6.10.7.3 Thickness shall be measured as T1 or T2, or both, at the locations shown in Figures 6.1A, 6.1B, 6.1C, or 6.1D and may be increased to provide for the thickness of allowable weld reinforcement, provided shims are used as specified in 6.10.3.3. Steel backing shall not be considered part of the weld or reinforcement in hole-type IQI or wire IQI selection.

6.10.7.4 Hole-type image quality indicators (IQI) shall be manufactured from steel, preferably stainless steel, and shall conform to dimensions shown in Figure 6.1E. For more detailed information, see ASTM E1025, *Hole-Type Image Quality Indicators Used for Radiography*. Each IQI shall be manufactured with three holes, one of which shall be of a diameter equal to twice the IQI thickness (2T). The diameter of the two remaining holes shall be selected by the manufacturer. They will ordinarily equal one times (1T) and four times (4T) the IQI thickness. IQI designations 10 through 25 shall contain a 4T hole.

6.10.7.5 Wire image quality indicators (IQI) shall be manufactured in accordance with Figure 6.1F. For more detailed information, see ASTM E747, *Standard Method for Controlling Quality of Radiographic Testing Using Wire Penetrators*.

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

6.10.8.1 Films shall have sufficient length and shall be placed to produce at least 10 mm of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

6.10.8.2 Welds longer than 350 mm may be radiographed by overlapping film cassettes and making a single exposure, or by using single-film cassettes and

making separate exposures. The provisions of 6.10.5 shall apply.

6.10.8.3 To check for backscattered radiation, a lead symbol "B," 12.7 mm high, and 1.6 mm thick, shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be considered unacceptable.

6.10.9 Film widths shall be sufficient to depict all portions of the weld joint, including the heat-affected zones (HAZ), and shall provide sufficient additional space for the required hole-type or wire IQIs and film identification without infringing upon the area of interest in the radiograph.

6.10.10 All radiographs shall be free from mechanical, chemical, or other blemishes to such extent that blemishes cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph.

6.10.10.1 Such blemishes include, but are not limited to the following:

- (1) Fogging
- (2) Processing defects such as streaks, water marks, or chemical stains
- (3) Scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears

6.10.10.2 Faulty techniques include the following:

- (1) Loss of detail due to poor screen-to-film contact
- (2) False indications due to defective screens or internal faults

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

6.10.11.1 The density measured shall be H & D density (radiographic density).

Note: H & D (radiographic) density is a measure of film blackening, expressed as:

$$D = \log I_o/I$$

where

D = H & D (radiographic) density

I_o = light intensity on the film, and

I = light transmitted through the film

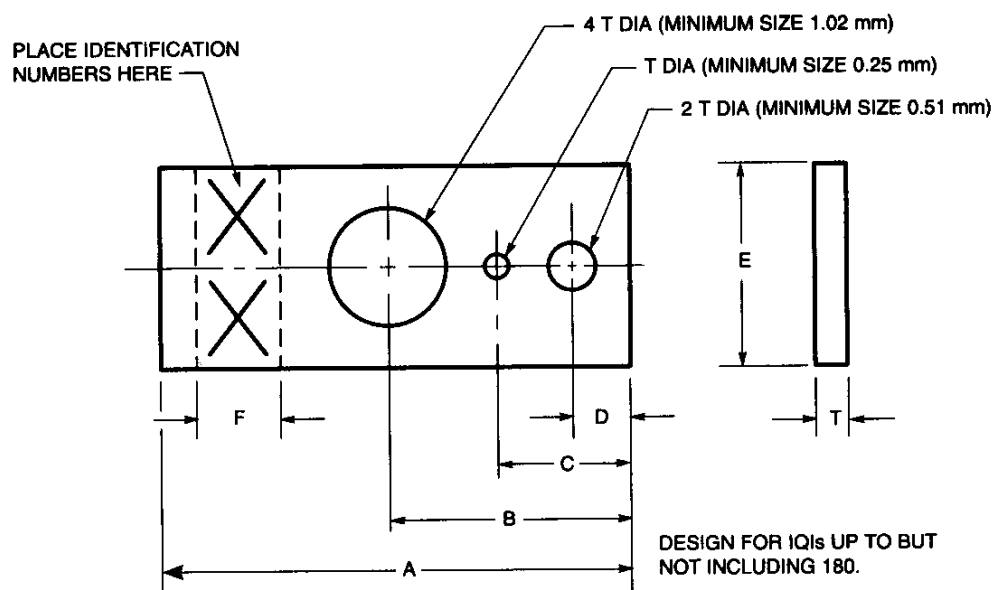


Table of Dimensions of IQI (in mm)							
Number	A	B	C	D	E	F	IQI Thickness and Hole Diameter Tolerance
5-20	38.10 ± 0.38	19.05 ± 0.38	11.13 ± 0.38	6.35 ± 0.38	12.70 ± 0.38	6.35 ± 0.80	±0.013
4-59	38.10 ± 0.38	19.05 ± 0.38	11.13 ± 0.38	6.35 ± 0.38	12.70 ± 0.38	6.35 ± 0.80	±0.06
0-179	57.15 ± 0.80	34.92 ± 0.80	19.05 ± 0.80	9.52 ± 0.80	25.40 ± 0.80	9.52 ± 0.80	±0.13

Notes:

1. IQIs No. 5 through 9 are not 1T, 2T, and 4T.
2. Holes shall be true and normal to the IQI. Do not chamfer.

Figure 6.1E—Hole-Type Image Quality Indicator (IQI) Design (see 6.10.7.4)

(Reprinted by permission of the American Society for Testing and Materials, copyright.)

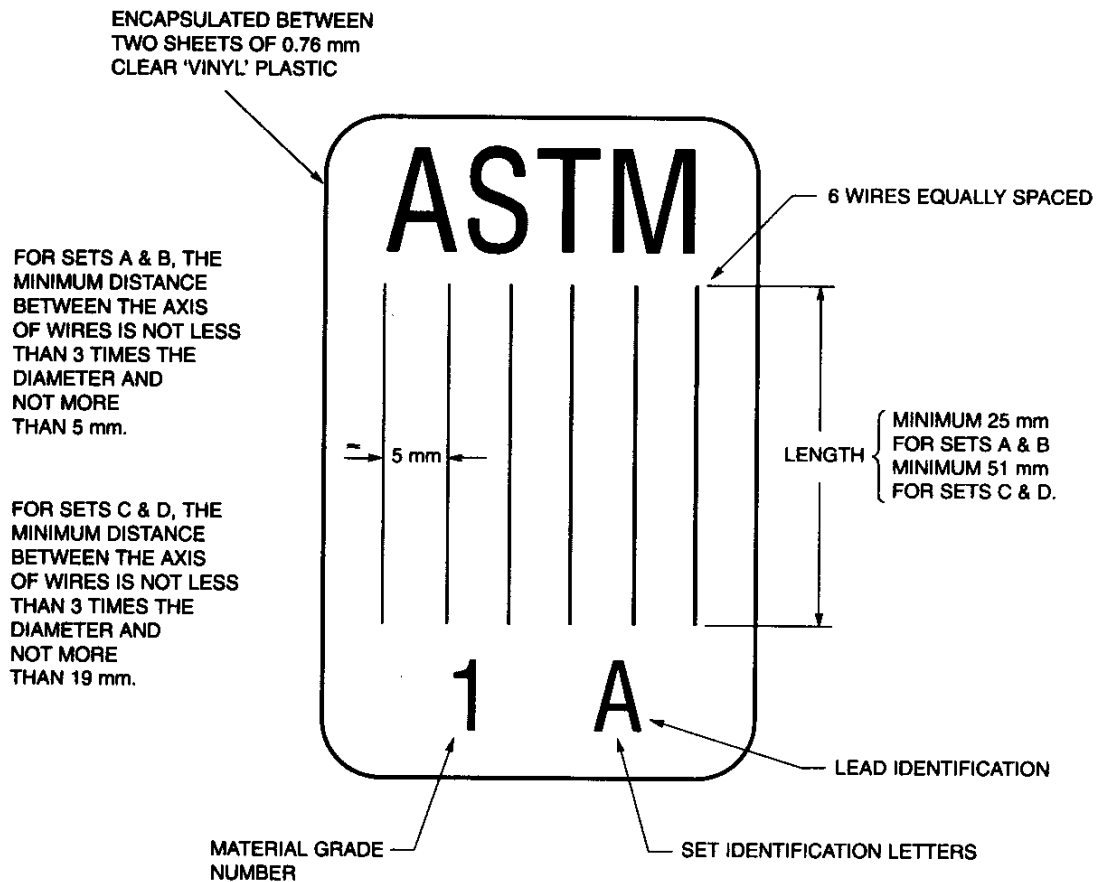


Image Quality Indicator (Wire Penetrameter) Sizes			
Wire Diameter, mm			
Set A	Set B	Set C	Set D
0.08	0.25	0.81	2.5
0.1	0.33	1.02	3.2
0.13	0.4	1.27	4.06
0.16	0.51	1.6	5.1
0.2	0.64	2.03	6.4
0.25	0.81	2.5	8

Figure 6.1F—Image Quality Indicator (Wire Penetrameter) (see 6.10.7.5)

(Reprinted by permission of the American Society for Testing and Materials, copyright.)

6.10.11.2 When weld transitions in thickness are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single-film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements of 6.10.11 shall be waived, unless otherwise provided in the contract documents.

6.10.12 A radiograph identification mark and two location identification marks shall be placed on the steel at each radiograph location. A corresponding radiograph identification mark and two location identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks made on the steel to provide a means for matching the developed radiograph to the weld. Additional identification information may be preprinted no less than 20 mm from the edge of the weld or shall be produced on the radiograph by placing lead figures on the steel.

6.10.13 Information required to show on the radiograph shall include the owner's contract identification, initials of the radiographic inspection company, initials of the fabricator, the fabricator's shop order number, the radiographic identification (erection) mark, the date, and the weld repair number, if applicable.

6.11 Acceptability of Welds

Welds shown by radiographic testing to have discontinuities unacceptable per 9.21.2 shall be corrected in accordance with 3.7.

6.12 Examination, Report, and Disposition of Radiographs

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

6.12.2 Before a weld subject to radiographic testing by the contractor for the Engineer is accepted, all of its radiographs, including any that show unacceptable quality prior to repair, and a report interpreting them, shall be submitted to the QA Inspector.

6.12.3 A full set of radiographs for welds subject to radiographic testing by the contractor for the Engineer, including any that show unacceptable quality prior to repair, shall be delivered to the owner upon completion of the work. The contractor's obligation to retain radiographs shall cease: (1) upon delivery of this full set to the owner, or (2) one full year after the completion of the contractor's work, provided the owner is given prior written notice.

Part C **Ultrasonic Testing of Groove Welds**

6.13 General

6.13.1 The procedures and standards set forth in Part C govern the ultrasonic testing of groove welds and HAZ between the thicknesses of 8 mm and 200 mm inclusive, when such testing is required by 6.7 of this code.

6.13.2 Variations in testing procedure, equipment, and acceptance standards not included in Part C of section 6 may be used upon agreement with the Engineer. Such variations include other thicknesses, weld geometries, transducer sizes, frequencies, couplant, painted surfaces, testing techniques, etc. Such approved variations shall be recorded in the contract records.

6.13.3 To detect possible piping porosity, radiography is required to supplement ultrasonic testing of electroslog welds (ESW) and electrogas welds (EGW).

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

6.14 Extent of Testing

6.14.1 The provisions of 6.7 identify the minimum extent of ultrasonic testing.

6.14.2 The ultrasonic operator shall, prior to making a UT examination, be furnished or have access to relevant information regarding weld-joint geometry, material thickness, and welding processes used in making the weldment. Any subsequent record of repairs made to the weldment shall also be made available to the ultrasonic operator.

6.15 Ultrasonic Equipment

6.15.1 The ultrasonic instrument shall be the pulse echo type suitable for use with transducers oscillating at frequencies between 1 and 6 megahertz (MHz). The display shall be an "A" scan rectified video trace.

6.15.2 The horizontal linearity of the test instrument shall be qualified over the full sound-path distance to be used in testing in accordance with 6.22.1. (See 6.17.1.)

6.15.3 Test instruments shall be internally stabilized so that after warm-up, no variation in response greater than 1 dB occurs with a supply voltage change of 15 percent nominal or, in the case of a battery, within the charge operating life. There shall be an alarm or meter to signal a drop in battery voltage prior to instrument shutoff due to battery exhaustion.

6.15.4 The test instrument shall have a calibrated gain control (attenuator) adjustable in discrete 1 or 2 dB steps over a range of at least 60 dB. The accuracy of the gain control (attenuator) settings shall be within plus or minus 1 dB. The procedure for qualification shall be as described in 6.17.2 and 6.22.2.

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

6.15.6 Straight beam (longitudinal wave) search unit transducers shall have an active area of not less than 300 square millimeters nor more than 650 square millimeters. The transducer shall be round or square. Transducer frequency shall be 2 to 2.5 MHz. Transducers shall be capable of resolving the three reflections as described in 6.21.1.3.

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

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

6.15.7.2 The transducer crystal shall be square or rectangular in shape and may vary from 15 mm to 25 mm in width and from 15 mm to 20 mm in height (see Figure 6.2). The maximum ratio of width to height shall be 1.2 to 1.0, and the minimum ratio 1.0 to 1.0.

6.15.7.3 The search unit shall produce a sound beam in the material being tested within plus or minus 2 degrees of one of the following proper angles: 70 degrees, 60 degrees, or 45 degrees, as described in 6.21.2.2.

6.15.7.4 Each search unit shall be marked to clearly indicate the frequency of the transducer, nominal angle of refraction, and index point. The index point location procedure is described in 6.21.2.1.

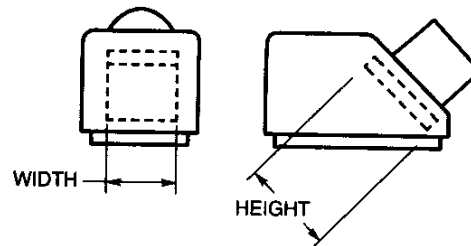


Figure 6.2—Transducer Crystal
(see 6.15.7.2)

6.15.7.5 Maximum allowable internal reflections from the search unit shall be as described in 6.17.4.

6.15.7.6 The dimensions of the search unit shall be such that the distance from the leading edge of the search unit to the index point shall not exceed 25 mm. (See Figure 6.3.)

6.15.7.7 The qualification procedure using the IIW reference block shall be in accordance with 6.21.2.6 and as shown in Figure 6.3.

6.16 Reference Standards

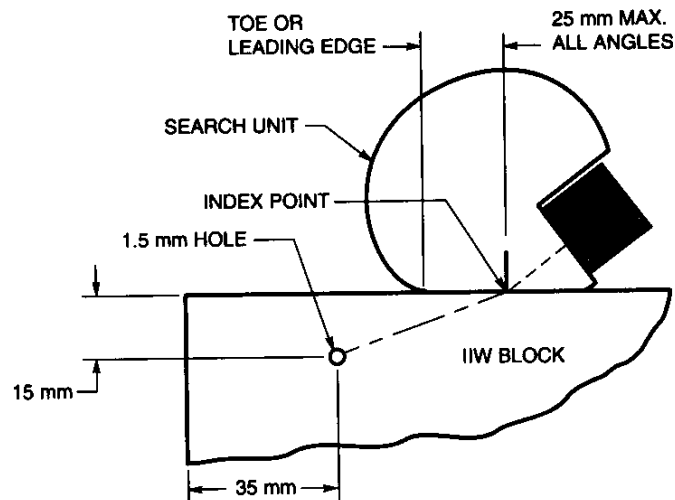
6.16.1 The International Institute of Welding (IIW) ultrasonic reference block, shown in Figure 6.4A, shall be the standard used for both distance and sensitivity calibration. Other portable blocks may be used, provided the reference level sensitivity for the instrument/search unit combination is adjusted to be equivalent to that achieved with the IIW Block. (See Annex VII, Part A, for examples.) Other approved designs are shown in Figure 6.4B.

6.16.2 The use of a "corner" reflector for calibration purposes is prohibited.

6.16.3 The combination of search unit and instrument shall resolve three holes in the RC resolution reference test block shown in Figure 6.4B. The search unit position is described in 6.21.2.5. The resolution shall be evaluated with the instrument controls set at normal test settings and with indications from the holes brought to mid-screen height. Resolution shall be sufficient to distinguish at least the peaks of indications from the three holes.

6.17 Equipment Qualification

6.17.1 The horizontal linearity of the test instrument shall be prequalified after each 40 hours of instrument use in each of the distance ranges over which the instru-



**Figure 6.3—Qualification Procedure of Search Unit
Using IIW Reference Block (see 6.15.7.6)**

ment will be used. The qualification procedure shall be in accordance with 6.22.1. (See Annex VII, VIIA3 for alternative method.)

6.17.2 The instrument's gain control (attenuator) shall meet the requirements of 6.15.4 and shall be checked for correct calibration at not to exceed two month intervals in accordance with 6.22.2. Alternative methods may be used for calibrated gain control (attenuator) qualification if proven at least equivalent with 6.22.2.

6.17.3 Maximum internal reflections from each search unit shall be verified at a maximum time interval of 40 hours of instrument use, in accordance with 6.22.3.

6.17.4 With the use of an approved calibration block, each angle beam search unit shall be checked after each eight hours of use to determine that the contact face is flat, that the sound entry point is correct, and that the beam angle is within the permitted plus or minus 2 degrees tolerance in accordance with 6.21.2.1 and 6.21.2.2. Search units which do not meet these requirements shall be corrected or replaced.

6.18 Calibration for Testing

6.18.1 All calibrations and tests shall be made with the reject (clipping or suppression) control turned off. Use of the reject (clipping or suppression) control may alter the

amplitude linearity of the instrument and invalidate test results.

6.18.2 Calibration for sensitivity and horizontal sweep (distance) shall be made by the ultrasonic operator just prior to testing and at the location of each weld.

6.18.3 Recalibration shall be made after a change of operators, after each 30 minute maximum time interval, or when the electrical circuitry is disturbed in any way which includes the following:

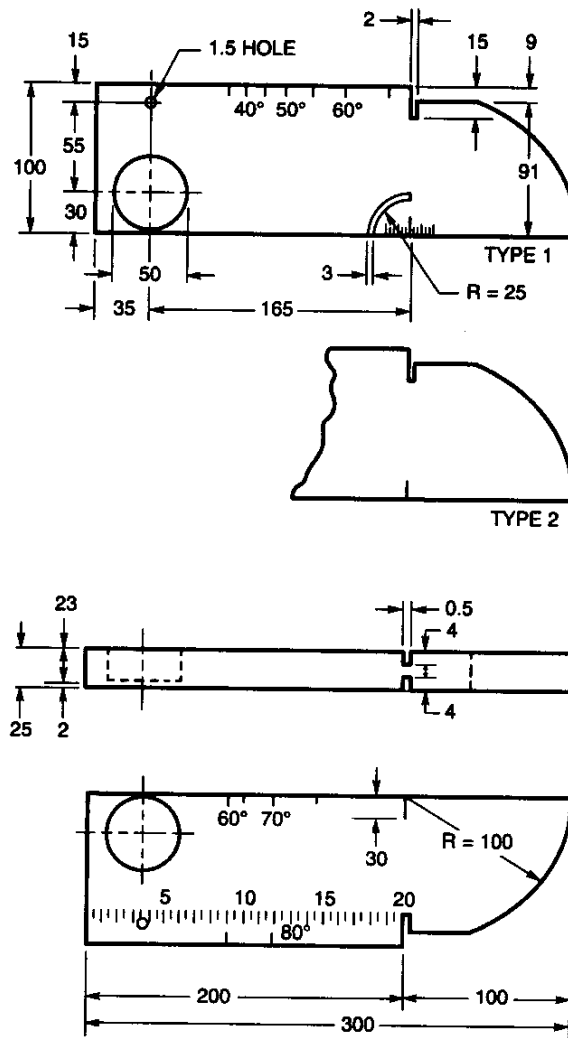
- (1) Transducer change
- (2) Battery change
- (3) Electrical outlet change
- (4) Coaxial cable change
- (5) Power outage (failure)

6.18.4 Calibration for straight-beam testing of base metal shall be made with the search unit applied to Face A of the base metal and performed as follows:

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

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

6.18.5 Calibration for angle beam testing shall be performed as follows (See Annex VII, VIIA2.4 for alternative method):



ALL DIMENSIONS IN mm

Notes:

1. The dimensional tolerance between all surfaces involved in referencing or calibrating shall be within ± 0.13 mm of detailed dimension.
2. The surface finish of all surfaces to which sound is applied or reflected from shall have a maximum of $3 \mu\text{m}$.
3. All material shall be M270M (A709M) Gr. 250 or acoustically equivalent.
4. All holes shall have a smooth internal finish and shall be drilled at 90° to the material surface.
5. Degree lines and identification markings shall be indented into the material surface so that permanent orientation can be maintained.
6. Other approved reference blocks with slightly different dimensions or distance calibration slot features are permissible.
7. These notes apply to all sketches in Figures 6.4A and 6.4B.

**Figure 6.4A—International Institute of Welding (IIW)
Ultrasonic Reference Blocks (see 6.16.1)**

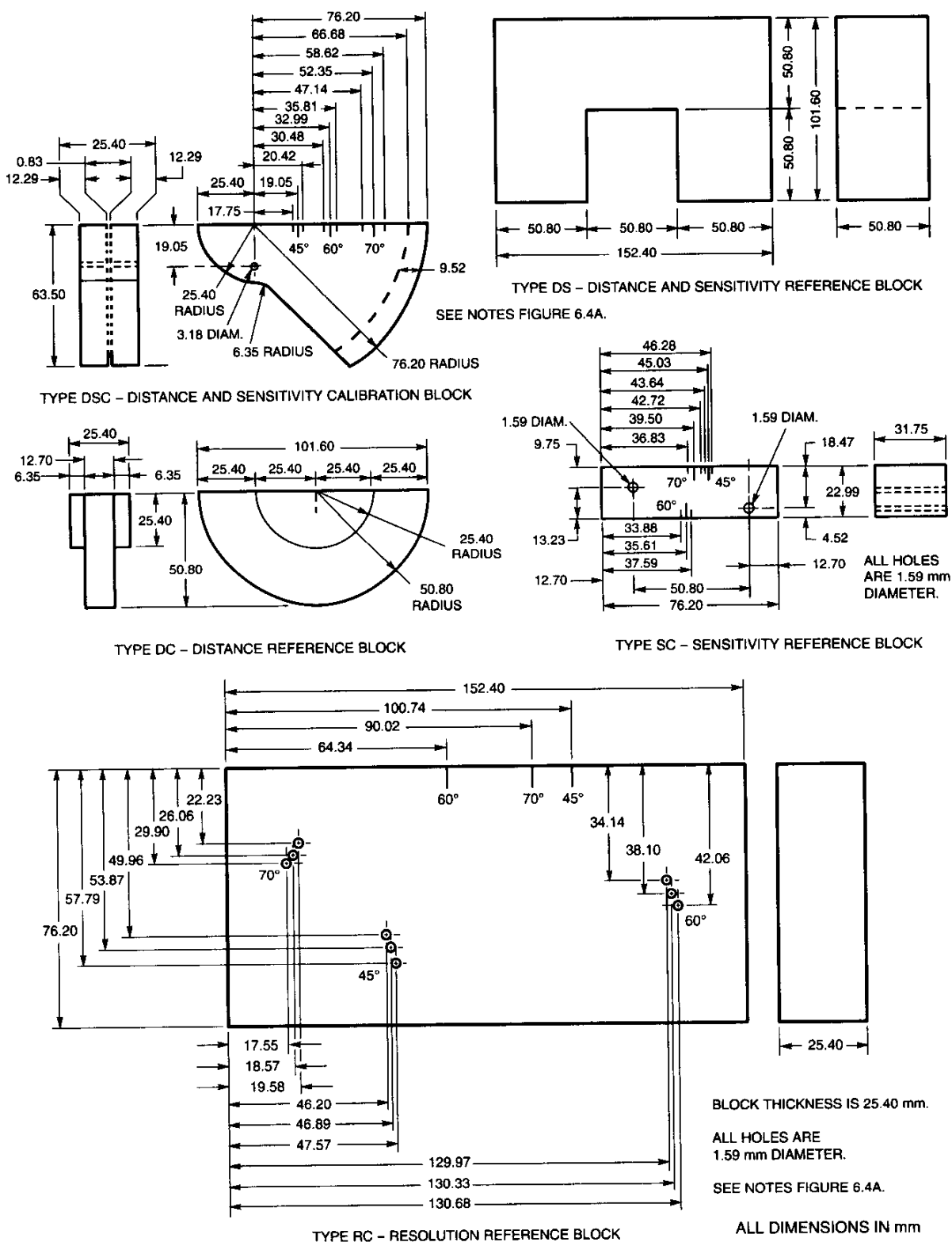


Figure 6.4B—Other Approved Ultrasonic Reference Blocks (see 6.16.1)

6.18.5.1 The horizontal sweep shall be adjusted to represent the actual sound path distance by using the IIW block or alternative blocks as specified in 6.16.1. The distance calibration shall be made using either the 125 mm scale or 250 mm scale on the CRT screen, whichever is appropriate, unless joint configuration or thickness prevents full examination of the weld at either of these settings, in which case, the distance calibration shall be made using 400 mm or 500 mm scale as required. The search unit position is described in 6.21.2.3.

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

6.18.5.2 The reference level sensitivity used for flaw evaluation ("b" on the ultrasonic test report, Annex VII, Part B, Form VII-11) is attained by adjusting the calibrated gain control (attenuator) of the flaw detector, meeting the requirements of 6.15, so that a maximized horizontal reference level trace deflection results on the display, in accordance with 6.21.2.4.

Note: A trace deflection adjusted to horizontal reference line height with calibrated gain control (attenuator).

See Annex VII, Part B, Form VII-11 for a sample ultrasonic test report form.

6.19 Testing Procedures

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

6.19.2 A "Y" accompanied with a weld identification number shall be clearly marked on the base metal adjacent to each weld that is ultrasonically tested. This marking is used for the following purposes:

- (1) Weld identification
- (2) Identification of Face A
- (3) Distance measurements and direction (+ or -) from the X line
- (4) Location measurement from weld ends or edges

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

6.19.4 A couplant material shall be used between the search unit and the test material. The couplant shall be

either glycerin or a cellulose gum and water mixture of a suitable consistency. A wetting agent may be added if needed. Light machine oil may be used for couplant on calibration blocks.

6.19.5 The entire base metal through which ultrasound must travel to test the weld shall be tested for laminar reflectors using a straight beam search unit conforming to the requirements of 6.15.6 and calibrated in accordance with 6.18.4. If any area of base metal exhibits total loss of back reflection or an indication equal to or greater than the original back reflection height is located in a position that will interfere with the normal weld scanning procedure, its size, location, and depth from the A face shall be determined and reported on the ultrasonic test report, and an alternate weld scanning procedure shall be used.

6.19.5.1 The reflector size evaluation procedure shall be in accordance with 6.23.1.

6.19.5.2 If part of a weld is inaccessible to testing in accordance with the requirements of Table 6.2, due to laminar content recorded in accordance with 6.19.5, the testing shall be conducted using one or more of the following alternative procedures as necessary to attain full weld coverage:

- (1) Grind the weld surface(s) flush.
- (2) Test from Faces A and B.
- (3) Use other search unit angles.

6.19.6 Welds shall be tested using an angle beam search unit conforming to the requirements of 6.15.7 with the instrument calibrated in accordance with 6.18.5 using the angles shown in Table 6.2. Following calibration and during testing, the only instrument adjustment permitted is the sensitivity-level adjustment with the calibrated gain control (attenuator). The reject (clipping or suppression) control shall be turned off. Sensitivity shall be increased from the reference level for weld scanning in accordance with the provisions of Tables 9.1 or 9.2, as applicable.

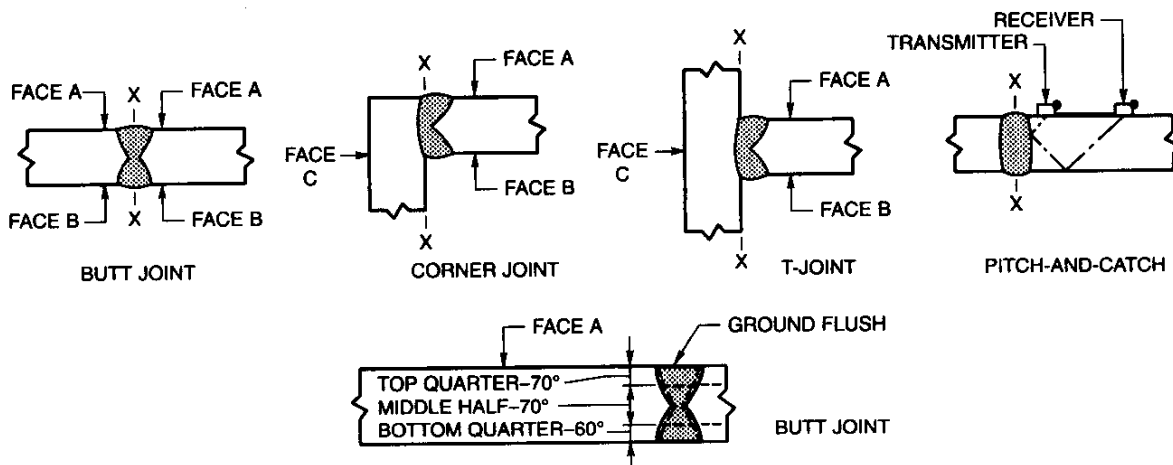
6.19.6.1 The testing angle and scanning procedure shall be in accordance with those shown in Table 6.2.

6.19.6.2 All butt joint welds shall be tested from each side of the weld axis. Corner and T-joint welds shall be primarily tested from one side of the weld axis only. All welds shall be tested using the applicable scanning pattern or patterns shown in Figure 6.6 as necessary to detect both longitudinal and transverse flaws. It is intended that, as a minimum, all welds be tested by passing sound through the entire volume of the weld and the HAZ in two crossing directions, wherever practical.

6.19.6.3 When a discontinuity indication appears on the screen, the maximum attainable indication from the

Table 6.2
Testing Angle (see 6.19.6)

Procedure Chart																
Material Thickness, mm																
Weld Type	8 to 38	> 38 to 45	> 45 to 60	> 60 to 90	> 90 to 110	> 110 to 130	> 130 to 160	> 160 to 180	> 180 to 200							
	*	*	*	*	*	*	*	*	*							
Butt	1	O	1	F	1G or 4	F	1G or 5	F	6 or 7	F	8 or 10	F	9 or 11	F	12 or 13	F
T-	1	O	1	F or XF	4	F or XF	5	F or XF	7	F or XF	10	F or XF	11	F or XF	13	F or XF
Corner	1	O	1	F or XF	1G or 4	F or XF	1G or 5	F or XF	6 or 7	F or XF	8 or 10	F or XF	9 or 11	F or XF	13 or 14	F or XF
Electrogas & Electroslag	1	O	1	O	1G or 4	1**	1G or 3	P1 or P3	6 or 7	P3	11 or 15	P3	11 or 15	P3	11 or 15	P3



Notes:

- Where possible, all examinations shall be made from Face A and in Leg I, unless otherwise specified in this Table.
- Root areas of single groove weld joints which have backing strips not requiring removal by contract, shall be tested in Leg I, where possible, with Face A being that opposite the backing strip. (Grinding of the weld face or testing from additional weld faces may be necessary to permit complete scanning of the weld root.)
- Examination in Leg II or III shall be made only to satisfy provisions of this table or when necessary to test weld areas made inaccessible by an unground weld surface, or interference with other portions of the weldment, or to meet the requirements of 6.19.6.2.
- A maximum of Leg III shall be used only where thickness or geometry prevents scanning of complete weld areas and heat-affected zones in Leg I or Leg II.
- On tension welds on bridges, the top quarter of thickness shall be tested with the final leg of sound progressing from Face B toward Face A, the bottom quarter of thickness shall be tested with the final leg of sound progressing from Face A toward Face B; i.e., the top quarter of thickness shall be tested either from Face A in Leg II or from Face B in Leg I at the contractor's option, unless otherwise specified in the contract documents.
- The weld face indicated shall be ground flush before using procedure 1G, 6, 8, 9, 12, 14, or 15. Face A for both connected members shall be in the same plane.

(See Legend and Notes on next page)

Table 6.2 (Continued)**Legend:**

X — Check from Face "C."

G — Grind weld face flush.

O — Not required.

A Face — the face of the material from which the initial scanning is done (on T- and corner joints, follow above sketches).

B Face — opposite the "A" face (same plate).

C Face — the face opposite the weld on the connecting member or a T- or corner joint.

* — Required only where display reference height indication of discontinuity is noted at the weld metal-base metal interface while searching at scanning level with primary procedures selected from first column.

** — Use 400 mm or 500 mm screen distance calibration.

P — Pitch and catch shall be conducted for further discontinuity evaluation in only the middle half of the material thickness with only 45 deg or 70 deg transducers of equal specification, both facing the weld. (Transducers must be held in a fixture to control positioning—see sketch.) Amplitude calibration for pitch and catch is normally made by calibrating a single search unit. When switching to dual search units for pitch and catch inspection, there should be assurance that this calibration does not change as a result of instrument variables.

F — Weld metal-base metal interface indications shall be further evaluated with either 70 deg, 60 deg, or 45 deg transducer—whichever sound path is nearest to being perpendicular to the suspected fusion surface.

Procedure Legend**Area of Weld Thickness**

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

discontinuity shall be adjusted to produce a horizontal reference level trace deflection on the display. This adjustment shall be made with the calibrated gain control or (attenuator), and the instrument reading in decibels shall be used as the "Indication Level," "a," for calculating the "Indication Rating," "d," as shown on the test report (Annex VII, Part B, Form VII-11).

6.19.6.4 The "Attenuation Factor," "c," on the test report is attained by subtracting 25 mm from the sound path distance and multiplying the remainder by 0.08. This factor shall be rounded out to the nearest dB value. Fractional values less than 1/2 dB shall be reduced to the lower dB level and those of 1/2 or greater increased to the higher level.

6.19.6.5 The "Indication Rating," "d," in the UT Report, Annex VII, Part B, Form VII-11, represents the algebraic difference in decibels between the indication level and the reference level with correction for attenuation as indicated in the following expressions:

Instruments with gain in dB:

$$a - b - c = d$$

Instruments with attenuation in dB:

$$b - a - c = d$$

6.19.7 The length of flaws shall be determined in accordance with the procedure in 6.23.2.

6.19.8 Each weld discontinuity shall be accepted or rejected on the basis of its indication rating and its length in accordance with Tables 9.1 or 9.2. Only those discontinuities which are rejectable need be recorded on the test report, except that for welds designated in the contract documents as being "Fracture Critical," ratings which are up to and including 6 dB less critical than rejectability shall be recorded on the test report.

6.19.9 Each rejectable discontinuity shall be indicated on the weld by a mark directly over the discontinuity for its entire length. The depth from the surface and indication rating shall be noted on nearby base metal.

6.19.9.1 Evaluation of retested areas of repaired welds must be tabulated on a new line on the report form. If the original form is used, an R1, R2, etc., shall prefix the indication number, designating the number of repairs having been made in that specific area.

6.19.9.2 If additional report forms are used, the R number shall prefix the report number.

6.19.10 Welds found unacceptable by ultrasonic testing shall be repaired by methods permitted by 3.7 of this code. Repaired areas shall be retested ultrasonically, with

results tabulated on the original form (if available) or additional report forms.

6.20 Preparation and Disposition of Reports

6.20.1 A report form which clearly identifies the work and the area of inspection shall be completed by the ultrasonic technician at the time of inspection. The report form for welds that are acceptable need only contain sufficient information to identify the weld, the Inspector (signature), and the acceptability of the weld. An example of such a form is shown in Annex VII, Part B, Form VII-11.

6.20.2 Before a weld subject to ultrasonic testing by the contractor for the Engineer is accepted, all report forms pertaining to the weld, including any that show unacceptable quality prior to repair, shall be submitted to the QA Inspector.

6.20.3 A full set of completed report forms of welds subject to ultrasonic testing by the contractor for the Engineer, including any that show unacceptable quality prior to repair, shall be delivered to the owner upon completion of the work. The contractor's obligation to retain ultrasonic reports shall cease (1) upon delivery of this full set to the owner or (2) one full year after completion of the contractor's work, provided that the owner is given prior written notice.

6.21 Calibration of the Ultrasonic Unit With IIW or Other Approved Reference Blocks

See 6.16 and Figures 6.4A, 6.4B, and 6.5.

6.21.1 Longitudinal Mode

6.21.1.1 The distance calibration procedure is as follows: (see Annex VII, VIIA1 for alternative method):

- (1) Set the transducer in position G on the IIW block.
- (2) Adjust instrument to produce indications at 25 mm, 50 mm, 75 mm, 100 mm, etc., on the display.

6.21.1.2 The amplitude procedure is as follows (see Annex VII, VIIA1.2 for alternative method):

- (1) Set the transducer in position G on the IIW block.
- (2) Adjust the gain until the maximized indication from first back reflection attains 50 to 75 percent screen height.

6.21.1.3 The resolution procedure is as follows:

- (1) Set the transducer in position F on the IIW block.

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

6.21.1.4 Horizontal linearity qualification procedures shall be in accordance with 6.17.1.

6.21.1.5 The gain control (attenuator) qualification is as follows:

- (1) Set the transducer in position T on DS block.
- (2) Move the transducer toward position U per instructions in 6.17.2. (See 6.17.2.1)

6.21.2 Shear Wave Mode (Transverse)

6.21.2.1 Locate or check the transducer sound entry point (index point) by the following procedure:

- (1) Set the transducer in position D on the IIW block.

(2) Move the transducer until the signal from the radius is maximized. The point on the transducer which aligns with the radius line on the calibration block is the point of sound entry. (See Annex VII, VIIA2.1 for alternative method.)

6.21.2.2 Check or determine the transducer sound-path angle by one of the following procedures:

(1) Set the transducer in position B on IIW block for angles 40 degrees through 60 degrees, or in position C on IIW block for angles 60 degrees through 70 degrees. (See Figure 6.5.)

(2) For the selected angle, move the transducer back and forth over the line indicative of the transducer angle until the signal from the radius is maximized. Compare the sound entry point on the transducer with the angle

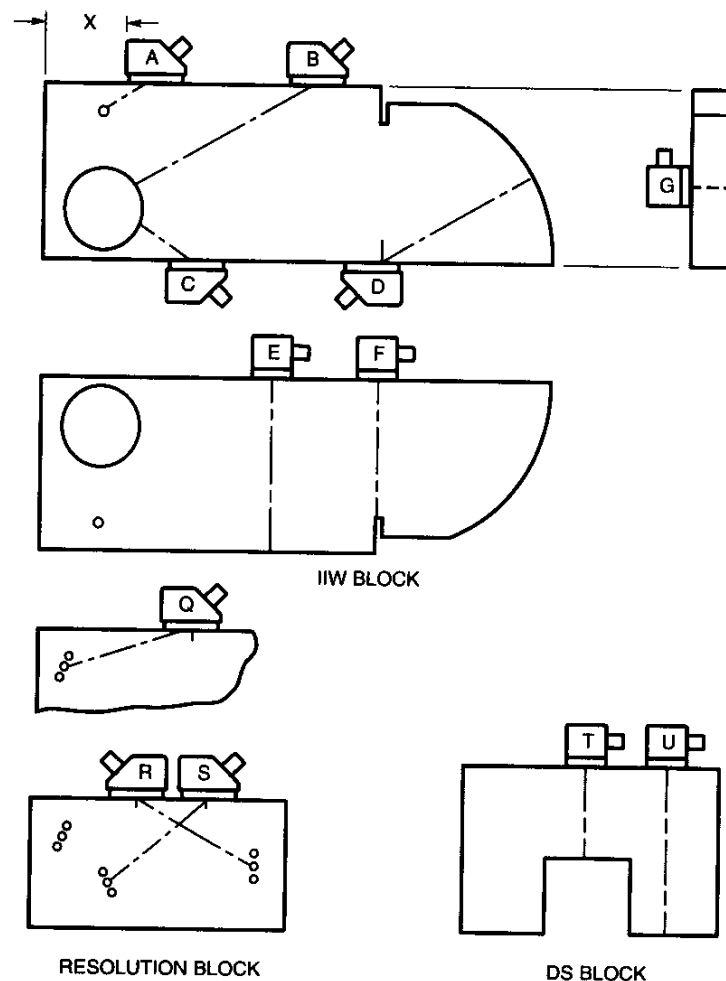


Figure 6.5—Transducer Positions (Typical) (see 6.21)

mark on the calibration block (tolerance ± 2 degrees). (See Annex VII, VIIA2.2 for alternative methods.)

6.21.2.3 The distance calibration procedure is as follows:

(1) Set the transducer in position D on the IIW block (any angle).

(2) Adjust the instrument to attain indications at 100 mm and 200 mm or 225 mm on the display; 100 mm and 225 mm on Type 1 block; or 100 mm and 200 mm on a Type 2 block. (See Annex VII for alternate methods using the DSC or DC block.)

6.21.2.4 The amplitude or sensitivity calibration procedure is as follows:

(1) Set the transducer in position A on the IIW block (any angle);

(2) Adjust the maximized signal from the 1.5 mm hole to attain a horizontal reference-line height indication. (See Annex VII, VIIA2.4 for alternative method)

(3) The maximum decibel reading obtained shall be used as the "Reference Level", "b" reading on the Test Report sheet (Annex VII, Part B, Form VII-11) per 6.16.1.

6.21.2.5 The resolution procedure is as follows:

(1) Set the transducer on resolution block RC position Q for 70 degree angle, position R for 60 degree angle, or position S for 45 degree angle.

(2) Resolve the three test holes, at least to the extent of distinguishing the peaks of the indications from the three holes, by the transducer and instrument.

6.22 Equipment Qualification Procedures

6.22.1 Horizontal Linearity Procedure

Note: Since this qualification procedure is performed with a straight beam search unit which produces longitudinal wave with a sound velocity of almost double that of shear wave, it is necessary to double the shear wave distance ranges to be used in applying this procedure.

6.22.1.1 Example: The use of a 250 mm screen calibration in shear wave would require a 500 mm screen calibration for this qualification procedure. The following procedure shall be used for instrument qualification (See Annex VII, VIIA3, for alternative method.)

(1) Couple a straight-beam search unit meeting the requirements of 6.15.6 to the IIW or DS block in Position G, T, or U (see Figure 6.5) as necessary to attain 5 back reflections in the qualification range being certified. (See Figure 6.5.)

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

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

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

6.22.2 Decibel dB Accuracy Procedure

Note: In order to attain the required accuracy (± 1 percent) in reading the indication height, the display must be graduated vertically at 2 percent intervals at horizontal mid-screen. These graduations shall be placed on the display between 60 percent and 100 percent of screen height. This may be accomplished with use of a graduated transparent screen overlay. If this overlay is applied as a permanent part of the ultrasonic unit, care should be taken that the overlay does not obscure normal testing displays.

(1) Couple a straight-beam search unit, meeting the requirements of 6.15.6, to the DS block shown in Figure 6.4B and position "T," Figure 6.5. (See 6.17.2.1.)

(2) Adjust the distance calibration so that the first 50 mm back reflection indication (hereafter called "the indication") is at horizontal midscreen.

(3) Adjust the calibrated gain or attenuation control so that the indication is exactly at or slightly above 40 percent screen height.

(4) Move the search unit toward position U (see Figure 6.5), until the indication is at exactly 40 percent screen height.

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

(6) Record the dB reading under "a" and actual percent screen height under "b" from step 5 on the certification report (Annex VII, Part B, Form VII-8), line 1.

(7) Move the search unit further toward position U, Figure 6.5, until the indication is at exactly 40 percent screen height.

(8) Repeat step 5.

(9) Repeat step 6; except, information should be applied to the next consecutive line on Annex VII, Part B, Form VII-8.

(10) Repeat steps 7, 8, and 9 consecutively until the full range of the gain control (attenuator) is reached (60 dB minimum).

(11) Apply the information from columns "a" and "b" to equation 6.22.2.2 or the nomograph described in 6.22.2.3 to calculate the corrected dB.

(12) Apply corrected dB from step 11 to column "c."

(13) Subtract Column "c" value from Column "a" value and apply the difference in Column "d," dB error.

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

Note: These values may be either positive or negative and so noted. Examples of Application of Forms VII-8, VII-9, and VII-10 are found in Annex VII, Part B.

(15) Form VII-9 provides a relatively simple means of evaluating data from item

(14) Instructions for this evaluation are given in (16) through (18).

(16) Apply the dB information from column "e" (Form VII-8) vertically and dB reading from column "a" (Form VII-8) horizontally as X and Y coordinates for plotting a dB curve on Form VII-9.

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

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

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

6.22.2.1 The decibel calculating equation is as follows:

$$(1) \text{ dB}_2 - \text{dB}_1 = 20 \times \text{Log} (\%_2 \cdot \%_1)$$

or

$$\text{dB}_2 = 20 \times \text{Log} (\%_2 \cdot \%_1) + \text{dB}_1$$

(2) As related to Annex VII, Part B, Form VII-8:

dB_1 = Column a

dB_2 = Column c

$\%_1$ = Column b

$\%_2$ = Defined on Form VII-8

6.22.2.2 For notes on the use of the nomograph, see Annex VII, Part B; Form VII-10:

(1) Columns a, b, c, d, and e are on certification sheet, Annex VII, Part B, Form VII-8.

(2) The A, B, and C scales are on the nomograph, Annex VII, Part B, Form VII-10.

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

6.22.2.3 Procedures for using the nomograph are as follows:

(1) Extend a straight line between the decibel reading from Column "a" applied to the C scale and the corresponding percentage from Column "b" applied to the A scale.

(2) Use the point where the straight line from step 1 crosses the pivot line B as a pivot point for a second straight line.

(3) Extend a second straight line from the AVERAGE percentage point on the A scale through the pivot point developed in step 2 and on to the dB scale C.

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

6.22.2.4 For an example of the use of the nomograph, see Annex VII, Part B, Form VII-10.

6.22.3 Procedure for internal reflections is as follows:

(1) Calibrate the equipment in accordance with 6.18.5.

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

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

(4) The screen area beyond 10 mm sound path and above reference level height shall be free of any indication. ||

6.23 Flaw Size Evaluation Procedures

6.23.1 Straight (Longitudinal) Beam Testing. The size of lamellar discontinuities is not always easily determined, especially those that are smaller than the transducer size. When the discontinuity is larger than the transducer, a full loss of back reflection will occur and a 6 dB loss of amplitude and measurement to the centerline of the transducer is usually reliable for determining flaw edges. However, the approximate size evaluation of those reflectors, which are smaller than the transducer, must be made by beginning outside of the discontinuity with equipment calibrated in accordance with 6.18.4 and moving the transducer toward the area of discontinuity until an indication on the screen begins to form. The leading edge of the search unit at this point is indicative of the edge of the discontinuity. ||

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

6.24 Scanning Patterns

See Figure 6.6.

6.24.1 Longitudinal Discontinuities

6.24.1.1 Scanning Movement A. Rotation angle $\alpha = 10$ degrees.

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

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

Note: Movements A, B, and C are combined into one scanning pattern.

6.24.2 Transverse Discontinuities

6.24.2.1 Use scanning pattern D (when welds are ground flush).

6.24.2.2 Use scanning pattern E (when weld reinforcement is not ground flush); Scanning angle $e = 15$ degrees max.

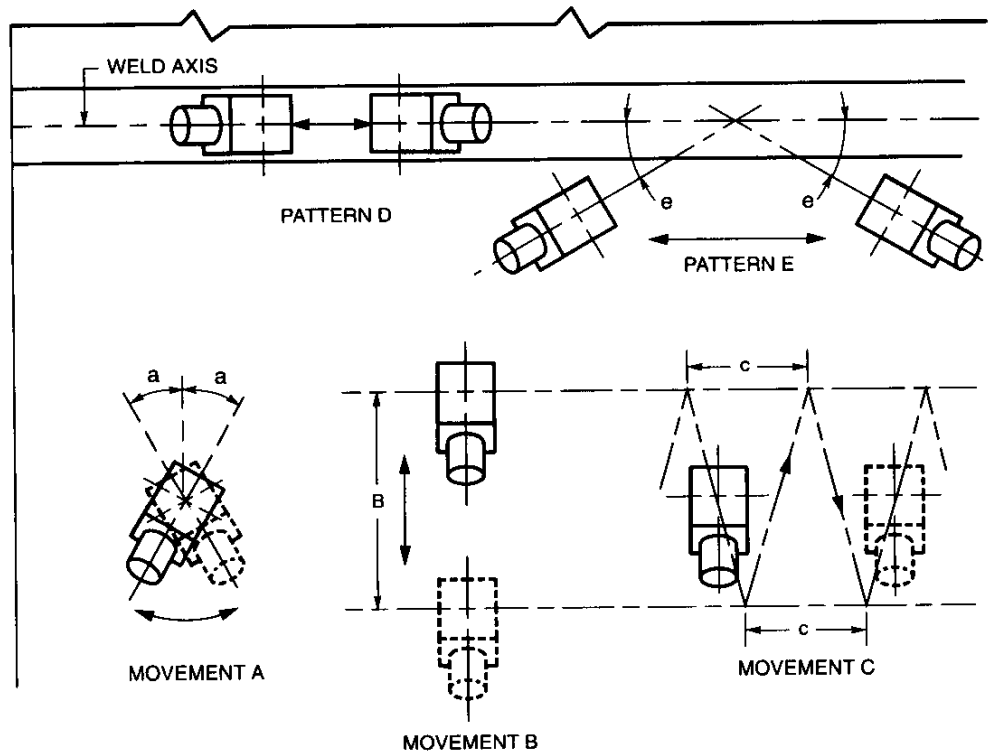
Note: The scanning pattern is to be such that the full weld section is covered.

6.24.3 ESW or EGW Welds (Additional Scanning Pattern)—Scanning Pattern E. Search unit rotation angle e shall be between 45 degrees and 60 degrees.

Note: The scanning pattern shall be such that the full weld section is covered.

6.25 Examples of dB Accuracy Certification

Annex VII, Part B, shows examples of the use of Forms VII-8, VII-9, and VII-10 for the solution to a typical application of 6.22.2.



Notes:

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

Figure 6.6—Plan View of UT Scanning Patterns (see 6.24)

7. Stud Welding

7.1 Scope

Section 7 contains general requirements for welding steel studs to steel (see 7.2.7 and 9.2 for approved steels). In addition, it stipulates specific requirements for the following:

- (1) Workmanship, preproduction testing, operator qualification, and application qualification testing, when required, all to be performed by the contractor
- (2) Quality control and quality assurance inspection of stud welding during production
- (3) Mechanical properties of steel studs, and requirements for qualification of stud bases, all tests and documentation to be furnished by the stud manufacturer

7.2 General Requirements

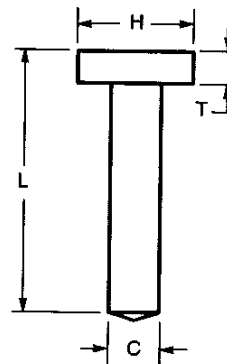
7.2.1 Studs shall be of suitable design for arc welding to steel members with the use of automatically timed stud welding equipment. The type and size of the stud shall be as specified by the drawings, specifications, or special provisions. For headed-type studs, see Figure 7.1.

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

7.2.3 A suitable deoxidizing and arc stabilizing flux for welding shall be furnished with each stud of 8 mm diameter or larger. Studs less than 8 mm in diameter may be furnished with or without flux.

7.2.4 Only studs with qualified stud bases shall be used. A stud base, to be qualified, shall have passed the test prescribed in Annex VI. The arc shield used in production shall be the same as used in qualification tests or as recommended by the manufacturer. Qualification of stud bases in accordance with Annex VI shall be at the manufacturer's expense.

7.2.5 Finish shall be produced by heading, rolling, or machining. Finished studs shall be of uniform quality and condition, free of injurious laps, fins, seams, cracks,



Note: L = manufactured length—length specified by Engineer plus upset distance.

Standard Dimensions, mm				
12.7	+0.00 -0.25	± 1.6	25.4 ± 0.4	7.1
15.9	+0.00 -0.25	± 1.6	31.7 ± 0.4	7.1
19.0	+0.00 -0.38	± 1.6	31.7 ± 0.4	9.5
22.1	+0.00 -0.38	± 1.6	34.9 ± 0.4	9.5
25.4	+0.00 -0.38	± 1.6	41.3 ± 0.4	12.7

Figure 7.1—Dimension and Tolerances of Standard-Type Shear Connectors (see 7.2.1)

twists, bends, or other injurious discontinuities. Radial cracks or bursts in the head of a stud shall not be cause for rejection, provided that the cracks or bursts do not extend more than half the distance from the head periphery to the shank, as determined by visual inspection.

Note: Heads of shear connectors or anchor studs are subject to cracks or bursts, which are names for the same thing. Cracks or bursts designate an abrupt interruption of the periphery of the stud head by radial separation of

the metal. Such interruptions do not adversely affect the structural strength, corrosion resistance, nor other functional requirements of headed studs.

7.2.6 Only bases qualified under Annex VI shall be used. When requested by the Engineer, the contractor shall provide the following information:

- (1) A description of the stud and arc shield
- (2) Certification from the manufacturer that the stud base is qualified as specified in 7.2.4
- (3) Qualification test data

7.2.7 M270M Grades 690/690W (A709M Grades 690/690W) steels shall not be stud welded without approval of the Engineer.

7.3 Mechanical Requirements

7.3.1 Studs shall be made from cold-drawn bar stock conforming to the requirements of ASTM A108, *Specification for Steel Bars, Cold Finished, Standard Quality*, Grades G10100 through G10200, inclusive, either semi-killed or killed deoxidation.

7.3.1.1 Mechanical property requirements of studs other than outlined below shall be specified by the Engineer.

7.3.1.2 At the manufacturer's option, mechanical properties of studs shall be determined by testing either (1) the steel after cold finishing, or (2) the full diameter finished studs. In either case, the studs shall conform to the requirements shown in Table 7.1.

Table 7.1
Mechanical Property Requirements
for Studs (see 7.3.1.2)

	Type A*	Type B**
Tensile strength	380 MPa min.	415 MPa min.
Yield strength (0.2% offset)	—	345 MPa min.
Elongation (% in 50 mm)	17% min.	20% min.
Reduction of area	50% min.	50% min.

Notes:

*Type A studs shall be general purpose of any type and size used for purposes other than shear transfer in composite beam design and construction.

**Type B studs shall be studs that are headed, bent, or of other configuration in 12 mm through 23 mm diameter that are used as an essential component in composite beam design and construction.

7.3.2 Mechanical properties shall be determined in accordance with the applicable sections of ASTM A370, *Mechanical Testing of Steel Products*. A typical test fixture is used, similar to that shown in Figure 7.2.

7.3.3 Upon request by the Engineer, the contractor shall furnish the following:

7.3.3.1 The contractor shall provide the stud manufacturer's certification that the studs, as delivered, conform to the applicable requirements of 7.2 and 7.3.

7.3.3.2 The contractor shall provide certified copies of the stud manufacturer's test reports covering the last completed set of in-plant quality control mechanical tests, required by 7.3 for each stock size delivered. The quality control test shall have been made within the six month period before delivery of the studs.

7.3.4 When quality control tests are not available, the contractor shall furnish mechanical test reports conforming to the requirements of 7.3. The mechanical tests shall be on finished studs provided by the manufacturer of the studs. The number of tests to be performed shall be specified by the Engineer.

7.3.5 The Engineer may select studs of each type and size used under the contract as necessary for checking the requirements of 7.2 and 7.3. Furnishing these studs shall be at the contractor's expense. Testing shall be at the owner's expense.

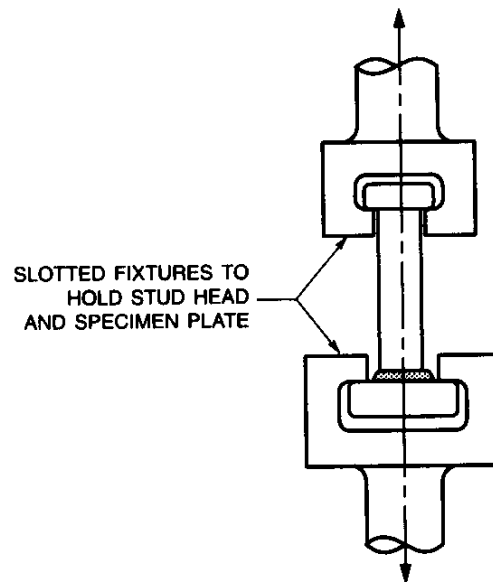


Figure 7.2—Typical Tension Test Fixture
(see 7.3.2)

7.4 Workmanship

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

7.4.2 The stud base shall not be painted, galvanized, nor cadmium-plated prior to welding.

7.4.3 The areas to which the studs are to be welded shall be free of scale, rust, moisture, and other injurious material to the extent necessary to obtain satisfactory welds. These areas may be cleaned by wire brushing, scaling, prick-punching, or grinding. Extreme care should be exercised when welding through metal decking.

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

7.4.5 Longitudinal and lateral spacings of stud shear connectors (type B) with respect to each other and to edges of beam or girder flanges may vary a maximum of 25 mm from the location shown in the drawings. The clear distance between studs shall not be less than 25 mm unless approved by the Engineer. The minimum distance from the edge of a stud base to the edge of a flange shall be the diameter of the stud plus 3 mm but preferably not less than 40 mm.

7.4.6 After welding, arc shields shall be broken free from studs to be embedded in concrete, and, where practical, from all other studs.

7.4.7 The studs, after welding, shall be free of any discontinuities or substances that would interfere with their intended function. However, nonfusion on the legs of the flash and small shrink fissures are acceptable.

Note: The fillet weld profiles shown in Figure 3.3 do not apply to the flash of automatically timed stud welds. The expelled metal around the base of the stud is designated as flash in accordance with Annex V of this code. It is not a fillet weld such as those formed by conventional arc welding. The expelled metal, which is excess to the weld required for strength, is not detrimental but, on the contrary, is essential to provide a good weld. The containment of this excess molten metal around a welded stud by the ferrule (arc shield) assists in securing sound fusion of the entire cross section of the stud base. The stud weld flash may have nonfusion in its vertical leg and overlap on its horizontal leg, and it may contain occasional small shrink fissures or other discontinuities that usually form at the top of the weld flash with essentially radial or longitudinal orientation, or both, to the axis of the stud. Such nonfusion, on the vertical leg of the flash, and small shrink fissures are acceptable.

7.5 Technique

7.5.1 Studs shall be welded with automatically timed stud welding equipment connected to a suitable source of direct current electrode negative (DCEN) power. Welding voltage, current, time, and gun settings for lift and plunge should be set at optimum settings, based on past practice, recommendations of stud and equipment manufacturer, or both. ANSI/AWS C5.4, *Recommended Practices for Stud Welding*, should also be used for technique guidance.

7.5.2 If two or more stud welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time, and so that the power source has fully recovered from making one weld before another weld is started.

7.5.3 While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

7.5.4 Welding shall not be done when the base metal temperature is below -20°C or when the surface is wet or exposed to falling rain or snow.

7.5.4.1 When the temperature of the base metal is below 0°C, one additional stud in each 100 studs welded shall be tested by methods specified in 7.7.1.3 and 7.7.1.4, except that the angle of testing shall be approximately 15 degrees. This is in addition to the first two studs tested for each start of a new production period or change in set-up.

7.5.4.2 Set-up includes stud gun, power source, stud diameter, gun lift and plunge, total welding lead length, or changes greater than $\pm 5\%$ in current (amperage) and time.

7.5.5 At the option of the contractor, studs may be fillet welded by the shielded metal arc process, provided the following requirements are met:

7.5.5.1 The minimum fillet size to be used shall be the larger of those required in Table 2.1 or Table 7.2.

Table 7.2
Minimum Fillet Weld Size for Small
Diameter Studs (see 7.5.5.1)

Stud Diameter, ϕ , mm	Min. Fillet Weld Size, mm
$\phi \leq 10$	6
$10 < \phi \leq 25$	8
$\phi > 25$	10

7.5.5.2 Welding shall be done with low-hydrogen electrodes 4.0 mm or 4.8 mm in diameter except that a smaller diameter electrode may be used on studs 10 mm or less in diameter or for out-of-position welds.

7.5.5.3 The stud base shall be prepared so that the base of the stud fits against the base metal.

7.5.5.4 All rust and mill scale at the location of the stud shall be removed from the base metal by grinding. The end of the stud shall also be clean.

7.5.5.5 The base metal to which studs are welded shall be preheated in accordance with the requirements of Table 4.4.

7.5.5.6 Fillet welded stud bases shall be visually inspected per 6.5.

7.6 Stud Application Qualification Requirements

7.6.1 Prequalification. Studs which are shop or field applied in the flat (down-hand) position to a planar and horizontal surface are deemed prequalified by virtue of the manufacturer's stud-base qualification tests (Annex VI), and no further application testing is required. The limit of flat position is defined as 0–15° slope on the surface to which the stud is applied.

The following are some non-prequalified stud applications that require tests of this section:

- (1) Studs which are applied on nonplanar surfaces or to a planar surface in the vertical or overhead positions.
- (2) Studs which are welded through decking. The tests should be with material representative of the condition to be used in construction.
- (3) Studs welded to steels other than those listed in 9.2.1.

7.6.2 Responsibilities for Tests. The contractor or stud applicator shall be responsible for the performance of these tests. Tests may be performed by the contractor or stud applicator, the stud manufacturer, or by another testing agency satisfactory to all parties involved.

7.6.3 Preparation of Specimens

7.6.3.1 Test specimens shall be prepared by welding the studs being qualified to specimen plates of M270M Grade 250 (A709M Grade 250) steel or any base metal listed in 9.2.1.

7.6.3.2 Weld position, nature of base metal and stud surfaces, current, and time shall be recorded.

7.6.4 Number of Specimens. Ten (10) specimens shall be welded consecutively using recommended procedures

and settings for each diameter, position, and surface geometry.

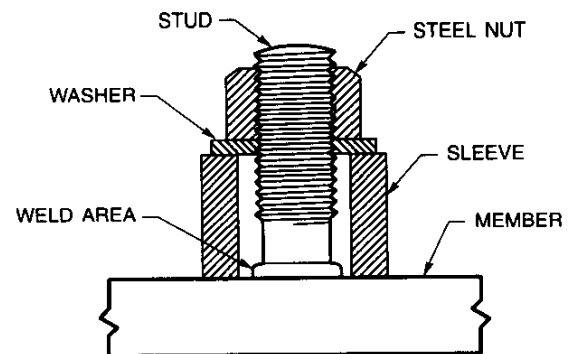
7.6.5 Tests Required. The ten (10) specimens shall be tested using one or more of the following test methods: bending, torquing, or tensioning.

7.6.6 Test Methods

7.6.6.1 Bend Test. Studs shall be bend tested by being bent 90 degrees from their original axis. A stud application shall be considered qualified if the studs are bent 90 degrees and fracture occurs in the plate or shape material or in the shank of the stud and not in the weld.

7.6.6.2 Torque Test. Studs shall be torque tested using a torque-test arrangement that is substantially in accordance with Figure 7.3. A stud application shall be considered qualified if all test specimens are torqued to destruction without failure in the weld.

7.6.6.3 Tension Test. Studs shall be tension tested to destruction using any machine capable of supplying the required force. A stud application shall be considered qualified if the test specimens do not fail in the weld.



Note: The dimensions shall be appropriate to the size of the stud. The threads of the stud shall be clean and free of lubricant other than the residue of cutting oil.

Required Torque for Testing Threaded Studs	
Nominal Diameter & Thread Pitch (mm)	Testing Torque (J)
M 6 × 1	6
M 8 × 1.25	12
M 10 × 1.5	20
M 12 × 1.75	50
M 14 × 2	73
M 16 × 2	100
M 20 × 2.5	180
M 22 × 2.5	285
M 24 × 3	430

Figure 7.3—Torque Testing Arrangement and Table of Testing Torques (see 7.6.6.2)

7.6.7 Application Qualification Test Data shall include the following:

- (1) Drawings that show shapes and dimensions of studs and arc shields
- (2) A complete description of stud and base materials and a description (part number) of the arc shield
- (3) Welding position and settings (current, time)
- (4) A record which shall be made for each qualification and that record shall be available for each contract

7.7 Production Control

7.7.1 Preproduction Testing

7.7.1.1 Before production welding with a particular set-up (see 7.5.4.2) and with a given size and type of stud, and at the beginning of each day's or shift's production, testing shall be performed on the first two studs that are welded. The stud technique may be developed on a piece of material similar to the production member in thickness and properties. If actual production thickness is not available, the thickness may vary plus or minus 25 percent. All test studs shall be welded in the same general position as required on the production member (flat, vertical, or overhead).

7.7.1.2 Instead of being welded to separate material, the test studs may be welded on the production member, except when separate plates are required by 7.7.1.5.

7.7.1.3 The test studs shall be visually examined. They shall exhibit full 360 degree flash.

7.7.1.4 In addition to visual examination, the test shall consist of bending the studs after they are allowed to cool, to an angle of approximately 30 degrees from their original axes by either striking the studs on the head with a hammer or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud. At temperatures below 10°C, bending shall preferably be done by continuous slow application of load. For threaded studs, the torque test of Figure 7.3 shall be substituted for the bend test.

7.7.1.5 If on visual examination the test studs do not exhibit 360 degree flash, or if on testing, failure occurs in the weld zone of either stud, the procedure shall be corrected, and two more studs shall be welded to separate material or on the production member and tested in accordance with the provisions of 7.7.1.3 and 7.7.1.4. If either of the second two studs fails, additional welding shall be continued on separate plates until two consecutive studs are tested and found to be satisfactory before any more production studs are welded to the member.

7.7.2 Production Welding. Once production welding has begun, any changes made to the welding set-up (see 7.5.4.2) as determined in 7.7.1 shall require that the testing in 7.7.1.3 and 7.7.1.4 be performed prior to resuming production welding.

7.7.3 In production, studs on which a full 360 degree flash is not obtained may, at the option of the contractor, be repaired by adding the minimum fillet weld as required by 7.5.5 in place of the missing flash. The repair weld shall extend at least 10 mm beyond each end of the discontinuity being repaired.

7.7.4 Operator Qualification

7.7.4.1 The preproduction test required by 7.7.1, if successful, shall also serve to qualify the stud welding operator.

7.7.4.2 Before any production studs are welded by an operator not involved in the preproduction set-up of 7.7.1, the first two studs welded by the operator shall be tested in accordance with the provisions of 7.7.1.3 and 7.7.1.4. When two consecutively welded studs have been tested and found satisfactory, the operator may then weld production studs.

7.7.5 If an unacceptable stud has been removed from a component subjected to tensile stresses, the area from which the stud was removed shall be made smooth and flush.

7.7.5.1 Where in such areas the base metal has been pulled out in the course of stud removal, shielded metal arc welding (SMAW) with low-hydrogen electrodes in accordance with the requirements of this code shall be used to fill the pockets, and the weld surface shall be ground flush.

7.7.5.2 In compression areas of members, if stud failures are confined to shanks or fusion zones of studs, a new stud may be welded adjacent to each unacceptable area in lieu of repair and replacement on the existing weld area (see 7.4.3). If base metal is pulled out during stud removal, the repair provisions shall be the same as for tension areas, except that when the depth of discontinuity is the lesser of 3 mm or 7 percent of the base-metal thickness, the discontinuity may be faired by grinding in lieu of filling with weld metal.

7.7.5.3 Where a replacement stud is to be provided, the base-metal repair shall be made prior to welding the replacement stud.

7.7.5.4 Replacement studs (other than threaded type which should be torque tested) shall be tested by bending to an angle of approximately 15 degrees from their original axis.

7.7.5.5 The areas of components exposed to view in completed structures shall be made smooth and flush where a stud has been removed.

7.8 Inspection Requirements

7.8.1 If visual inspection reveals any stud that does not show a full 360 degree flash or any stud that has been repaired by welding, such stud shall be bent to an angle of approximately 15 degrees from its original axis.

7.8.2 The method of bending shall be in accordance with 7.7.1.4. The direction of bending for studs with less than a 360 degree flash shall be opposite to the missing portion of the flash.

7.8.3 Threaded studs shall be torque tested. Torque testing shall be in accordance with Figure 7.3.

7.8.4 The inspector, where conditions warrant, may select a reasonable number of additional studs to be subjected to the tests specified in 7.8.1.

7.8.5 The bent stud shear connectors (Type B) and other studs to be embedded in concrete (Type A) that show no

sign of failure shall be acceptable for use and left in the bent position. All bending and straightening when required shall be done without heating, before completion of the production stud welding operation, except as otherwise provided in the contract.

7.8.6 If, in the judgment of the Engineer, studs welded during the progress of the work are not in accordance with code provisions, as indicated by inspection and testing, corrective action shall be required of the contractor at the contractor's expense. The contractor shall make the set-up changes necessary to insure that studs subsequently welded will meet code requirements.

7.8.7 At the option and the expense of the owner, the contractor may be required, at any time, to submit studs of the types used under the contract for a qualification check in accordance with the procedures of Annex VI.

8. Statically Loaded Structures

NO APPLICATIONS WITHIN THIS CODE

9. Welded Steel Bridges

Part A *General Requirements*

9.1 Application

This section supplements sections 1 through 6 and is to be used in conjunction with the *AASHTO Standard Specification for Highway Bridges* or the *AASHTO LRFD Bridge Design Specification* for the design and construction of bridges.

9.2 Base Metal

9.2.1 Unless otherwise specified, steel base metal to be welded under this code shall meet the requirements of the latest edition of AASHTO M270M (ASTM A709M) for the grade of steel shown on the plans or listed in the specifications. Thickness limitations shall not apply to bearing components. All Grade 345 steel that is to be welded shall be Type 1, 2, or 3. Other steels may be approved by the Engineer. See 1.2.2.

9.2.3 Use of Unlisted Base Metals. When a steel other than one of those listed in 9.2.1 is approved under the provisions of the general specification, and such steel is proposed for welded construction under this code, welding procedure specifications (WPSs) shall be established by qualification in accordance with the requirements of 5.13. The fabricator shall have the responsibility for establishing the welding procedure by qualification.

9.2.3.1 The Engineer shall require evidence of adequate weldability of the steel, which as a minimum will require the following:

(1) Acceptance by other national codes such as ASME, AWS (Offshore Applications), and ABS (Ships) of the steel for similar or stricter requirements for strength and toughness at equivalent loading rates.

(2) A minimum history of five-year use under similar conditions of loading.

(3) Records of past weld testing that would verify adequate resistance of the steel to hydrogen cracking at medium restraint levels. These tests should also establish the maximum and minimum heat input range for each welding process to be used in construction.

9.2.3.2 The responsibility for determining weldability, including the assumption of additional testing costs involved, is assigned to the party who either specifies a material not listed in 9.2.1 or who proposes the use of a substitute material not listed in 9.2.1. The party proposing the use of a substitute material not listed in 9.2.1 shall assume the additional costs involved in establishing the welding procedure as required in 9.2.3.

9.2.3.3 When a grade of steel not listed in 9.2.1 is required by the Engineer or contract documents, a weldability investigation shall be conducted in accordance with the supplementary requirements at the end of this section (Part D).

9.2.3.4 When base metals not listed in 9.2.1 are approved for welding to base metals of the same specification and grade or to steels listed in 9.2.1, the welding procedure shall be qualified by test under the provisions of 5.13.

(1) In addition, when specified in the contract documents or ordered by the Engineer, Charpy V-notch tests shall be made to measure the toughness of the coarse-grained area of the heat-affected zone (HAZ) (see 5.4.3.1).

(2) The WPS shall list all welding variables and the minimum preheat and interpass temperature for the thicknesses listed in Table 4.4.

(a) When quenched and tempered steels are to be welded, both the minimum and maximum preheat and interpass temperatures shall be listed for each welding heat input and thickness as shown in Table 12.5.

(b) The WPS shall list any special precautions necessary to avoid weld and HAZ cracking and to insure that the required strength, ductility, and toughness will be produced.

9.2.4 Base Metal for Weld Tabs and Backing

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

(1) The weld tab may be of any of the steels listed in 9.2.1 except that Grade 690 or 690W tabs shall not be used on lower strength steels.

(2) Base metal used as temporary weld extensions shall be exempt from toughness testing.

9.2.4.2 Backing. Steel backing shall conform to the following requirements:

(1) When welding any approved steel listed in 9.2.1, backing may be of any of the steels listed in 9.2.1 except that Grade 690 or 690W backing shall not be used on lower strength steels.

(2) When welding a steel qualified in accordance with 9.2.3, backing may be Grades 485W, 345, 345W, 250 or the steel qualified.

(3) Backing not exceeding 10 mm × 30 mm, furnished as bar stock or cut from plate, is exempt from toughness testing requirements.

9.2.5 Base Metal Limitations

The provisions of this code are not intended for use with steels having a minimum specified yield strength over 690 MPa.

Part B Structural Details

9.3 General

In general, stress concentrations should be avoided. This can be accomplished by sizing parts and organizing components to minimize constraint against ductile behavior, and avoiding unnecessary concentrations of welds, particularly where there are short unwelded portions of base metal between welds. Welds should not be larger than necessary. Welds should be sized to carry required loads at appropriate design stresses. Excess weld metal increases residual stress, and, when carried to extreme, may result in unacceptable distortion, cracks or lamellar tears. The organization of parts in welded assemblies and details of welded joints shall afford ample access for the deposition of all required weld passes.

9.4 Noncontinuous Beams

The connections at the ends of noncontinuous beams shall be designed with flexibility so as to avoid excessive secondary stresses due to bending. Seated connections with a flexible or guiding device to prevent end twisting are recommended.

9.5 Participation of Floor System

Details of the floor system should be so designed as to avoid, insofar as possible, unintended participation in chord or flange stresses.

9.6 Lap Joints

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

9.6.2 If longitudinal fillet welds are used alone in lap joints of end connections, the length of each fillet weld shall be no less than the perpendicular distance between the welds (shown as dotted line in Figure 9.1). The transverse spacing of the welds shall not exceed 16 times the thickness of the connected thinner part unless suitable provision is made (as by intermediate plug or slot welds) to prevent buckling or separation of the parts. The longitudinal fillet weld may be either at the edges of the member or in slots.

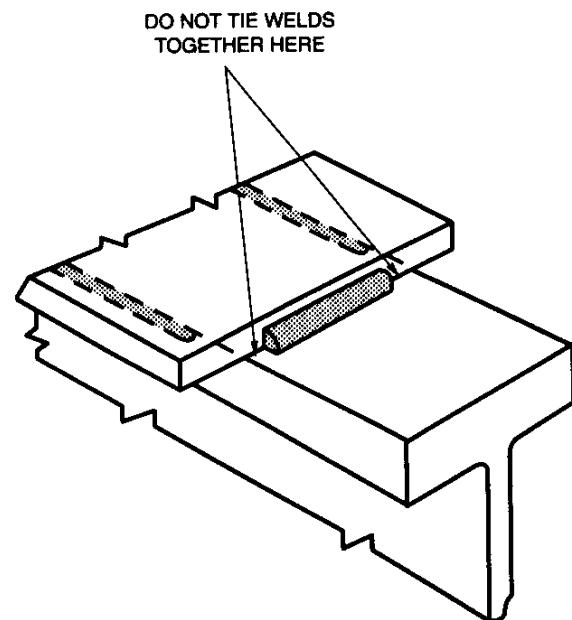


Figure 9.1—Fillet Welds on Opposite Sides of a Common Plane of Contact (see 9.11.2)

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

9.6.4 Lap joints are Category E details and should be avoided, when possible, in members subject to tension or reversal of stresses.

9.7 Corner and T-Joints

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

9.7.2 Corner and T-joints parallel to the direction of computed stress between components of built-up members designed for axial stress need not be complete joint penetration groove welds. Fillet welds or a combination of partial joint penetration welds and reinforcing fillet welds may be used.

9.8 Prohibited Types of Joints and Welds

The joints and welds listed in the following paragraphs are prohibited:

(1) All partial joint penetration groove welds in butt joints except those conforming to 9.14

(2) Complete joint penetration groove welds, in all members carrying calculated stress or in secondary members subject to tension or the reversal of stress, made from one side only without any backing, or with backing other than steel, that has not been qualified in accordance with 5.13

(3) Intermittent groove welds

(4) Intermittent fillet welds, except as approved by the Engineer

(5) Bevel-groove and J-groove welds in butt joints in the flat, vertical and overhead positions (see Figure 2.4)

(6) Plug and slot welds in members subject to tension and reversal of stress

9.9 Combinations of Welds

If two or more of the general types of welds (groove, fillet, plug, 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 (see Annex I). However, such methods of adding individual capacities of welds do not apply to fillet welds reinforcing complete joint penetration groove welds.

9.10 Welds in Combination with Rivets and Bolts

In new work, rivets or 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 plans should indicate whether holes should be filled and in what manner.

9.11 Fillet Weld Details

9.11.1 Fillet welds which support a tensile force that is not parallel to the axis of the weld shall not terminate at the corners of parts or members, but shall be returned continuously, full size, around the corner for a length equal to twice the weld size where such return can be made in the same plane. Boxing shall be indicated on design and detail drawings.

9.11.2 Fillet welds deposited on the opposite sides of a common plane of contact between two parts shall be interrupted at a corner common to both welds (see Figure 9.1).

9.12 Eccentricity of Connections

9.12.1 Eccentricity between intersecting parts and members shall be avoided insofar as practical.

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

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

9.12.4 For axially stressed angle members, the center of gravity of the connecting welds shall preferably lie between the line of the center of gravity of the angle's cross section and the centerline of the connected leg. If the center of gravity of the connecting weld lies outside of this zone, the total stresses, including those due to the

eccentricity from the center of gravity of the angle, shall not exceed those permitted by this code.

9.13 Connections or Splices— Tension and Compression Members

Connections or splices of tension or compression members made by groove welds shall have complete joint penetration welds. Connections or splices made with fillet welds, except as noted in 9.14, shall be designed for an average of the calculated stress and the strength of the member, but not less than 75 percent of the strength of the member, or if there is repeated application of load, the maximum stress or stress range in such connection or splice shall not exceed the fatigue stress permitted by the applicable AASHTO specification.

9.14 Connections or Splices in Compression Members with Milled Joints

If members subject only to compression are spliced and full-milled bearing is provided, the splice material and its welding shall be arranged, unless otherwise stipulated by the applicable general specifications, to hold all parts in alignment and shall be proportioned to carry 50 percent of the computed stress in the member. Where such members are in full-milled bearing on base plates, there shall be sufficient welding to hold all parts securely in place.

9.15 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 continuous welds to make the pieces act in unison.

9.16 Transition of Thicknesses or Widths at Butt Joints

9.16.1 Butt joints 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 transverse to 2.5 longitudinal 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 9.2).

9.16.2 In butt joints between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished as specified in 9.16.1 when offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected. When the offset is equal to or less than the thickness of the thinner part connected, the face of the weld shall be sloped no more than 1 transverse to 2.5 longitudinal 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 9.16.1.

9.16.3 Butt joints 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 transverse to 2.5 longitudinal with the edge of either part or shall be transitioned with a 600 mm minimum radius tangent to the narrower part at the center of the butt joint (see Figure 9.3). A radius transition is required for M270M Grades 690/690W (A709M Grades 690/690W) and M270M Grade 485W (A709M Grade 485W).

9.17 Girders and Beams

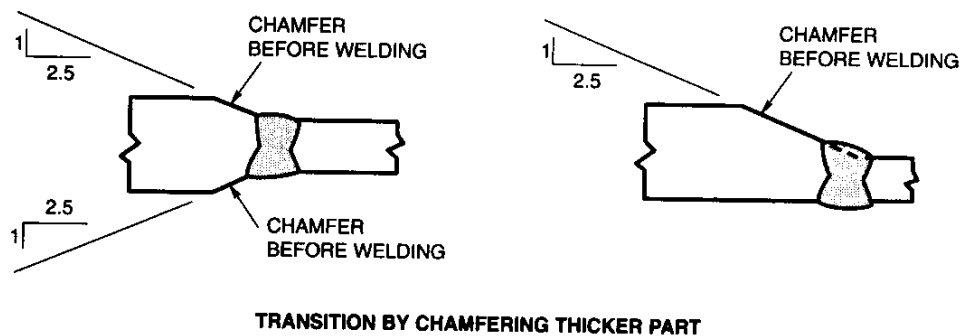
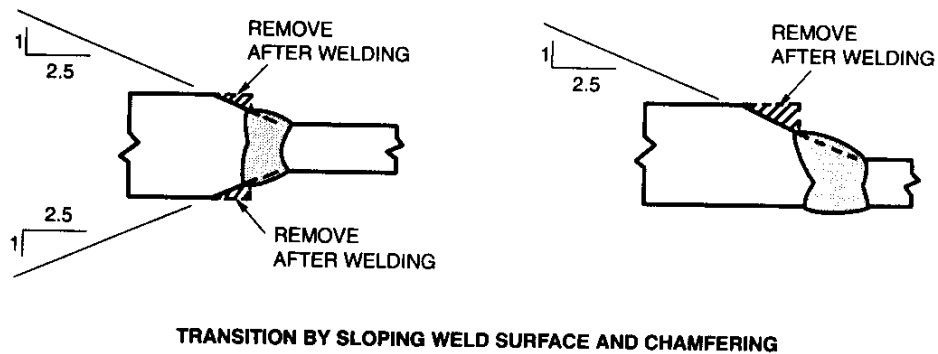
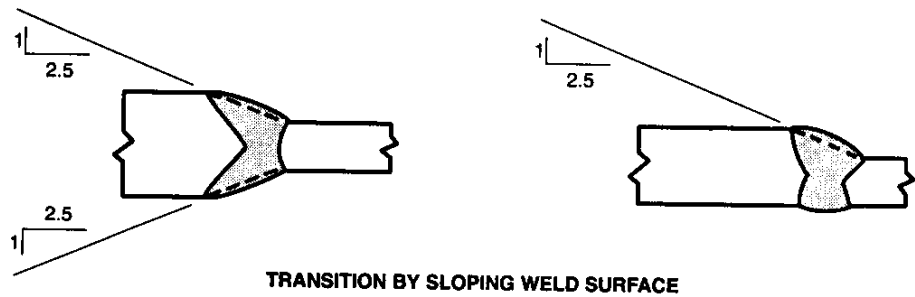
9.17.1 Connections or splices in beams or girders when made by groove welds shall have complete joint penetration welds. Connections or splices made with fillet or plug welds shall be designed for the average of the calculated stress and the strength of the member, but not less than 75 percent of the strength of member. When there is repeated application of load, the maximum stress or stress range in such connections or splices shall not exceed the fatigue stress permitted by the AASHTO specification.

9.17.2 Splices between sections of rolled beams or built-up girders shall preferably be made in a single transverse plane. Shop splices of webs and flanges in built-up girders, made before the webs and flanges are joined to each other, may be located in a single transverse plane or multiple transverse planes, but the fatigue stress provisions of the AASHTO specifications shall apply.

Part C Workmanship

9.18 Preparation of Material

9.18.1 Edges of material thicker than specified in the following list shall be trimmed if and as required to produce



CENTERLINE ALIGNMENT
(PARTICULARLY APPLICABLE TO WEB PLATES)

OFFSET ALIGNMENT
(PARTICULARLY APPLICABLE TO FLANGE PLATES)

Notes:

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

Figure 9.2—Transition of Thickness at Butt Joints of Parts Having Unequal Thickness
(see 9.16.1)

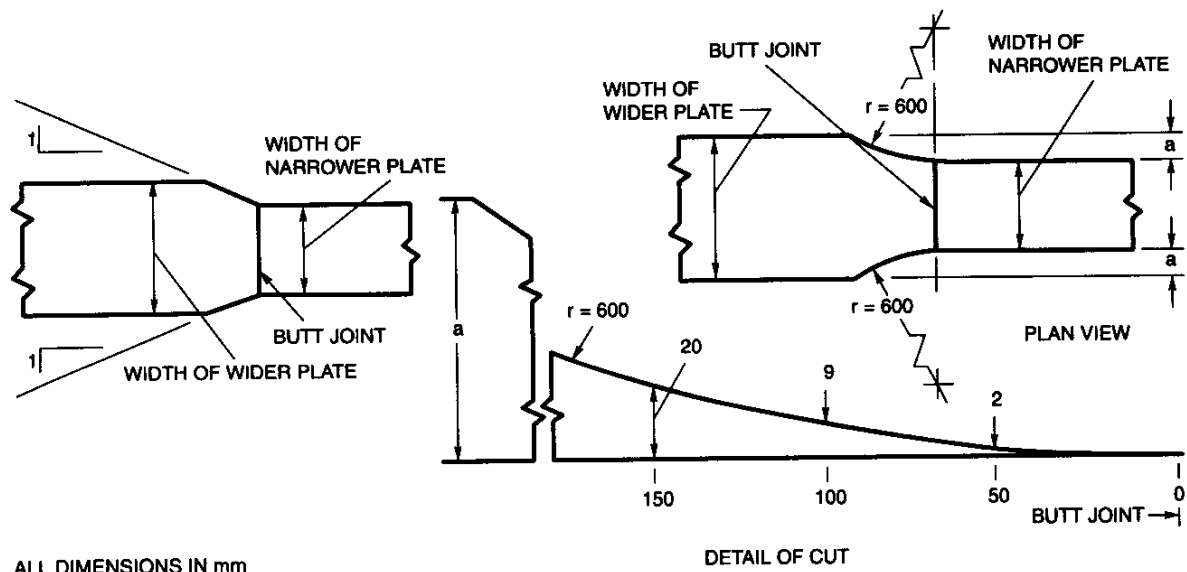


Figure 9.3—Transition of Width at Butt Joints of Parts Having Unequal Width (see 9.16.3)

a satisfactory welding edge wherever a weld along the edge is to carry calculated stress:

Sheared edges of material thicker than	12 mm
Rolled edges of plates (other than universal mill plates) thicker than	10 mm
Toes of angles or rolled shapes (other than wide flange sections) thicker than	16 mm
Universal mill plates or edges of flanges of wide flange sections thicker than	25 mm

The form of edge preparation for butt joints shall conform to the requirements of 2.9 except as modified by 2.6.

9.18.2 Steel and weld metal may be thermally cut, provided a smooth and regular surface free from cracks and notches is secured, and provided that an accurate profile is secured by the use of a mechanical guide. Freehand thermal cutting shall be done only where approved by the Engineer.

9.19 Dimensional Tolerances

The dimensions of structural members shall be within the tolerances specified in 3.5. The following shall also apply:

9.19.1 Variations from flatness of girder webs shall be determined by measuring offsets from a straight edge whose length is no less than the least dimension of any panel. The straight edge shall be placed in any position of maximum variation on the web with the ends of the straight edge adjacent to opposite panel boundaries.

9.19.2 Variation from flatness of webs having a depth, D , and a thickness, t , in panels bounded by stiffeners or flanges, or both, whose least panel dimension is d shall not exceed the following (all dimensions in mm):

Intermediate stiffeners on both sides of web

Interior girders—

where $D/t < 150$ — maximum variation = $d/115$
 where $D/t \geq 150$ — maximum variation = $d/92$

Fascia girders—

where $D/t < 150$ — maximum variation = $d/130$
 where $D/t \geq 150$ — maximum variation = $d/105$

Intermediate stiffeners on one side only of web

Interior girders—

where $D/t < 100$ — maximum variation = $d/100$
 where $D/t \geq 100$ — maximum variation = $d/67$

Fascia girders —

where $D/t < 100$ — maximum variation = $d/120$
 where $D/t \geq 100$ — maximum variation = $d/80$

No intermediate stiffeners — maximum variation = $D/150$
 (See Annex IV for tabulation.)

9.19.3 Web distortion of twice the allowable tolerances of 9.19.2 shall be satisfactory when occurring at the end of a girder which has been drilled, or subpunched and reamed either during assembly or to a template for a field bolted splice, provided, when the splice plates are bolted, the web assumes the proper dimensional tolerances.

9.19.4 If architectural considerations require tolerances more restrictive than described above, specific reference must be included in the bid documents.

9.20 Temporary Welds

Temporary welds shall be subject to the same WPS requirements as final welds. They shall be removed unless otherwise permitted by the Engineer. When they are removed, the surface shall be made flush with the original surface. There shall be no temporary welds in tension zones of members of quenched and tempered steels. Temporary welds at other locations shall be shown on shop drawings. Removal of temporary welds shall conform to the requirements of 3.3.7.3 and 3.3.7.4.

9.21 Quality of Welds

Note: See Annex B for a description of discontinuities.

9.21.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if it shows the following requirements:

9.21.1.1 The weld shall have no cracks.

9.21.1.2 Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.

9.21.1.3 All craters are to be filled to the full cross section of the weld, except for the ends of intermittent fillet welds outside of their effective length when such welds are permitted in the design.

9.21.1.4 Weld profiles are to be in accordance with 3.6.

9.21.1.5 In primary members, undercut shall be no more than 0.25 mm deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1 mm deep for all other cases.

9.21.1.6 The frequency of piping porosity in the surface of fillet welds shall not exceed one in 100 mm or six in 1200 mm of weld length and the maximum diameter shall not exceed 2.4 mm.

(1) A subsurface inspection for porosity shall be performed whenever piping porosity 2.4 mm or larger in diameter extends to the surface at intervals of 300 mm or less over a distance of 1200 mm, or when the condition of electrodes, flux, base metal, or the presence of weld cracking indicates that there may be a problem with piping or gross porosity.

(2) This subsurface inspection shall be a visual inspection of 300 mm exposed lengths of the fillet weld throat after it has been ground or removed by air carbon arc gouging to a depth of 1/2 the design throat. When viewed at mid-throat of the weld, the sum of the diameters of all porosity shall not exceed 10 mm in any 25 mm length of weld or 20 mm in any 300 mm length of weld.

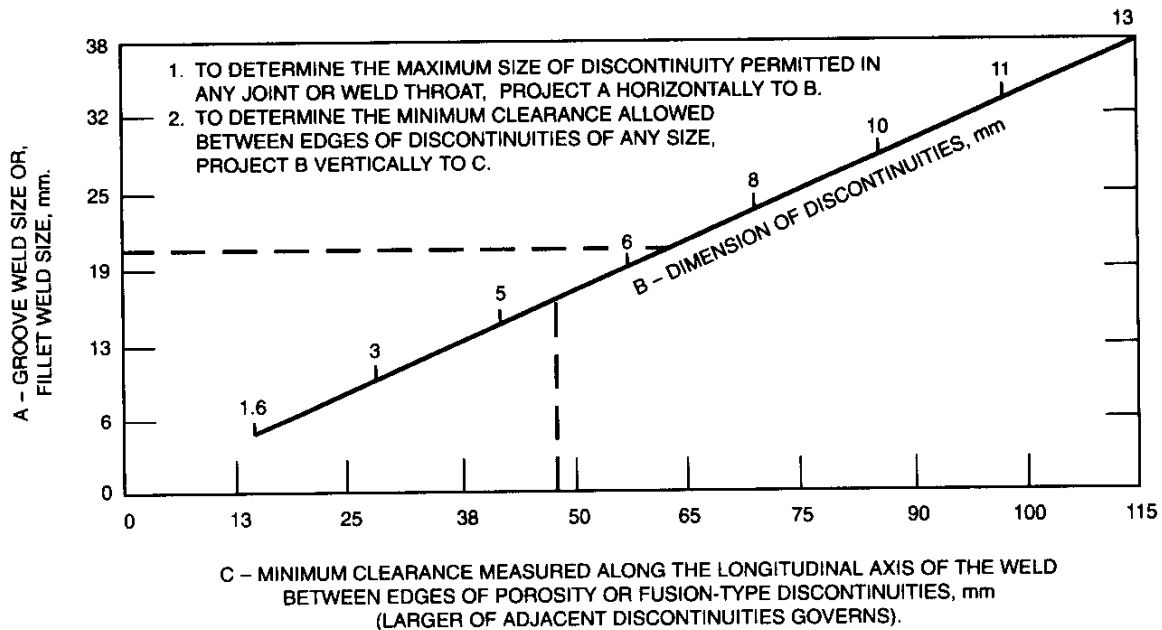
9.21.1.7 A fillet weld in any single continuous weld shall be permitted to underrun the nominal fillet weld size specified by 2 mm without correction, provided that the undersize portion of the weld does not exceed 10 percent of the length of the weld. On the web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.

9.21.1.8 Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 100 mm of length, and the maximum diameter shall not exceed 2.4 mm.

9.21.1.9 Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for M270M Grades 690/690W (A709M Grades 690/690W) steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.

9.21.2 Radiographic and Magnetic-Particle Inspection. Welds that are subject to radiographic or magnetic-particle testing in addition to visual inspection shall have no cracks and shall be unacceptable if the radiograph or magnetic-particle testing shows any of the types of discontinuities listed in 9.21.2.1, 9.21.2.2, 9.21.2.3, or 9.21.2.4.

9.21.2.1 For welds subject to tensile stress under any condition of loading, the greatest dimension of any porosity or fusion-type discontinuity that is 1.6 mm or larger in greatest dimension shall not exceed the size, B, indicated in Figure 9.4 for the effective throat or weld size involved. The distance from any porosity or fusion-type discontinuity described above to another such discontinuity, to an edge, or to the toe or root of any intersecting flange-to-web weld shall be not less than the minimum clearance allowed, C, indicated in Figure 9.4 for the size of discontinuity under examination.



NOTE: Adjacent discontinuities, spaced less than the minimum spacing required, shall be measured as one length equal to the sum of the total length of the discontinuities plus the length of the space between them and evaluated as a single discontinuity.

Figure 9.4—Weld Quality Requirements for Discontinuities Occurring in Tension Welds (Limitations of Porosity and Fusion Discontinuities) (see 9.21.2.1)

9.21.2.2 For welds subject only to compressive stress and specifically indicated as such on the design drawings, the greatest dimension of porosity or a fusion-type discontinuity that is 3 mm or larger in greatest dimension shall not exceed the size, B, nor shall the space between adjacent discontinuities be less than the minimum clearance allowed, C, indicated by Figure 9.5 for the size of discontinuity under examination.

9.21.2.3 Independent of the requirements of 9.21.2.1 and 9.21.2.2, discontinuities having a greatest dimension of less than 1.6 mm shall be unacceptable if the sum of their greatest dimensions exceeds 10 mm in any 25 mm length of weld.

9.21.2.4 The limitations given by Figures 9.4 and 9.5 for 38 mm weld size shall apply to all weld sizes greater than 38 mm.

9.21.2.5 Annex A illustrates the application of the requirements given in 9.21.2.1.

9.21.3 Ultrasonic Inspection

9.21.3.1 Welds that are subject to ultrasonic testing in addition to visual inspection are acceptable if they meet the following requirements:

(1) Welds subject to tensile stress under any condition of loading shall conform to the requirements of Table 9.1.

(2) Welds subject to compressive stress shall conform to the requirements of Table 9.2.

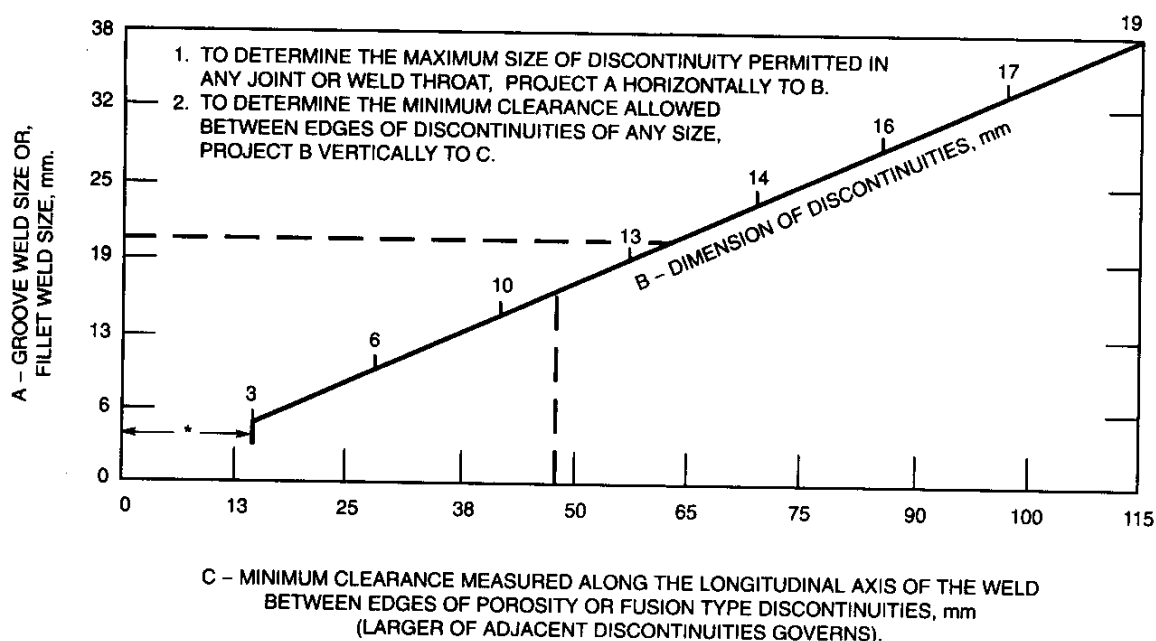
9.21.3.2 Ultrasonically tested welds are evaluated on the basis of a discontinuity reflecting ultrasound in proportion to its effect on the integrity of the weld.

(1) Indications of discontinuities that remain on the cathode ray tube as the search unit is moved towards and away from the discontinuity (scanning movement "b") may be indicative of planar discontinuities with significant flaw height dimension.

(2) As the orientation of such discontinuities, relative to the sound beam, deviates from the perpendicular, dB ratings which do not permit direct, reliable evaluation of the welded joint integrity may result.

(3) When indications that exhibit these planar characteristics are present at scanning sensitivity, a more detailed evaluation of the discontinuity by other means may be required (e.g., alternate ultrasonic techniques, radiography, grinding or gouging for visual inspection, etc.).

9.21.3.3 Complete joint penetration web-to-flange welds shall conform to the requirements of Table 9.2,



*The maximum size of a discontinuity located within this distance from an edge of plate shall be 3 mm, but a 3 mm discontinuity must be 6 mm or more away from the edge. The sum of discontinuities less than 3 mm in size and located within this distance from the edge shall not exceed 5 mm. Discontinuities 2 mm to less than 3 mm will not be restricted in other locations unless they are separated by less than 2 L (L being the length of the larger discontinuity); in which case, the discontinuities shall be measured as one length equal to the total length of the discontinuities and space and evaluated as shown in Figure 9.5.

Figure 9.5—Weld Requirements for Discontinuities Occurring in Compression Welds (Limitations of Porosity or Fusion Type Discontinuities) (see 9.21.2.2)

and acceptance for discontinuities detected by scanning movements other than scanning pattern "E" (see 6.24.2.2) may be based on a weld thickness equal to the actual web thickness plus 25 mm.

(1) Discontinuities detected by scanning pattern E shall be evaluated to the criteria of 9.21.3.1 for the actual web thickness.

(2) When such web-to-flange welds are subject to calculated tensile stress normal to the weld axis, they shall be so designated on design drawings and shall conform to the requirements of Table 9.1.

9.21.4 Liquid Penetrant Inspection. Welds that are subject to liquid penetrant testing, in addition to visual inspection, shall be evaluated on the basis of the requirements for visual inspection.

9.21.5 Timing of Nondestructive Testing

9.21.5.1 When welds are subject to nondestructive testing in accordance with 9.21.2, 9.21.3, and 9.21.4, the testing may begin immediately after the completed welds have cooled to ambient temperature.

9.21.5.2 Acceptance of welds in M270M Grades 690/690W (A709M Grades 690/690W) steels shall be based on nondestructive testing performed not less than 48 hours after completion of the welds.

Part D Supplementary Requirements

Supplementary requirements shall not apply unless specified by the Engineer or in contract documents. Tests other than the longitudinal-bead-weld underbead cracking test may be specified.

S9.22 Weldability Investigation

S9.22.1 The weldability investigation described herein shall be made for the grade or type of steel of the applicable ASTM specification when such investigation is required by 9.2.3 of this code.

Table 9.1
Ultrasonic Acceptance-Rejection Criteria—Tensile Stress (see 9.21.3.1)

Flaw Severity Class	Weld Thickness* and Search Unit Angle										
	8 through 20	> 20 through 38	> 38 through 60			> 60 through 100			> 100 through 200		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+10 & lower	+8 & lower	+4 & lower	+7 & lower	+9 & lower	+1 & lower	+4 & lower	+6 & lower	-2 & lower	+1 & lower	+3 & lower
Class B	+11	+9	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	-1 0	+2 +3	+4 +5
Class C	+12	+10	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7
Class D	+13 & up	+11 & up	+9 & up	+12 & up	+14 & up	+6 & up	+9 & up	+11 & up	+3 & up	+6 & up	+8 & up

Notes:

- Class B and C flaws shall be separated by at least 2L, L being the length of the longer flaw, except that when two or more such flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the flaw shall be considered a single acceptable flaw.
- Class B and C flaws shall not begin at a distance less than 2L from the end of the weld, L being the flaw length.
- Flaws detected at "scanning level" in the root face area of complete joint penetration double groove weld joints shall be evaluated using an indicating rating 4 dB more sensitive than described in 6.19.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d").
- For indications that remain on the display as the search unit is moved, refer to 9.21.3.2.

*Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm.

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

Class B (medium flaws)
Any indication in this category having a length greater than 20 mm shall be rejected.

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

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

Scanning Levels	
Sound path (mm)**	Above Zero Reference, dB
through 60 mm	20
> 60 through 125	25
> 125 through 250	35
> 250 through 400	45

**This column refers to sound path distance; NOT material thickness.

Table 9.2
Ultrasonic Acceptance-Rejection Criteria—Compressive Stress (see 9.21.3.1)

Flaw Severity Class	Weld Thickness* and Search Unit Angle										
	8 through 20	> 20 through 38	> 38 through 60			> 60 through 100			> 100 through 200		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	-2 & lower	+1 & lower	+3 & lower	-5 & lower	-2 & lower	0 & lower	-7 & lower	-4 & lower	-1 & lower
Class B	+6	+3	-1 0	+2 +3	+4 +5	-4 -3	-1 0	+1 +2	-6 -5	-3 -2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	-2 to +2	+1 +2	+3 +4	-4 to +2	-1 to +2	+2 +3
Class D	+8 & up	+5 & up	+3 & up	+6 & up	+8 & up	+3 & up	+3 & up	+5 & up	+3 & up	+3 & up	+4 & up

Notes:

- Class B and C flaws shall be separated by at least 2L, L being the length of the longer flaw, except that when two or more such flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the flaw shall be considered a single acceptable flaw.
- Class B and C flaws shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the flaw length.
- Flaws detected at "scanning level" in the root face area of complete joint penetration double groove weld joints shall be evaluated using an indicating rating 4 dB more sensitive than described in 6.19.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d").
- Electroslag or electrogas welds: Flaws detected at "scanning level" which exceed 50 mm in length shall be suspected as being piping porosity and shall be further evaluated with radiography.
- For indications that remain on the display as the search unit is moved, refer to 9.21.3.2.

*Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined, given in mm.

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

Class B (medium flaws)
 Any indication in this category having a length greater than 20 mm shall be rejected.

Class C (small flaws)
 Any indication in this category having a length greater than 50 mm shall be rejected.

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

Scanning Levels	
Sound path (mm)**	Above Zero Reference, dB
through 60 mm	14
> 60 through 125	19
> 125 through 250	29
> 250 through 400	39

**This column refers to sound path distance; NOT material thickness.

S9.23 Proof of Weldability

The Engineer may accept other tests as proof of weldability for steels to be used on specific projects.

S9.24 Weldable Steels

Steels listed as weldable in 9.2.1 shall be approved by the AASHTO Subcommittee on Bridges and Structures.

S9.25 Longitudinal-Bead-Weld Underbead Cracking Tests

S9.25.1 The producer shall prepare a report of the longitudinal-bead-weld underbead cracking tests presenting complete details, with photographs, of test procedures and test results.

Note: The longitudinal-bead-weld underbead-cracking test, also known as the Battelle underbead cracking test, is described in FHWA report number FHWA-RD-83, "Assessing Fracture Toughness and Cracking Susceptibility of Steel Weldments—A Review," available from the National Technical Information Service, Springfield, VA 22161.

The report shall include recommendations for welding procedures, including filler metals, preheat and interpass temperatures, and any other special procedures necessary for obtaining acceptable welds. These recommendations shall include information for the shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), and flux cored arc welding (FCAW) processes.

S9.25.2 The report shall include a statement of the producer's established chemical composition for the steel at the time the tests were made. The report shall be considered applicable and acceptable until such time as this specified composition may be changed.

S9.25.3 When requested by the Engineer, contractors shall make available a copy of the producer's report for the grade or type of steel they propose to use on a contract.

S9.26 Testing Procedure

S9.26.1 Materials for tests shall be selected from five heats representing high-side, mid-range, and low-side, chemical analyses consistent with thickness applications.

For each heat, tests shall be made for plate thickness (nominal) of 12 mm, 25 mm, and 50 mm, except as limited by maximum production thickness. For plate thicknesses of 12 mm, tests shall be made at temperatures of 0°C and 20°C. For the plate thickness of 25 mm and 50 mm, tests shall be made at 0°C, 20°C, and 100°C.

S9.26.2 For each test temperature, 10 specimens shall be welded with E6010 electrodes and 10 with E7018 electrodes. Welding electrodes shall conform to ANSI/AWS A5.1, *Specification for Covered Carbon Steel Arc Welding Electrodes*.

S9.26.3 Test specimens shall consist of blocks, 50 mm wide by 75 mm long in the direction of rolling, cut with full plate thickness from the plate material to be tested.

S9.26.4 A weld bead 30 mm in length shall be deposited on the surface of each block along the longitudinal centerline. The bead shall be deposited with a 3.2 mm diameter electrode, using a current of 100 amperes at 24 to 26 volts and a travel speed of 250 mm per minute to produce a heat input of approximately 600 J/mm.

S9.26.5 The blocks shall be precooled or preheated to the specified temperature and, during welding and for one minute afterwards, shall be immersed to 5 mm of its top surface in a liquid bath at the specified temperature. It shall be removed from the bath, aged 24 hours at room temperature, and then tempered for one hour at 600°C.

S9.26.6 The blocks shall be sectioned longitudinally at the center of the weld and examined for underbead cracks by either a magnetic particle or metallographic technique. The total length of cracks in each block shall be expressed as a percentage of the bead length. When adjacent cracks overlap, the length of the overlap shall not be included.

S9.27 WPS Qualification Tests

S9.27.1 The contractor shall prepare WPS qualification tests in accordance with section 5 of this code, except that the tests shall be made for the thinnest and thickest material to be welded for the contract.

S9.27.2 The WPS to be used by the contractor shall conform to the producer's recommendations for filler metals, preheat and interpass temperatures, heat inputs (when specified), or other special requirements.

S9.27.3 The mechanical properties of the weld metal, and the chemical composition and mechanical properties of the base metal, shall be as approved by the Engineer.

10. Tubular Structures

NO APPLICATIONS WITHIN THIS CODE

11. Strengthening and Repairing Existing Structures

NO APPLICATIONS WITHIN THIS CODE

12.4 Base Metal Requirements

12.4.1 Approved Base Metals. All steels listed in 9.2.1 are approved for use in the construction of FCMs. Other steels may be approved by the Engineer.

12.4.2 Fine-Grain Practice. Mill orders shall specify killed fine-grain practice for steel used in FCMs.

12.4.3 Prohibition of Mill Repairs. Mill order shall stipulate that no welded repairs shall be performed by the producing mill.

12.4.4 Optional Base Metal Requirements. When the contract documents require heat treatment, toughness, chemistry or other provisions that are not part of AASHTO M270M (ASTM A709M), or this FCP, these requirements shall be listed in the mill order.

12.4.4.1 Optional Through-Thickness and Low-Sulfur Requirements. The Engineer may, when deemed necessary due to significant applied tensile stress in the through-thickness (Z) direction at specific locations in the structure, specify that individual plates shall have low sulphur (0.010 percent maximum) or improved through-thickness properties (20 percent reduction of area as described in ASTM A770/A770M), or both. Each plate required to have low sulphur and improved through-thickness properties shall be clearly identified on the plans. All requirements for such steels in addition to the requirements of this FCP shall be specified in the contract documents.

12.4.4.2 Optional Heat Treatment. The Engineer may order individual plates or parts to be normalized, or quenched and tempered (Q&T), for special applications. All manufacturing requirements, such as forging, heat treatment, and testing requirements not part of the AASHTO material specifications, shall be clearly specified in the contract documents. The minimum CVN toughness values required at specific test temperatures shall be stated.

12.4.5 Toughness. The toughness of base-metal shapes, plates and bars shall be as specified in AASHTO M270M (ASTM A709M) for Fracture Critical Impact Test Requirements. The Grade of Steel, Method of Joining and AASHTO Temperature Zone in which the structure will be constructed shall be noted in the mill order.

12.4.5.1 Supplementary Requirements. Individual steel plates may be specified to have a toughness exceeding the minimums listed in 12.4.5 by listing special requirements in the contract documents. This exception to routine design practice, if deemed necessary, should be restricted to unusually critical applications, for example, suspended span bridge hangers. Each plate required to

meet special toughness requirements shall be clearly identified.

12.4.5.2 Mill Orders. Mill orders shall specify supplementary requirements for Charpy V-notch impact toughness meeting the requirements of this FCP.

12.4.6 Base Metal Identification. When heat numbers and other identification markings are applied by die stamping, low-stress dies shall be used.

12.5 Welding Processes

12.5.1 Approved Processes. Unless otherwise provided in the contract documents, the SMAW, SAW, and FCAW processes may be used to construct or repair FCMs.

12.5.2 Prohibited Processes and Procedure Restrictions. Electroslag welding (ESW) and electrogas welding (EGW) shall not be used to weld FCMs. GMAW may only be used with the approval of the Engineer. When GMAW is permitted, qualification tests, procedure control and nondestructive testing shall be as specified by the Engineer.

12.5.3 Preferred Processes and Procedures. The Engineer may designate the use of specific processes, or process controls for specific bridge welds. All special provisions shall be listed in the contract documents. Other restrictions on the use of welding processes or procedures, if any, shall be listed in the contract documents.

12.6 Consumable Requirements

12.6.1 Heat or Lot Testing. All welding consumables shall be heat or lot tested by the manufacturer to determine conformance with the requirements of this FCP. Certified copies of test results shall be provided to the Engineer. Heat and lot shall be as defined in the latest edition of ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*. Consumables shall be tested by welding as specified in the appropriate AWS filler metal specifications. All tests required by ANSI/AWS A5.01, Schedule J, shall be performed and reported.

During welding consumable testing, materials of the same specification and manufacture, but not necessarily the same heat or lot to be combined during production welding shall be used. For example, a specific heat or lot of SAW electrode need not be tested with the specific lot of SAW flux that will be used in production welding, provided both meet all other requirements of the FCP and are representative of the consumables to be furnished.

12.6.1.1 Exemptions. Welding consumables produced under continuing quality assurance programs audited and approved by one or more of the following agencies shall be exempt from the heat and lot testing requirements of 12.6.1.

- (1) American Bureau of Shipping (ABS)
- (2) Lloyd's Register of Shipping
- (3) American Society of Mechanical Engineers (ASME)

12.6.2 Diffusible Hydrogen of Weld Metal. Provisions are made in the FCP to limit increases in diffusible hydrogen during production welding and to provide for anticipated hydrogen by control of preheating and interpass temperatures.

12.6.2.1 Testing. Except for SMAW, which shall be monitored on the basis of electrode-coating moisture content, tests shall be conducted on welds produced during classification testing to determine the amount of diffusible hydrogen per 100 grams of weld metal. Diffusible hydrogen tests shall be performed under mercury or by the gas chromatograph method as specified in ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*. Testing shall be done by heat and lot of welding consumable under the provisions of 12.6. When welding consumables are accepted under the provisions of 12.6.1.1, heat and lot testing shall be waived, provided the certificate of conformance lists diffusible hydrogen or coating moisture content test results, as appropriate, obtained during classification testing.

Production welds are not required to be tested for diffusible hydrogen.

12.6.2.2 Electrode Optional Supplemental Moisture-Resistant Designator Requirements for Tack Welding. SMAW electrodes used for tack welding under the provisions of 12.13.1.2 on steel that is not preheated shall conform to the AWS filler metal specifications optional supplemental diffusible hydrogen designator H4. Electrodes classified with the optional R designator and E7018M electrodes may also be used for tack welding steel that is not preheated. Such electrodes shall have a coating moisture content consistent with the optional supplemental diffusible hydrogen designator H4.

12.6.2.3 Electrode Optional Supplemental Moisture-Resistant Designator Requirements for Welding. SMAW electrodes used to weld base metal with a minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All SMAW electrodes used to weld base metal with a minimum specified yield strength

greater than 345 MPa shall conform to the diffusible hydrogen requirements of the AWS filler metal specification optional supplemental designator H4 or H8.

12.6.2.4 Special Requirements. Filler metal manufacturers shall specify any special precautions in excess of those contained in this FCP that are necessary to ensure the deposited weld metal will meet the diffusible hydrogen limits of the specified classification when the consumables are removed from protective packaging and used without delay. Special storage provisions, maximum storage life, special handling and welding procedures, if any, shall be completely described.

12.6.3 Weld Metal Strength and Ductility Requirements. Weld metal strength and ductility shall conform to the requirements of Tables 4.1 and 4.2 unless otherwise provided in the contract documents.

12.6.4 Weld Metal Toughness Requirements

12.6.4.1 Matching Strength Groove Welds. Groove welds required to have a yield strength equal to the minimum specified yield strength of the base metal shall have a Charpy V-notch toughness equal to, or exceeding that, specified in Table 12.1.

12.6.4.2 Undermatching Strength Welds. All welds permitted to have undermatching yield strength shall have a minimum CVN toughness of 34 J@ - 30°C.

12.6.5 Shielded Metal Arc Welding (SMAW)

12.6.5.1 SMAW Electrodes. All SMAW electrodes shall be manufactured, packaged in hermetically sealed containers, stored, transported and delivered so that when removed from the container, the electrodes are undamaged and meet the diffusible hydrogen limits specified in 12.6.2.

Table 12.1
Toughness of Weld Metal with Matching Strength (see 12.6.4.1)

M270M Steel (A709M), Grades as Noted	CVN Toughness, minimum	Testing Temperature
250	34J	-30°C
345	34J	-30°C
345W	34J	-30°C
485W	41J	-30°C
690/690W	48J	-35°C

12.6.5.2 Sealed Containers. Electrode containers shall remain sealed until the electrodes are to be used in the work or are placed in heated storage as specified in 12.6.5.3. Containers shall be examined before opening to ensure there is no damage to the hermetic seal. Electrodes shall be examined before use to ensure there is no damage to the coating that may adversely affect weld quality. Electrodes from containers that have lost their hermetic seal and electrodes with broken coatings within the usable length shall not be used.

12.6.5.3 Storage. After removal from the containers, electrodes not immediately dispensed for use shall be continuously stored in electrically heated, thermostatically controlled ovens at a minimum temperature of 120°C until dispensed for use in the work.

12.6.5.4 Drying Temperatures. Electrode ovens shall be designed for the storage and drying of electrodes. Ovens shall be capable of maintaining temperatures between 120°C–290°C. The term *drying* as used here shall mean heating of electrodes to a temperature of 230–290°C for a minimum of four hours. If the temperature inside the oven falls below 110°C for a period of up to eight hours, or below 50°C for up to four hours, all electrodes shall be dried at a temperature of 230–290°C for a minimum of four hours or shall not be used to weld FCMs. Electrodes exposed to lower temperatures beyond these limits, or to the atmosphere beyond the limits of 12.6.5.6, shall be redried or replaced as specified in 12.6.5.7, 12.6.5.8, or 12.6.5.9.

12.6.5.5 Storage Ovens. Each oven shall have a door that is sealed and latched. The door shall be kept shut when not charging or discharging electrodes. Each oven shall have a small port that may be opened briefly to insert a thermometer to measure the temperature of the oven without opening the door. The port shall be kept shut when not in use. Alternatively, ovens may be furnished with thermometers that permit direct reading of the inside temperature without opening the oven.

12.6.5.6 Maximum Atmospheric Exposure of SMAW Electrodes. Except as provided in 12.6.5.8, SMAW electrodes shall not be exposed to the atmosphere for periods of time greater than those specified in Table 4.7.

12.6.5.7 Nonmoisture-Resistant Electrodes. E70XX and E80XX electrodes not designated moisture resistant which are exposed to the time limit of Table 4.7, (but not exceeding that) and moisture-resistant electrodes exposed up to the limit specified in 12.6.5.8, may be returned to an oven and dried at 230–290°C for a minimum of four hours or according to the manufacturer's requirements, then returned to continuously heated storage or redispensed for use in the work. Moisture resistant elec-

trodes that have been redried shall conform to the exposure limitations of Table 4.7. Electrodes may be redried once.

12.6.5.8 Optional Supplemental Moisture-Resistant Designators. Electrodes with the AWS filler metal specifications optional supplemental moisture resistance designator "R" may be exposed to the atmosphere for up to nine hours when welding steels with a minimum specified yield strength of 345 MPa or less. Moisture-resistant electrodes shall be received in containers that bear the additional designator R, or H4R.

12.6.5.9 Electrodes for Grades 485W, 690/690W Steels. All electrodes used to weld Grade 485W and 690/690W steels shall meet the maximum exposure requirements of Table 4.7. When such electrodes are exposed to the atmosphere for periods exceeding the limits specified, but not by more than one hour, they shall be dried for at least two hours by heating in an approved oven to a temperature of 425–540°C, or as recommended by the manufacturer, before being returned to heated storage or dispensed for use.

12.6.5.10 Production Welding Electrode Usage. Electrodes removed from heated storage shall be dispensed directly to welders for immediate use. They shall be kept in containers that protect them from contamination by moisture, oil, grease, and other sources of hydrogen, until used. The containers (scabbards) may be open at the top. Welders shall not be given more electrodes than can be used within the exposure limits permitted by this FCP.

12.6.6 Submerged Arc Welding (SAW)

12.6.6.1 Diffusible Hydrogen. All SAW electrodes and fluxes used to weld base metal with minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All SAW electrodes and fluxes used to weld base metal with a minimum specified yield strength greater than 345 MPa shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4 or H8.

12.6.6.2 Electrode and Flux Packaging. Electrodes shall be received in packaging that protects the electrode and coatings, if present, from damage. When removed from protective packaging and installed on machines, care shall be taken to protect the electrodes and coatings, if present, from deterioration or damage. No one shall modify or lubricate an electrode after manufacture for any reason. Flux shall be received in moisture-resistant packaging, transported and stored in a manner that will preserve the original manufactured condition. Flux from

containers and packages that have been broken or opened prior to use shall not be used to weld FCMs.

12.6.6.3 Flux Handling and Drying (Baking). All of the contents of each container of SAW flux shall be placed in an approved storage and drying oven directly upon opening the flux to the atmosphere. All flux shall be baked at 290°C minimum for at least two hours, or as recommended by the manufacturer, and then stored continuously at 120°C minimum until dispensed for use. Hot make-up flux may be carried to machines in steel pails and stored at the point of welding for up to four hours, provided the flux is protected from contamination by an appropriate cover.

12.6.6.4 Drying and Storage Temperatures. Flux drying and storage ovens shall be electrically heated and thermostatically controlled to provide temperatures of 120–290°C. Flux ovens shall be capable of drying and storing flux without causing a breakdown in particle size or segregation of components. Openings for charging and discharging of flux shall be closed when not in use. Each oven shall have a small port that may be opened briefly to insert a thermometer to measure the temperature of the oven without opening the door. The port shall be kept shut when not in use. Alternatively, ovens may be furnished with thermometers that permit direct reading of the inside temperature without opening the oven.

12.6.6.5 Discharge and Refill of Flux Hoppers. Welding machine flux hoppers and pressure containers shall be emptied of flux, entrapped fines and other particles, each time welding is suspended for 10 hours or more. Just prior to the resumption of welding, the hoppers and containers shall be refilled with new, properly dried, flux taken directly from a storage or baking oven.

12.6.6.6 Open Top Flux Systems. When open top, hopper-type flux systems have not been refilled, or welding has been suspended for six hours, the top 10 mm of flux in the hopper shall be removed and appropriate make-up flux added before welding is resumed.

12.6.6.7 Time Limits for Flux Replacement. The time limits of 12.6.6.5 and 12.6.6.6 may be extended based upon the results of tests acceptable to the Engineer. Tests conducted to demonstrate that the diffusible hydrogen limits of this FCP can be met without replacing flux as required by the referenced subsections shall include, as a minimum, a description of the welding and flux-handling system, the relative humidity during testing, and the results of mercury or gas chromatograph diffusible hydrogen tests conducted in accordance with the provisions of ANSI/AWS A4.3. To be acceptable, diffusible hydrogen tests after extended time without replacement shall conform to the requirements of the optional diffus-

ible hydrogen designator of the filler metal and flux being used.

12.6.6.8 Pneumatic Flux Delivery Systems. Compressed air used in pneumatic flux delivery systems shall be effectively filtered and dried to remove moisture, oil, rust and other contaminants. Dryers, unless automatically drained, shall be manually drained daily to ensure proper operation. Air lines shall be checked by venting the line to the atmosphere away from the work whenever the pressure container is refilled to verify the air is clean and dry.

12.6.6.9 Flux Recovery. Unfused flux may be recovered from clean base-metal surfaces and reused as permitted by 4.8.4. Flux may be recovered directly back into welding machine flux containers, provided it is recovered within a maximum of five minutes of being deposited on the steel. Flux recovered within a maximum of one hour may be returned to a flux drying oven. Flux exposed to the atmosphere for more than one hour after welding, and all flux that cannot be recovered from clean, dry, metal surfaces, shall be discarded. All recovered flux shall be redried at a temperature of 290°C minimum for at least two hours, or as recommended by the manufacturer, before reuse.

12.6.6.10 Recovered Flux. When flux is recovered, at least one third of the total flux used in welding shall be properly dried new flux. It shall be added in a way that will ensure mixing with the recovered flux in conformance with the provisions of 4.8.4. A written description of the contractor's flux recovery procedure shall be available for examination by welders and inspectors.

12.6.6.11 Gravity Feed Delivery Systems. Operators of welders with gravity feed flux delivery systems may return flux directly back to the hopper during welding as provided in 12.6.6.9. During welding, properly dried new make-up flux representing at least 1/3 of the total volume shall be added at least hourly as welding progresses.

12.6.7 Flux Cored Arc Welding (FCAW)

12.6.7.1 Diffusible Hydrogen. All FCAW electrodes used to weld base metal with minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All FCAW electrodes used to weld base metal with a minimum specified yield strength greater than 345 MPa shall conform to the diffusible hydrogen requirements of the ANSI/AWS filler metal specifications optional supplemental designator H4 or H8.

12.6.7.2 Electrode Packaging. Electrodes for FCAW shall be received in moisture-resistant packages that are undamaged. They shall be protected against contamina-

tion and injury during shipment and storage. Electrode packages shall remain effectively sealed against moisture until the electrode is required for use. When removed from protective packaging and installed on machines, care shall be taken to protect the electrodes and coatings, if present, from deterioration or damage. No one shall modify or lubricate an electrode after manufacture for any reason except that drying shall be permitted when recommended by the manufacturer.

12.6.7.3 Shielding Gas. Any shielding gas or gas mixture qualified under the provisions of 5.12 or 5.13 may be used. The manufacturer shall provide certification that the gas or gas mixture conforms to the requirements of 4.13.

12.6.7.4 Electrode Storage. When welding is to be suspended for more than 8 hours, electrodes shall be removed from the machines and stored in airtight coverings or placed in a storage or drying oven maintained at a temperature of 120–290°C or as recommended by the manufacturer.

Electrodes not consumed within 24 hours of accumulated exposure outside sealed or heated storage shall be redried by baking as described in 12.6.7.6. Electrodes shall be identified to facilitate monitoring of total atmospheric exposure time.

12.6.7.5 Time Limit Extension for Electrode Exposure. The time limits of 12.6.7.4 may be extended based upon the results of tests acceptable to the Engineer. Tests conducted to demonstrate that the diffusible hydrogen limits of this FCP can be met at periods of exposure greater than specified in 12.6.7.4 shall include, as a minimum, a description of the maximum electrode atmospheric exposure time, the relative humidity during electrode exposure and weld testing, and the results of mercury or gas chromatograph diffusible hydrogen tests conducted in accordance with the provisions of ANSI/AWS A4.3. To be acceptable, diffusible hydrogen tests after extended exposure shall conform to the requirements of the optional supplemental diffusible hydrogen designator for the filler metal specified.

12.6.7.6 Drying Temperatures. When approved by the manufacturer, FCAW electrodes on metal supports may be baked once at 260–290°C for a minimum four hours, or as specified by the manufacturer, to restore their condition. If the electrode or the electrode support is damaged by baking, the electrode shall not be used to weld FCMs.

12.7 Welding Procedure Specification (WPS)

The provisions of section 5 shall apply, except as modified herein. Testing shall be done under the provisions of 5.12 or 5.13, unless otherwise stated in the contract documents. Filler metals and fluxes used for WPS qualification testing shall not be subject to the requirements of 12.6, or 12.6.2, provided the WPS and PQR show the same manufacturer's brand and type of filler metal and flux was used.

12.7.1 Limited Prequalification for SMAW. WPSs using SMAW electrodes classified as E7016, E7018, E7018-1 and E8018, including those with the "C" alloy and "M" military classifications and the optional supplemental designator "R" designating moisture resistance, are prequalified and exempt from WPS qualification test. All WPSs using other SMAW electrodes shall be qualified by tests as described in 5.12 or 5.13 in addition to the tests performed by the manufacturer for electrode classification.

12.7.2 Groove WPS Qualification. Except as provided in 12.7.1, groove WPSs shall be qualified by testing in accordance with the provisions of 5.12 or 5.13. Charpy V-notch impact toughness shall be as specified in 12.6.4.

12.7.3 Fillet WPS Qualification. Except as provided in 12.7.1, fillet WPSs shall be qualified by groove weld testing in accordance with the provisions of 5.12 or 5.13. In addition, fillet weld tests shall be conducted as specified in 5.10.3. Fillet weld tests shall be conducted using welding variables qualified by 5.12 or 5.13.

12.7.4 Period Of Effectiveness. When a specific contractor has not previously performed a WPS qualification test satisfying the provisions of this or a previous AASHTO FCP, the required tests shall be completed within one year prior to the start of production welding. All subsequent tests shall be conducted at a frequency that will ensure no qualification test record (PQR) used as a basis for preparation of WPSs is more than 36 months old.

12.7.5 Previous Qualification. The Engineer should accept evidence of previous qualification, provided the tests were performed in accordance with the requirements of this FCP. (See 5.3.)

12.8 Contractor Requirements

Contractors shall be certified under the AISC (American Institute of Steel Construction) Quality Certification Program, Category III, Major Steel Bridges with Fracture Critical Rating, or an equivalent program acceptable to the Engineer.

12.8.1 Individual Competence. All persons that construct, inspect, or test FCMs shall be competent to perform the tasks they are assigned to perform.

11. Strengthening and Repairing Existing Structures

NO APPLICATIONS WITHIN THIS CODE

12. AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members

12.1 General Provisions

This section shall apply to fracture critical nonredundant members. All steel bridge members and member components designated on the plans or elsewhere in the contract documents as fracture critical shall be subject to the additional provisions of this section. All other provisions of the code shall apply to the construction of fracture critical members (FCMs), except as modified or supplemented herein. Should any provision of this section be in conflict with other provisions of the code, the requirements of this section shall apply.

12.2 Definitions

12.2.1 Fracture Control Plan (FCP). The designation "FCP" shall mean fracture control plan and shall include all provisions of this section of the code.

12.2.2 Fracture Critical Member (FCM). Fracture critical members or member components are tension members or tension components of bending members (including those subject to reversal of stress), the failure of which would be expected to result in collapse of the bridge. The designation "FCM" shall mean fracture critical member or member component. Members and components that are not subject to tensile stress under any condition of live load are not fracture critical.

12.2.2.1 Attachments. Any attachment welded to a tension zone of an FCM member shall be considered an FCM when any dimension of the attachment exceeds 100 mm in the direction parallel to the calculated tensile stress in the FCM. Attachments designated FCM shall meet all requirements of this FCP.

12.2.2.2 Welds. All welds to FCMs shall be considered fracture critical and shall conform to the requirements of this FCP. Welds to compression members or compression areas of bending members are not fracture critical.

12.3 Contract Documents

12.3.1 Design Evaluation. The Engineer shall evaluate each bridge design to determine the location of any FCMs that may exist and shall ensure that all FCMs are properly designated as required by 12.3.2. The Engineer shall ensure that the contract documents contain all information necessary to order materials and properly construct FCMs as required by the design.

12.3.2 Prebid Designation of FCMs. All fracture critical members shall be identified on the plans, or otherwise described in the contract documents by the Engineer prior to bidding. Each FCM shall be individually designated. Each portion of a bending member that is fracture critical shall be clearly described giving the limits of the FCM. Within these limits, the provisions of 12.2.2 shall apply.

12.3.3 Shop Drawings. Shop drawings shall meet the requirements of 2.1.

12.3.3.1 Engineer's Review. The Engineer shall review all shop drawings to ensure that the Contractor has identified all FCMs. The Engineer shall check each shop drawing, including materials lists, for conformance with this FCP and the contract documents. WPSs for construction and repair are considered integral parts of shop drawings and shall be reviewed for acceptability. An indication of the Engineer's disposition of each drawing and procedure shall be shown by appropriate stamp, signature and date.

12.3.3.2 Acceptance. The Contractor shall provide detailed shop drawings and WPSs for review by the Engineer, whose acceptance, or acceptance-as-noted, shall be required prior to fabrication. Such acceptance shall be limited to mean the reviewed material appears to conform to the intent of the contract documents (including this FCP). The Contractor shall be responsible for producing acceptable work.

12.4 Base Metal Requirements

12.4.1 Approved Base Metals. All steels listed in 9.2.1 are approved for use in the construction of FCMs. Other steels may be approved by the Engineer.

12.4.2 Fine-Grain Practice. Mill orders shall specify killed fine-grain practice for steel used in FCMs.

12.4.3 Prohibition of Mill Repairs. Mill order shall stipulate that no welded repairs shall be performed by the producing mill.

12.4.4 Optional Base Metal Requirements. When the contract documents require heat treatment, toughness, chemistry or other provisions that are not part of AASHTO M270M (ASTM A709M), or this FCP, these requirements shall be listed in the mill order.

12.4.4.1 Optional Through-Thickness and Low-Sulfur Requirements. The Engineer may, when deemed necessary due to significant applied tensile stress in the through-thickness (Z) direction at specific locations in the structure, specify that individual plates shall have low sulphur (0.010 percent maximum) or improved through-thickness properties (20 percent reduction of area as described in ASTM A770/A770M), or both. Each plate required to have low sulphur and improved through-thickness properties shall be clearly identified on the plans. All requirements for such steels in addition to the requirements of this FCP shall be specified in the contract documents.

12.4.4.2 Optional Heat Treatment. The Engineer may order individual plates or parts to be normalized, or quenched and tempered (Q&T), for special applications. All manufacturing requirements, such as forging, heat treatment, and testing requirements not part of the AASHTO material specifications, shall be clearly specified in the contract documents. The minimum CVN toughness values required at specific test temperatures shall be stated.

12.4.5 Toughness. The toughness of base-metal shapes, plates and bars shall be as specified in AASHTO M270M (ASTM A709M) for Fracture Critical Impact Test Requirements. The Grade of Steel, Method of Joining and AASHTO Temperature Zone in which the structure will be constructed shall be noted in the mill order.

12.4.5.1 Supplementary Requirements. Individual steel plates may be specified to have a toughness exceeding the minimums listed in 12.4.5 by listing special requirements in the contract documents. This exception to routine design practice, if deemed necessary, should be restricted to unusually critical applications, for example, suspended span bridge hangers. Each plate required to

meet special toughness requirements shall be clearly identified.

12.4.5.2 Mill Orders. Mill orders shall specify supplementary requirements for Charpy V-notch impact toughness meeting the requirements of this FCP.

12.4.6 Base Metal Identification. When heat numbers and other identification markings are applied by die stamping, low-stress dies shall be used.

12.5 Welding Processes

12.5.1 Approved Processes. Unless otherwise provided in the contract documents, the SMAW, SAW, and FCAW processes may be used to construct or repair FCMs.

12.5.2 Prohibited Processes and Procedure Restrictions. Electroslag welding (ESW) and electrogas welding (EGW) shall not be used to weld FCMs. GMAW may only be used with the approval of the Engineer. When GMAW is permitted, qualification tests, procedure control and nondestructive testing shall be as specified by the Engineer.

12.5.3 Preferred Processes and Procedures. The Engineer may designate the use of specific processes, or process controls for specific bridge welds. All special provisions shall be listed in the contract documents. Other restrictions on the use of welding processes or procedures, if any, shall be listed in the contract documents.

12.6 Consumable Requirements

12.6.1 Heat or Lot Testing. All welding consumables shall be heat or lot tested by the manufacturer to determine conformance with the requirements of this FCP. Certified copies of test results shall be provided to the Engineer. Heat and lot shall be as defined in the latest edition of ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*. Consumables shall be tested by welding as specified in the appropriate AWS filler metal specifications. All tests required by ANSI/AWS A5.01, Schedule J, shall be performed and reported.

During welding consumable testing, materials of the same specification and manufacture, but not necessarily the same heat or lot to be combined during production welding shall be used. For example, a specific heat or lot of SAW electrode need not be tested with the specific lot of SAW flux that will be used in production welding, provided both meet all other requirements of the FCP and are representative of the consumables to be furnished.

12.6.1.1 Exemptions. Welding consumables produced under continuing quality assurance programs audited and approved by one or more of the following agencies shall be exempt from the heat and lot testing requirements of 12.6.1.

- (1) American Bureau of Shipping (ABS)
- (2) Lloyd's Register of Shipping
- (3) American Society of Mechanical Engineers (ASME)

12.6.2 Diffusible Hydrogen of Weld Metal. Provisions are made in the FCP to limit increases in diffusible hydrogen during production welding and to provide for anticipated hydrogen by control of preheating and interpass temperatures.

12.6.2.1 Testing. Except for SMAW, which shall be monitored on the basis of electrode-coating moisture content, tests shall be conducted on welds produced during classification testing to determine the amount of diffusible hydrogen per 100 grams of weld metal. Diffusible hydrogen tests shall be performed under mercury or by the gas chromatograph method as specified in ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*. Testing shall be done by heat and lot of welding consumable under the provisions of 12.6. When welding consumables are accepted under the provisions of 12.6.1.1, heat and lot testing shall be waived, provided the certificate of conformance lists diffusible hydrogen or coating moisture content test results, as appropriate, obtained during classification testing.

Production welds are not required to be tested for diffusible hydrogen.

12.6.2.2 Electrode Optional Supplemental Moisture-Resistant Designator Requirements for Tack Welding. SMAW electrodes used for tack welding under the provisions of 12.13.1.2 on steel that is not preheated shall conform to the AWS filler metal specifications optional supplemental diffusible hydrogen designator H4. Electrodes classified with the optional R designator and E7018M electrodes may also be used for tack welding steel that is not preheated. Such electrodes shall have a coating moisture content consistent with the optional supplemental diffusible hydrogen designator H4.

12.6.2.3 Electrode Optional Supplemental Moisture-Resistant Designator Requirements for Welding. SMAW electrodes used to weld base metal with a minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All SMAW electrodes used to weld base metal with a minimum specified yield strength

greater than 345 MPa shall conform to the diffusible hydrogen requirements of the AWS filler metal specification optional supplemental designator H4 or H8.

12.6.2.4 Special Requirements. Filler metal manufacturers shall specify any special precautions in excess of those contained in this FCP that are necessary to ensure the deposited weld metal will meet the diffusible hydrogen limits of the specified classification when the consumables are removed from protective packaging and used without delay. Special storage provisions, maximum storage life, special handling and welding procedures, if any, shall be completely described.

12.6.3 Weld Metal Strength and Ductility Requirements. Weld metal strength and ductility shall conform to the requirements of Tables 4.1 and 4.2 unless otherwise provided in the contract documents.

12.6.4 Weld Metal Toughness Requirements

12.6.4.1 Matching Strength Groove Welds. Groove welds required to have a yield strength equal to the minimum specified yield strength of the base metal shall have a Charpy V-notch toughness equal to, or exceeding that, specified in Table 12.1.

12.6.4.2 Undermatching Strength Welds. All welds permitted to have undermatching yield strength shall have a minimum CVN toughness of 34 J@ -30°C.

12.6.5 Shielded Metal Arc Welding (SMAW)

12.6.5.1 SMAW Electrodes. All SMAW electrodes shall be manufactured, packaged in hermetically sealed containers, stored, transported and delivered so that when removed from the container, the electrodes are undamaged and meet the diffusible hydrogen limits specified in 12.6.2.

Table 12.1
Toughness of Weld Metal with Matching Strength (see 12.6.4.1)

M270M Steel (A709M), Grades as Noted	CVN Toughness, minimum	Testing Temperature
250	34J	-30°C
345	34J	-30°C
345W	34J	-30°C
485W	41J	-30°C
690/690W	48J	-35°C

12.6.5.2 Sealed Containers. Electrode containers shall remain sealed until the electrodes are to be used in the work or are placed in heated storage as specified in 12.6.5.3. Containers shall be examined before opening to ensure there is no damage to the hermetic seal. Electrodes shall be examined before use to ensure there is no damage to the coating that may adversely affect weld quality. Electrodes from containers that have lost their hermetic seal and electrodes with broken coatings within the usable length shall not be used.

12.6.5.3 Storage. After removal from the containers, electrodes not immediately dispensed for use shall be continuously stored in electrically heated, thermostatically controlled ovens at a minimum temperature of 120°C until dispensed for use in the work.

12.6.5.4 Drying Temperatures. Electrode ovens shall be designed for the storage and drying of electrodes. Ovens shall be capable of maintaining temperatures between 120°C–290°C. The term *drying* as used here shall mean heating of electrodes to a temperature of 230–290°C for a minimum of four hours. If the temperature inside the oven falls below 110°C for a period of up to eight hours, or below 50°C for up to four hours, all electrodes shall be dried at a temperature of 230–290°C for a minimum of four hours or shall not be used to weld FCMs. Electrodes exposed to lower temperatures beyond these limits, or to the atmosphere beyond the limits of 12.6.5.6, shall be redried or replaced as specified in 12.6.5.7, 12.6.5.8, or 12.6.5.9.

12.6.5.5 Storage Ovens. Each oven shall have a door that is sealed and latched. The door shall be kept shut when not charging or discharging electrodes. Each oven shall have a small port that may be opened briefly to insert a thermometer to measure the temperature of the oven without opening the door. The port shall be kept shut when not in use. Alternatively, ovens may be furnished with thermometers that permit direct reading of the inside temperature without opening the oven.

12.6.5.6 Maximum Atmospheric Exposure of SMAW Electrodes. Except as provided in 12.6.5.8, SMAW electrodes shall not be exposed to the atmosphere for periods of time greater than those specified in Table 4.7.

12.6.5.7 Nonmoisture-Resistant Electrodes. E70XX and E80XX electrodes not designated moisture resistant which are exposed to the time limit of Table 4.7, (but not exceeding that) and moisture-resistant electrodes exposed up to the limit specified in 12.6.5.8, may be returned to an oven and dried at 230–290°C for a minimum of four hours or according to the manufacturer's requirements, then returned to continuously heated storage or redispensed for use in the work. Moisture resistant elec-

trodes that have been redried shall conform to the exposure limitations of Table 4.7. Electrodes may be redried once.

12.6.5.8 Optional Supplemental Moisture-Resistant Designators. Electrodes with the AWS filler metal specifications optional supplemental moisture resistance designator "R" may be exposed to the atmosphere for up to nine hours when welding steels with a minimum specified yield strength of 345 MPa or less. Moisture-resistant electrodes shall be received in containers that bear the additional designator R, or H4R.

12.6.5.9 Electrodes for Grades 485W, 690/690W Steels. All electrodes used to weld Grade 485W and 690/690W steels shall meet the maximum exposure requirements of Table 4.7. When such electrodes are exposed to the atmosphere for periods exceeding the limits specified, but not by more than one hour, they shall be dried for at least two hours by heating in an approved oven to a temperature of 425–540°C, or as recommended by the manufacturer, before being returned to heated storage or dispensed for use.

12.6.5.10 Production Welding Electrode Usage. Electrodes removed from heated storage shall be dispensed directly to welders for immediate use. They shall be kept in containers that protect them from contamination by moisture, oil, grease, and other sources of hydrogen, until used. The containers (scabbards) may be open at the top. Welders shall not be given more electrodes than can be used within the exposure limits permitted by this FCP.

12.6.6 Submerged Arc Welding (SAW)

12.6.6.1 Diffusible Hydrogen. All SAW electrodes and fluxes used to weld base metal with minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All SAW electrodes and fluxes used to weld base metal with a minimum specified yield strength greater than 345 MPa shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4 or H8.

12.6.6.2 Electrode and Flux Packaging. Electrodes shall be received in packaging that protects the electrode and coatings, if present, from damage. When removed from protective packaging and installed on machines, care shall be taken to protect the electrodes and coatings, if present, from deterioration or damage. No one shall modify or lubricate an electrode after manufacture for any reason. Flux shall be received in moisture-resistant packaging, transported and stored in a manner that will preserve the original manufactured condition. Flux from

containers and packages that have been broken or opened prior to use shall not be used to weld FCMs.

12.6.6.3 Flux Handling and Drying (Baking). All of the contents of each container of SAW flux shall be placed in an approved storage and drying oven directly upon opening the flux to the atmosphere. All flux shall be baked at 290°C minimum for at least two hours, or as recommended by the manufacturer, and then stored continuously at 120°C minimum until dispensed for use. Hot make-up flux may be carried to machines in steel pails and stored at the point of welding for up to four hours, provided the flux is protected from contamination by an appropriate cover.

12.6.6.4 Drying and Storage Temperatures. Flux drying and storage ovens shall be electrically heated and thermostatically controlled to provide temperatures of 120–290°C. Flux ovens shall be capable of drying and storing flux without causing a breakdown in particle size or segregation of components. Openings for charging and discharging of flux shall be closed when not in use. Each oven shall have a small port that may be opened briefly to insert a thermometer to measure the temperature of the oven without opening the door. The port shall be kept shut when not in use. Alternatively, ovens may be furnished with thermometers that permit direct reading of the inside temperature without opening the oven.

12.6.6.5 Discharge and Refill of Flux Hoppers. Welding machine flux hoppers and pressure containers shall be emptied of flux, entrapped fines and other particles, each time welding is suspended for 10 hours or more. Just prior to the resumption of welding, the hoppers and containers shall be refilled with new, properly dried, flux taken directly from a storage or baking oven.

12.6.6.6 Open Top Flux Systems. When open top, hopper-type flux systems have not been refilled, or welding has been suspended for six hours, the top 10 mm of flux in the hopper shall be removed and appropriate make-up flux added before welding is resumed.

12.6.6.7 Time Limits for Flux Replacement. The time limits of 12.6.6.5 and 12.6.6.6 may be extended based upon the results of tests acceptable to the Engineer. Tests conducted to demonstrate that the diffusible hydrogen limits of this FCP can be met without replacing flux as required by the referenced subsections shall include, as a minimum, a description of the welding and flux-handling system, the relative humidity during testing, and the results of mercury or gas chromatograph diffusible hydrogen tests conducted in accordance with the provisions of ANSI/AWS A4.3. To be acceptable, diffusible hydrogen tests after extended time without replacement shall conform to the requirements of the optional diffus-

ible hydrogen designator of the filler metal and flux being used.

12.6.6.8 Pneumatic Flux Delivery Systems. Compressed air used in pneumatic flux delivery systems shall be effectively filtered and dried to remove moisture, oil, rust and other contaminants. Dryers, unless automatically drained, shall be manually drained daily to ensure proper operation. Air lines shall be checked by venting the line to the atmosphere away from the work whenever the pressure container is refilled to verify the air is clean and dry.

12.6.6.9 Flux Recovery. Unfused flux may be recovered from clean base-metal surfaces and reused as permitted by 4.8.4. Flux may be recovered directly back into welding machine flux containers, provided it is recovered within a maximum of five minutes of being deposited on the steel. Flux recovered within a maximum of one hour may be returned to a flux drying oven. Flux exposed to the atmosphere for more than one hour after welding, and all flux that cannot be recovered from clean, dry, metal surfaces, shall be discarded. All recovered flux shall be redried at a temperature of 290°C minimum for at least two hours, or as recommended by the manufacturer, before reuse.

12.6.6.10 Recovered Flux. When flux is recovered, at least one third of the total flux used in welding shall be properly dried new flux. It shall be added in a way that will ensure mixing with the recovered flux in conformance with the provisions of 4.8.4. A written description of the contractor's flux recovery procedure shall be available for examination by welders and inspectors.

12.6.6.11 Gravity Feed Delivery Systems. Operators of welders with gravity feed flux delivery systems may return flux directly back to the hopper during welding as provided in 12.6.6.9. During welding, properly dried new make-up flux representing at least 1/3 of the total volume shall be added at least hourly as welding progresses.

12.6.7 Flux Cored Arc Welding (FCAW)

12.6.7.1 Diffusible Hydrogen. All FCAW electrodes used to weld base metal with minimum specified yield strength of 345 MPa or less shall conform to the diffusible hydrogen requirements of the AWS filler metal specifications optional supplemental designator H4, H8 or H16. All FCAW electrodes used to weld base metal with a minimum specified yield strength greater than 345 MPa shall conform to the diffusible hydrogen requirements of the ANSI/AWS filler metal specifications optional supplemental designator H4 or H8.

12.6.7.2 Electrode Packaging. Electrodes for FCAW shall be received in moisture-resistant packages that are undamaged. They shall be protected against contamina-

tion and injury during shipment and storage. Electrode packages shall remain effectively sealed against moisture until the electrode is required for use. When removed from protective packaging and installed on machines, care shall be taken to protect the electrodes and coatings, if present, from deterioration or damage. No one shall modify or lubricate an electrode after manufacture for any reason except that drying shall be permitted when recommended by the manufacturer.

12.6.7.3 Shielding Gas. Any shielding gas or gas mixture qualified under the provisions of 5.12 or 5.13 may be used. The manufacturer shall provide certification that the gas or gas mixture conforms to the requirements of 4.13.

12.6.7.4 Electrode Storage. When welding is to be suspended for more than 8 hours, electrodes shall be removed from the machines and stored in airtight coverings or placed in a storage or drying oven maintained at a temperature of 120–290°C or as recommended by the manufacturer.

Electrodes not consumed within 24 hours of accumulated exposure outside sealed or heated storage shall be redried by baking as described in 12.6.7.6. Electrodes shall be identified to facilitate monitoring of total atmospheric exposure time.

12.6.7.5 Time Limit Extension for Electrode Exposure. The time limits of 12.6.7.4 may be extended based upon the results of tests acceptable to the Engineer. Tests conducted to demonstrate that the diffusible hydrogen limits of this FCP can be met at periods of exposure greater than specified in 12.6.7.4 shall include, as a minimum, a description of the maximum electrode atmospheric exposure time, the relative humidity during electrode exposure and weld testing, and the results of mercury or gas chromatograph diffusible hydrogen tests conducted in accordance with the provisions of ANSI/AWS A4.3. To be acceptable, diffusible hydrogen tests after extended exposure shall conform to the requirements of the optional supplemental diffusible hydrogen designator for the filler metal specified.

12.6.7.6 Drying Temperatures. When approved by the manufacturer, FCAW electrodes on metal supports may be baked once at 260–290°C for a minimum four hours, or as specified by the manufacturer, to restore their condition. If the electrode or the electrode support is damaged by baking, the electrode shall not be used to weld FCMs.

12.7 Welding Procedure Specification (WPS)

The provisions of section 5 shall apply, except as modified herein. Testing shall be done under the provisions of 5.12 or 5.13, unless otherwise stated in the contract documents. Filler metals and fluxes used for WPS qualification testing shall not be subject to the requirements of 12.6, or 12.6.2, provided the WPS and PQR show the same manufacturer's brand and type of filler metal and flux was used.

12.7.1 Limited Prequalification for SMAW. WPSs using SMAW electrodes classified as E7016, E7018, E7018-1 and E8018, including those with the "C" alloy and "M" military classifications and the optional supplemental designator "R" designating moisture resistance, are prequalified and exempt from WPS qualification test. All WPSs using other SMAW electrodes shall be qualified by tests as described in 5.12 or 5.13 in addition to the tests performed by the manufacturer for electrode classification.

12.7.2 Groove WPS Qualification. Except as provided in 12.7.1, groove WPSs shall be qualified by testing in accordance with the provisions of 5.12 or 5.13. Charpy V-notch impact toughness shall be as specified in 12.6.4.

12.7.3 Fillet WPS Qualification. Except as provided in 12.7.1, fillet WPSs shall be qualified by groove weld testing in accordance with the provisions of 5.12 or 5.13. In addition, fillet weld tests shall be conducted as specified in 5.10.3. Fillet weld tests shall be conducted using welding variables qualified by 5.12 or 5.13.

12.7.4 Period Of Effectiveness. When a specific contractor has not previously performed a WPS qualification test satisfying the provisions of this or a previous AASHTO FCP, the required tests shall be completed within one year prior to the start of production welding. All subsequent tests shall be conducted at a frequency that will ensure no qualification test record (PQR) used as a basis for preparation of WPSs is more than 36 months old.

12.7.5 Previous Qualification. The Engineer should accept evidence of previous qualification, provided the tests were performed in accordance with the requirements of this FCP. (See 5.3.)

12.7.5 Previous Qualification. The Engineer should accept evidence of previous qualification, provided the tests were performed in accordance with the requirements of this FCP. (See 5.3.)

12.8 Contractor Requirements

Contractors shall be certified under the AISC (American Institute of Steel Construction) Quality Certification Program, Category III, Major Steel Bridges with Fracture Critical Rating, or an equivalent program acceptable to the Engineer.

12.8.1 Individual Competence. All persons that construct, inspect, or test FCMs shall be competent to perform the tasks they are assigned to perform.

12.8.2 Welding Personnel Qualifications. All welders, including welding operators and tack welders, shall be qualified by test within 6 months of beginning welding or shall be regularly requalified on an annual basis. For welders and welding operators, initial qualification shall be based upon acceptable results of both mechanical (bend) and radiographic tests as described in section 5, Part B. Annual requalification may be based upon acceptable results of radiographic testing of production groove welds or test plates as approved by the Engineer. Tack welders shall be qualified as described in section 5, Part B.

12.9 As-Received Inspection of Base Metal

All base-metal surfaces and edges shall be visually inspected for discontinuities. The standards for visual acceptance of shape, plate, and bar-rolled surfaces shall be as described in AASHTO M160/M160M (ASTM A6/A6M) unless otherwise provided in the contract documents.

12.10 Thermal Cutting

Edges and ends of plates shall be cut to size by thermal cutting. Universal mill and sheared plates shall have a minimum of 5 mm of material removed from rolled or sheared edges and from ends by thermal cutting prior to assembly and welding. This provision does not apply to edges of bars and shapes as defined in AASHTO M160/M160M (ASTM A6/A6M), or the ends of stiffeners and connection plates where there is no calculated tensile stress.

12.10.1 Thermal-Cut Edge Requirements. Thermal-cut edges (TCEs) shall meet the requirements of 3.2 unless otherwise specified in the contract documents.

12.10.2 Magnetic-Particle Testing. When discontinuities are discovered visually, they shall be inspected further using the Yoke method of magnetic-particle testing described in 6.7.6.2.

12.10.3 Laminar Discontinuities. No laminar discontinuities shall be permitted in the fusion face of groove welds in butt joints subject to calculated tensile stress normal to the weld axis, or in the sides (edges) of contiguous base metal within 300 mm of such welds.

12.10.4 Allowable Discontinuities. Except as provided in 12.10.3, base metal at the fusion face of butt, T- and corner joints may have discontinuities permitted by 3.2. Repair welding, if any, shall be done in accordance with

the provisions of 12.17.3. Excavated, or repaired, surfaces shall be finished to produce conditions suitable for final welding.

12.11 Repair of Base Metal

Base-metal discontinuities adjacent to fracture-critical butt joints as described in 12.10.3 shall be repaired or replaced by the Contractor in accordance with the following options:

12.11.1 Rotation of Base Metal. The base metal may be rotated end for end when it is possible to remove discontinuities from areas subject to calculated tensile stress.

12.11.2 Thermal Cutting. When the unacceptable discontinuities are localized, they may be removed by thermal cutting to sound metal, reducing the length of the effected plate, bar, or shape. This requires adjacent pieces of steel to be extended beyond their detailed length and mandates relocation of the affected butt joint. Relocation of butt welds from their detailed location shall require approval by the Engineer. All changes in weld location shall be recorded on the shop drawings.

12.11.3 Repairs. Repairs may be made by welding under the provisions of 12.17.

12.11.4 Replacement. With the Engineer's approval, the Contractor may remove a defective portion of the base metal and replace it with new material of the same or greater strength, toughness and corrosion resistance, except Grades 485W and 690/690W shall not be substituted for lower strength steels. Replacement steel and welds necessary to affect the base-metal substitution shall conform to all requirements of the FCP. Unless otherwise approved by the Engineer, the minimum replacement length shall be 1.5 m. All base metal replacements shall be recorded in the inspection records and shop drawings.

12.12 Straightening, Curving, and Cambering

Cold bending is prohibited for all fracture critical steels. Bent and distorted material may be corrected prior to assembly and welding by approved upset-shortening methods (heat straightening, curving and cambering). Finished FCMs constructed of as-rolled and normalized steels may be heated to produce slight reductions in excessive camber as described in 3.2.7, or to produce a curvature equivalent to a circular radius not less than 300 m. All heating corrections to straightness and cam-

ber and heat curving shall be done by heat-shrink methods described in 3.7.3.

Exceptions to the provisions of this subsection shall require the Engineer's approval.

No permanent welds or base metal shall be removed or cut to affect a dimensional change without prior approval of the Engineer. Base metal and weld metal that is sharply bent or kinked shall be rejected and replaced.

12.13 Tack Welds and Temporary Welds

12.13.1 Tack Welds

12.13.1.1 Location. All tack welds used in assembly shall be located within the joint unless otherwise approved by the Engineer.

12.13.1.2 Requirements. All tack welds shall meet the requirements of Table 12.2, or shall be removed as specified in 12.13.3.

12.13.2 Temporary Welds. All welds not shown as permanent welds on the drawings or approved by the Engineer shall be removed as specified in 12.13.3.

12.13.3 Weld Removal. When required, weld removal shall include all of the weld plus 3 mm of the adjacent base metal to remove the HAZ. Weld and base metal removal sites shall be faired to adjacent surfaces on a slope not steeper than 1 into the metal to 10 along the surface. The surface roughness shall not exceed 3 μm .

12.14 Preheat and Interpass Temperature Control

Preheat and interpass temperature control shall be as specified in 4.2. The minimum preheat and interpass temperature for AASHTO M270M Grade 250, 345, 345W and 485W (ASTM A709M Grade 250, 345, 345W, and 485W) steels shall be as specified in Tables 12.3 and 12.4. The minimum and maximum preheat temperatures for Grades 690/690W steels shall be as listed in Table 12.5. The maximum preheat and maximum interpass temperature for Grade 485W steel shall not exceed 200°C for thicknesses up to 40 mm inclusive and 260°C for greater thicknesses.

12.15 Postweld Thermal Treatments

12.15.1 Postheat. Postheat shall be required when specified in the contract documents, WPS, repair procedure, or when required by the Engineer to prevent cracking or minimize lamellar tearing.

12.15.1.1 Minimum Temperature Prior to Postheat. When postheat is required, the weld shall not be allowed to cool below the minimum preheat and interpass temperature before being raised to the postweld heat treatment (PWHT) temperature.

12.15.1.2 Postheat Temperature Limitations. When postheat is required, welds and adjacent base metal shall be heated to a temperature of 230°C minimum to 315°C

Table 12.2
Tack Weld Requirements (see 12.13.1.2)

Type	WPS Required?	Min. Size	Min. Length	Min. Preheat	Notes
Remelted by SAW	No	None	None	None	1, 2, 3
Covered by non-SAW	Yes	Table 2.1 or 2.2	75 mm	Table 12.3, 12.4 or 12.5	1
Tack welds outside joint	Yes	Table 2.1 or 2.2	75 mm	Table 12.3, 12.4 or 12.5	1, 4
Tack welds < 75 mm long, or smaller than Table 2.1 or 2.2	Yes	None	None	200°C	1

Notes:

1. Filler metals listed in Tables 4.1 or 4.2 shall be used.
2. GMAW may be used for tack welding without Engineer approval.
3. SMAW electrodes shall meet the requirements of 12.6.2.
4. Tack welds outside the joint require Engineer approval. See 12.13.1.1.

Table 12.3
M270M (A709M) Gr. 250 345 Minimum Preheat and Interpass Temperatures, °C (see 12.14)

Heat Input (as calculated by 5.12) kJ/mm									
	1.2 < HI ≤ 2.0			2.0 < HI ≤ 2.8			HI > 2.8		
Thickness t ≤ (mm)	H4	H8	H16	H4	H8	H16	H4	H8	H16
t ≤ 20	40	60	100	40	40	60	40	40	40
20 < t ≤ 40	60	100	100	60	65	100	40	60	80
40 < t ≤ 60	100	120	120	80	100	120	60	80	80
t > 60	140	160	180	140	140	160	120	140	140

Note: H4, H8, and H16 are electrode optional supplemental designators for diffusible hydrogen.

Table 12.4
M270M (A709M) Gr. 345W, 485W Minimum Preheat and Interpass Temperatures, °C (see 12.14)

Heat Input (as calculated by 5.12) kJ/mm									
	1.2 < HI ≤ 2.0			2.0 < HI ≤ 2.8			HI > 2.8		
Thickness t ≤ (mm)	H4	H8	H16	H4	H8	H16	H4	H8	H16
t ≤ 20	40	60	80	40	40	60	40	40	40
20 < t ≤ 40	100	100	120	80	100	120	60	80	100
40 < t ≤ 60	140	160	180	140	140	160	120	140	160
t > 60	180	180	200	160	180	200	140	160	180

Note: H4, H8, and H16 are electrode optional supplemental designators for diffusible hydrogen.

Table 12.5
M270M (A709M) Gr. 690, 690W Minimum and Maximum Preheat/Interpass Temperature, °C (see 12.14)

Heat Input (as calculated by 5.12) kJ/mm					
Thickness t (mm)	1.2 ≤ HI < 1.6	1.6 ≤ HI < 2.0	2.0 ≤ HI < 2.8	2.8 ≤ HI < 3.6	3.6 ≤ HI
6 ≤ t ≤ 10	40–60	—	—	—	—
10 < t ≤ 13	60–160	40–100	—	—	—
13 < t ≤ 20	120–200	100–180	40–120	—	—
20 < t ≤ 25	—	120–200	120–200	60–160	—
25 < t ≤ 50	—	—	120–200	120–200	100–180
t > 50	—	—	150–240	140–240	140–240

Note: The table applies to electrodes with the H4 or H8 optional supplemental designator for diffusible hydrogen limits.

maximum for not less than one hour for each 25 mm of weld thickness, or two hours, whichever is less. The minimum heating time for repair welds shall be one hour for each 25 mm of repair weld depth from the surface, but not less than one hour. Longer heating periods may be used.

12.15.2 Postweld Heat Treatment (PWHT). Any heating of welds or base metal by sources other than the welding arc to temperatures in excess of 480°C except for brief periods required for approved heat curving, cambering and straightening, shall be considered PWHT.

12.15.2.1 Approval. All PWHT shall be approved by the Engineer.

12.15.2.2 Controls. PWHT shall be completely described giving details of minimum and maximum temperature, maximum heating and cooling rates, minimum and maximum time at specified temperatures and all other details necessary to control the heat treatment.

12.15.2.3 Testing. Tests shall be performed to determine the effects of the proposed heat treatment on the strength, ductility, and toughness of welds and base metal before heating. The Engineer may accept records of previous qualification tests in lieu of testing. Magnetic particle and ultrasonic tests, when required, shall be repeated or performed after the weldment has cooled to ambient temperature.

12.16 Weld Inspection

All welds, including repair welds, shall be inspected as required by section 6 and shall meet the additional requirements of this FCP.

12.16.1 Quality Assurance/Quality Control (QA/QC). The Engineer shall provide Quality Assurance (QA) inspection as necessary to verify the proper and sufficient implementation of this FCP and applicable provisions of the contract documents. QA inspection by the Engineer shall not relieve the Contractor from the responsibility to conform to all requirements of the contract documents, including the requirement to provide Quality Control (QC) inspection and tests as described in section 6 and this FCP.

12.16.1.1 Inspectors. Inspectors shall be qualified as specified in 6.1.3. Lead QC and QA Inspectors shall have a minimum of three years experience in steel bridge fabrication inspection. A lead inspector shall be defined as the leader of the QA or QC inspection team at a specific work location, one who assigns other inspectors as necessary and supervises their work. The lead inspector shall be familiar with and shall have seen each FCM that

he or she has inspection responsibility for and may accept as described in 12.16.5.2. All inspectors shall have the authority to accept or reject materials and workmanship subject to review by the lead inspector.

12.16.1.2 NDT Technicians. NDT technicians shall be qualified to ASNT Level II or III in accordance with the provisions of Recommended Practice SNT-TC-1A. Level II technicians shall be supervised by an individual qualified to Level III. Level III individuals shall possess a currently valid ASNT Level III certificate. The Engineer may accept alternative qualifications which are deemed equivalent.

12.16.2 Type of Weld and NDT Required

12.16.2.1 Tension and Repaired Butt Welds. Butt joints in tension and repaired groove welds in butt joints shall be QC inspected by both radiographic (RT) and ultrasonic test (UT).

12.16.2.2 T- and Corner Joint Tension and Repaired Groove Welds. All tension and repaired groove welds in T- and corner joints shall be QC inspected by UT.

12.16.2.3 Fillet Weld Repairs. Fillet weld repairs shall be inspected by magnetic-particle tests (MT). The test length shall include 100 percent of the length of the repair, and, when appropriate, at least 300 mm beyond the ends of each repair weld.

12.16.3 RT Requirements. Radiographic testing shall be done using hole-type image quality indicators as described in Table 6.1 and Figure 6.1E.

12.16.4 Cooling Times Prior to Inspection. RT and preliminary visual inspections may be performed as soon as welds have cooled. UT, MT and final visual inspection shall be done after the welds have cooled to ambient temperature for at least the following minimum time periods:

- (1) Fillet welds on steel with a minimum specified yield strength of 345 MPa or less, 24 hours
- (2) Fillet welds on steel with a minimum specified yield strength greater than 345 MPa, 48 hours.
- (3) Groove welds in steel with a minimum specified yield strength of 345 MPa or less; 24 hours when the weld depth is 50 mm or less, and 48 hours when the weld depth is greater than 50 mm.
- (4) Groove welds in steel with a minimum specified yield strength greater than 345 MPa; 48 hours when the weld depth is 50 mm or less and 72 hours when the weld depth is greater than 50 mm.

12.16.5 Inspection and Record Keeping

12.16.5.1 Certified Reports. Certified copies of mill test reports, visual and NDT inspection reports, radiographs and other documentation that materials and work-

manship conform to the requirements of the contract documents shall be available for examination and shall be included in the permanent record. All fracture-critical base metal shall be identified with a specific mill test report. Heat and mill test report identity shall be maintained when base metal is cut for use in other FCMs. All repairs requiring documentation under the provisions of 12.17.3 shall be recorded in the inspection records. The inspection record of each fracture critical erection piece shall be identified by the erection mark listed in the shop drawings.

12.16.5.2 Identification of Inspectors. All Contractor (QC) and Engineer (QA) inspectors that have inspected FCMs shall be identified in the inspection records. The QC and QA Lead Inspectors that have inspected the FCM, reviewed the inspection records and performance of assistant inspectors, and determined that the FCM meets the requirements of this FCP and the contract documents shall sign and date the inspection record noting their acceptance.

12.17 Repair Welding

Repair welding is defined as any welding, including removal of weld or base metal in preparation for welding, necessary to correct unacceptable discontinuities in materials or workmanship. Welded repairs shall be categorized as noncritical (see 12.17.2) or critical (see 12.17.3), with separate requirements for each.

12.17.1 WPS Requirements. Repair welding shall be done in accordance with an approved WPS. The WPS may be preapproved per 12.17.2, or individually approved per 12.17.3.

12.17.1.1 Approval Procedure. The Contractor may prepare procedures and specifications for the repair of anticipated routine problems and submit them to the Engineer for approval before beginning the work. The Contractor may use preapproved repair WPSs as soon as the QA inspector has verified the discontinuity to be repaired is covered by the procedure.

12.17.1.2 Drawings. Repair WPSs shall include sketches, or full-size drawings, as necessary to describe the unacceptable discontinuity and the proposed method of repair. WPSs for critical repairs described in 12.17.3 shall document the location of the unacceptable discontinuities to be repaired.

12.17.1.3 Location. Unacceptable discontinuities to be repaired shall be shown in plan view, elevation, and section as necessary to describe the defect prior to repair. The drawings shall be revised, if necessary, at the completion of repairs to document differences between the

presumed initial type, size, orientation, and location of the unacceptable discontinuity and the final complete description of the unacceptable discontinuity as observed and measured during repair.

12.17.2 Noncritical Repair Welds. Noncritical repair welds are generally welds to deposit additional weld beads or layers to compensate for insufficient weld size and to fill limited excavations to remove unacceptable edge or surface discontinuities, rollover or undercut, including:

(1) Gouges in cut edges that are 10 mm deep, or less.

(2) Laminar discontinuities less than 25 mm deep, or with a depth less than one-half the thickness of the cut edge, whichever is less, provided the discontinuity is not within 300 mm of a butt joint loaded in tension. Repair shall be made by excavating from the cut edge.

(3) Repair of base-metal surfaces as provided in AASHTO M160/M160M (ASTM A6/A6M).

(4) First-time excavation and repair from one side of groove welds and fillet welds which contain unacceptable porosity, slag and fusion discontinuities, provided the excavations do not exceed the following limits:

<u>Length of Weld "L"</u> <u>(in meters)</u>	<u>Length of Excavation</u>
Up to 0.5 m	L or 250 mm, whichever is less
Over 0.5 m to 1.0 m	300 mm
Over 1.0 m to 2.0 m	450 mm
Over 2.0 m to 4.0 m	600 mm
Over 4.0 to 8.0 m	900 mm
Over 8.0 m	900 mm or 10% L, whichever is greater

The depth of groove weld excavation shall not exceed 65 percent of the weld size shown on the drawings.

(5) Repairs to cracks confined to root passes discovered and corrected before depositing subsequent weld passes.

(6) Repairs to ends of members where there is no deadload or liveload stress.

(7) Deposition of weld metal up to 10 mm deep, or 1/4 the base-metal thickness, whichever is less, to correct for length or joint geometry.

(8) Except as required by 12.15, PWHT is not required, unless the excavation is greater than 25 mm deep.

12.17.2.1 Noncritical Repair Procedures. Provision is made for the preapproval and use of noncritical repair procedures and WPSs to ensure that the Contractor has an acceptable plan for routine repairs prior to beginning the work.

12.17.3 Critical Weld Repairs. Except as provided in 12.17.2, all welded repairs are considered critical. They include, but are not limited to the following:

(1) Repair of gouges in cut edges greater than 10 mm deep.

(2) Repair of laminar discontinuities, except as provided in 12.17.2(2). Repair may be made from the cut edge, or from a surface, as approved by the Engineer.

(3) Repair of surface or internal discontinuities in rolled, forged, and cast products not covered by 12.17.2(3).

(4) Repair of cracks in base metal and welds including lamellar tears except as provided in 12.17.2(5).

(5) Corrections requiring weld removal and rewelding except as provided in 12.17.2(4).

(6) All welding to correct errors in fabrication such as improper cutting, punching, drilling, machining, assembly, etc.

12.17.4 Approval. All critical repairs to base metal and welds shall be approved by the Engineer prior to beginning the repair and shall be documented giving details of the type of discontinuity and extent of repair.

12.17.5 QA/QC Inspection. All repair welding shall be subject to QC and QA inspection.

12.17.6 Repair Procedure Minimum Provisions. Except that noncritical repairs described in 12.17.2 need not be recorded, all repair WPSs shall include at least the following provisions listed in the order in which the work will be performed:

(1) Surfaces shall be cleaned as necessary to facilitate visual inspection and nondestructive tests so that QC and QA inspectors can accurately characterize the discontinuity(s) of concern. Surfaces shall be ground when necessary to facilitate visual inspection and NDT.

(2) Unacceptable discontinuities to be repaired shall be recorded as required by 12.17.1.3, and in addition, the location of the excavation and proposed repair to edges, ends, holes, welds and other details of the FCM shall be shown.

(3) The preheating temperature prior to air carbon arc gouging shall be listed in the WPS. Preheat for gouging shall not be less than 65°C.

(4) The method and extent of excavation to remove unacceptable weld and base metal discontinuities shall be completely described, and, when appropriate, shall include the sequence of progressive excavations.

(5) Magnetic-particle inspection (MT) and other non-destructive tests, if ordered by the Engineer, shall be used to verify that all of the defect is removed.

(6) All thermal cut and gouged surfaces that will be welded upon shall be ground to produce a smooth, bright surface. Oxygen gouging is not permitted.

(7) All temporary weld extensions and steel backing, including the method of attachment, shall be shown in detail.

(8) Preheat and interpass temperature controls shall be listed. They shall meet, or exceed, the following minimum requirements:

(a) All steels with a minimum specified yield strength of 485 MPa or less, in thicknesses up to 40 mm inclusive, shall have a minimum preheat and interpass temperature of 160°C. For thicknesses greater than 40 mm, the minimum preheat and interpass temperature shall be 200°C.

(b) Grade 690/690W steels shall have a preheat and interpass temperature that conforms to the requirements of Table 12.5 for the heat input used, except that the minimum temperature shall be 110°C. Care shall be taken when welding Grade 690/690W steels to ensure that the combined preheat or interpass temperature plus welding heat input does not exceed the manufacturer's recommendations.

(9) Welding shall be done as described in the approved repair procedure. WPSs qualified for welding of FCMs need not be requalified for repair welding, provided the joint detail used allows access for welding.

(10) Peening, if required, shall be listed in the repair procedure and shall conform to the requirements of 3.8. Any additional requirements shall be completely described.

(11) All repair welds in groove excavations shall be postheated as stated in 12.15. Other weld repairs, such as repair or replacement of fillet welds and welding of shallow excavations described in 12.17.2, shall be postheated when ordered by the Engineer. Postheating, when required, shall be as described in the repair procedure.

(12) Repaired surfaces shall be ground flush with adjacent base metal or weld surfaces, or finished with slight reinforcement that is faired to adjoining surfaces as approved by the Engineer.

(13) Postweld heat treatments, when required, shall be listed in the repair procedure and shall conform to the requirements of 12.15.

Annexes

Mandatory Information

These Annexes contain information and requirements that are considered a part of the standard.

Annex I	Effective Throat
Annex II	Effective Throats of Fillet and Skewed T-Joints
Annex III	Suggested Sample Welding Forms
Annex IV	Flatness of Girder Webs—Bridges
Annex V	Terms and Definitions
Annex VI	Manufacturers Stud Base Qualification Requirements
Annex VII	Qualification and Calibration of Ultrasonic Units with Other Approved Reference Blocks
Annex VIII	Guidelines on Alternative Methods for Determining Preheat

Nonmandatory Annexes

These Annexes are not considered a part of the standard and are provided for information purposes.

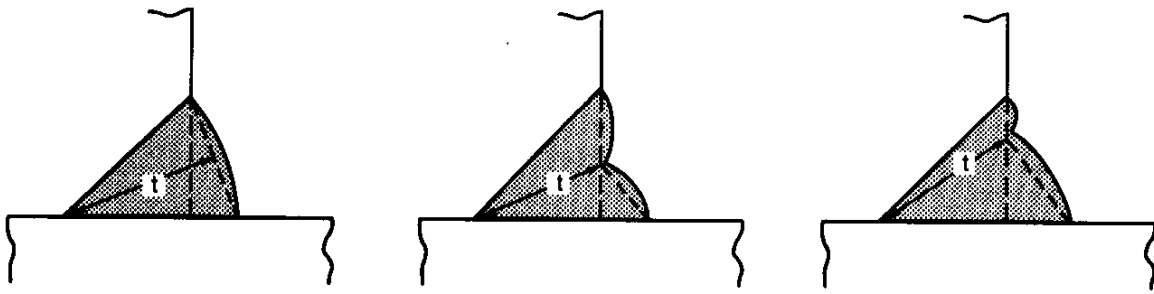
Annex A	Weld Quality Requirements for Tension Joints
Annex B	Description of Common Weld and Base Metal Discontinuities
Annex C	Short Circuiting Transfer
Annex D	Guidelines for Preparation of Technical inquiries to the Joint AASHTO/AWS Subcommittee on Bridge Welding

Annex I

Effective Throat

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)



Note: The effective throat of a weld is the minimum distance from the root of the joint to its face, with or without a deduction of 3 mm as required by 2.3.1.3, less any convexity.

Annex II

Effective Throats of Fillet Welds in Skewed T-Joints

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

Table II is a tabulation showing equivalent leg size factors for a range of dihedral angles between 60° and 135°, assuming there is no root opening. Root opening(s) 2 mm or greater, but not exceeding 5 mm, shall be added directly to the leg size. The required leg size for fillet welds in skewed joints is calculated using the equivalent leg size factor for correct dihedral angle, as shown in the example.

Example (SI Units)

Given: Skewed T-joint, angle: 75 degrees; root opening: 2 mm
Required: Strength equivalent to 90 degrees fillet weld of size: 8 mm
Procedure: (1) Factor for 75 degrees from Table II-1: 0.86

(2) Equivalent leg size, w , of skewed joint, without root opening:

$$w = 0.86 \times 8 = 6.9 \text{ mm}$$

(3) With root opening of: 2.0 mm

(4) Required leg size, w , of skewed fillet weld: [(2) + (3)]

(5) Rounding up to a practical dimension: $w = 9.0 \text{ mm}$

For fillet welds having equal measured legs (w_n), the distance from the root of the joint to the face of the diagrammatic weld (t_n) may be calculated as follows:

For root openings $> 2 \text{ mm}$ and $\leq 5 \text{ mm}$, use

$$t_n = \frac{w_n - R_n}{2 \sin \frac{\Psi}{2}}$$

For root openings $< 2 \text{ mm}$, use

$$R_n = 0 \text{ and } t'_n = t_n$$

where the measured leg of such fillet weld (w_n) is the perpendicular distance from the surface of the joint to the opposite toe, and (R) is the root opening, if any, between parts. See Figure 2.3. Acceptable root openings are defined in 3.3.1.

Table II-1
Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints, $R = 0$

Dihedral angle, Ψ	60°	65°	70°	75°	80°	85°	90°	95°
Comparable fillet weld size for same strength	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03
Dihedral angle, Ψ	100°	105°	110°	115°	120°	125°	130°	135°
Comparable fillet weld size for same strength	1.08	1.12	1.16	1.19	1.23	1.25	1.28	1.31

Annex III

Suggested Sample Welding Forms

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

This Annex contains six forms that the Structural Welding Committee has approved for the recording of WPS qualification, welder qualification, welding operator qualification, and tack welder qualification data required by this code. Also included are laboratory report forms for recording the results of nondestructive examination of welds.

It is suggested that the qualification and NDT information required by this code be recorded on these forms or similar forms which have been prepared by the user. Variations of these forms to suit the user's needs are permissible. These forms are available from AWS.

(Manufacturer's name

and address)

CERTIFICATION OF CONFORMANCE

Supplied to: _____ Date: _____

Purchase Order No.: _____ Quantity: _____ Project No.: _____

Reported to _____

Process:SMAW ☐
GMAW ☐SAW ☐
ESW ☐FCAW ☐
EGW ☐AWS A5. _____
and Classification

Trade Name

Material:

Electrode Designation

Wire Designation

Flux Designation

Gas/Gas Mixture

This is to certify that the above noted material, as supplied under the above Purchase Order Number, meets the requirements of AWS A5. _____ - _____ on _____, 19____.

(day, month) (year)

The results of the required manufacturer's annual tests are shown on the attached Certified Material Test Report. Test results for this Certification shall include:

- (a) Mechanical Tests: Tensile and Yield Strengths (MPa), Elongation (in 50 mm, %), and Charpy V-Notch (J at test temperature).
- (b) Chemical Analysis for: C, Mn, Si, P, S, Ni, Cr, Mo, Cu, V, Al, Ti, or Zr, as required by the applicable filler metal specification.
- (c) Fillet Weld Test.
- (d) Radiographic Results.

For applicable test requirements, see the appropriate AWS filler metal specification.

Signature: _____ Date: _____ Title: _____

Form IIIa

Form IIIa—Certificate of Conformance to Requirements for Welding Electrodes

WELDING PROCEDURE SPECIFICATION

Material specification _____
Welding process _____
Manual or machine _____
Position of welding _____
Filler metal specification _____
Filler metal classification _____
Flux _____
Shielding gas _____ Flow rate _____
Single or multiple pass _____
Single or multiple arc _____
Welding current _____
Polarity _____
Welding progression _____
Root treatment _____
Preheat and interpass temperature _____
Postheat temperature _____
Heat Input Min _____ Max _____

WELDING PROCEDURE

Pass no.	Electrode size	Welding current		Travel speed	Joint detail
		Amperes	Volts		

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in Section 5.

Procedure no. _____

Contractor _____

Revision no. _____

Authorized By _____

Form III-2

Date _____

Form III-2—Sample Welding Procedure Specification

PROCEDURE QUALIFICATION RECORD

Contractor _____ Test Date _____
 Process _____ Filler Metal _____
 Position _____
 Electrode(s) Mfg. Designation _____ AWS Classification _____
 Flux Mfg. Designation _____ AWS Classification _____
 Electrode Extension _____

	Diam.	Current	WFS*	Voltage	Current & Polarity
Electrode (1)	_____	_____	_____	_____	_____
(2)	_____	_____	_____	_____	_____
(3)	_____	_____	_____	_____	_____

Calculated Heat Input _____ (See 5.12)
 Shielding Gas _____ Flow Rate _____
 Dew Point _____ Travel Speed _____
 Base Metal Specification & Thickness _____
 (Attach Certified Copy of Mill Test Report)

Preheat Temp. _____ Interpass Temp. Min. _____ Max. _____

SPECIMEN	TEST RESULTS
All Weld Metal Tension (AWMT)	Tensile Strength (MPa) _____ Yield Strength (MPa) _____ Elongation in 50 mm (%) _____ Reduction in Area % _____
Side Bends	1. _____ 2. _____ 3. _____ 4. _____
Reduced Section Tension	Tension Strength 1. _____ Location of Break 1. _____ 2. _____ 2. _____
Charpy V-Notch Impact	(_____ , _____ , _____ , _____ , _____) Avg. J** _____ @ _____ °C
Toughness of Weld Metal	(_____ , _____ , _____ , _____ , _____) Avg. J** _____ @ _____ °C
SMAW, SAW, FCAW, GMAW — 5 Reg.	
ESW & EGW — 8 Reg.	**Discard the highest and lowest values and average the remaining values.
Chemistry of Deposited Weld Metal	C _____ Mn _____ Si _____ P _____ S _____ Ni _____ Cr _____ Mo _____ V _____ Cu _____
When Required by Contract Documents	

REMARKS Visual _____ Radiographic Test _____

*Wire feed may be used in lieu of current when a correlation curve is provided for the same electrode diameter and same electrode extension.

Test Witness: _____ Agency: _____

Results Reviewed: _____ State Acceptance: _____

Form III-1 Date: _____

**Form III-1—Procedure Qualification Record (PQR)
 for Qualification, Pretest, and Verification Results**

WELDER AND WELDING OPERATOR QUALIFICATION RECORD

Welder or welding operator's name _____ Identification no. _____
 Welding process _____ Manual _____ Semiautomatic _____ Machine _____
 Position _____
 (Flat, horizontal, overhead or vertical—if vertical, state whether upward or downward)
 In accordance with procedure specification no. _____
 Material specification _____
 Thickness range this qualifies _____

FILLER METAL

Specification no. _____ Classification _____ F no. _____
 Describe filler metal (if not covered by AWS specification) _____

Is backing used? _____
 Filler metal diameter and trade name _____ Flux for submerged arc or gas for gas metal arc or flux
 cored arc welding _____

VISUAL INSPECTION (9.21.1)

Appearance _____ Undercut _____ Piping porosity _____

Guided Bend Test Results

Type	Result	Type	Result

Test conducted by _____ Laboratory test no. _____
 per _____ Test date _____

Fillet Test Results

Appearance _____ Fillet size _____
 Fracture test root penetration _____ Macroetch _____
 (Describe the location, nature, and size or any crack or tearing of the specimen.)
 Test conducted by _____ Laboratory test no. _____
 per _____ Test date _____

RADIOGRAPHIC TEST RESULTS

Film identification	Results	Remarks	Film identification	Results	Results

Test witnessed by _____ Test no. _____
 per _____

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of ANSI/AASHTO/AWS D1.5, (_____) Bridge Welding Code.
 (year)

Manufacturer or Contractor _____

Authorized By _____

Date _____

REPORT OF RADIOGRAPHIC EXAMINATION OF WELDS

Project _____
Quality requirements—Section no. _____
Reported to _____

WELD LOCATION AND IDENTIFICATION SKETCH

Technique

Source _____
Film to source _____
Exposure time _____
Screens _____
Film type _____

(Describe length, width, and thickness of all joints radiographed)

[illegible]

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of ANSI/AASHTO/AWS D1.5, () Bridge Welding Code.
(year)

Radiographer(s) _____ **Manufacturer or Contractor** _____

Interpreter _____ Authorized By _____

Test Date _____ Date _____

Form III-7

Form III-7—Report of Radiographic Examination of Welds

WELD LOCATION AND IDENTIFICATION SKETCH

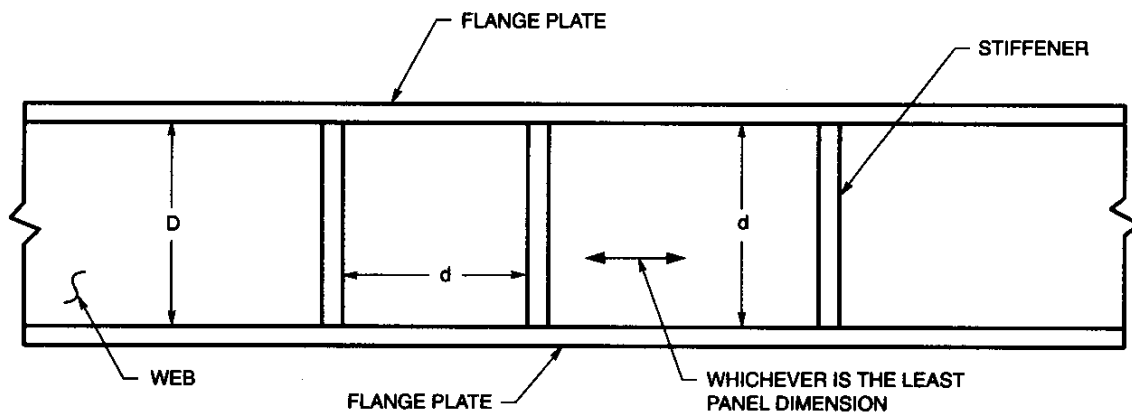
Form III-8—Report of Magnetic Particle Examination of Welds

Annex IV

Flatness of Girder Webs—Bridges

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)



NOTES:

1. D = DEPTH OF WEB
2. d = LEAST PANEL DIMENSION

Intermediate Stiffener on Both Sides of Web—Fascia Girders

Thickness of Web, mm	Depth of Web, mm	Least Panel Dimension, mm											
		780	1040										
8	Less than 1200	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
	1200 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
9	Less than 1350	780	1040	1300									
	1350 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
10	Less than 1500	780	1040	1300									
	1500 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
11	Less than 1650	780	1040	1300	1560								
	1650 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
12	Less than 1800	780	1040	1300	1560								
	1800 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
14	Less than 2100	780	1040	1300	1560	1820	2080						
	2100 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
16	Less than 2400	780	1040	1300	1560	1820	2080	2340					
	2400 and over	630	840	1050	1260	1470	1680	1890	2100	2310	2520	2730	2940
		Maximum Permissible Variation, mm											
		6	8	10	12	14	16	18	20	22	24	26	28

Intermediate Stiffeners on One Side of Web Only—Fascia Girders

Thickness of Web, mm	Depth of Web, mm	Least Panel Dimension, mm											
		720											
8	Less than 800	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
	800 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
9	Less than 900	720											
	900 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
10	Less than 1000	720	960										
	1000 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
11	Less than 1100	720	960										
	1100 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
12	Less than 1200	720	960	1200									
	1200 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
14	Less than 1400	720	960	1200									
	1400 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
16	Less than 1600	720	960	1200	1440								
	1600 and over	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240
		Maximum permissible variation, mm											
		6	8	10	12	14	16	18	20	22	24	26	28

Intermediate Stiffeners on Both Sides of Web—Interior Girders

Thickness of Web, mm	Depth of Web, mm	Least Panel Dimension, mm											
		690	920	1150									
8	Less than 1200	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	1200 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
9	Less than 1350	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	1350 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
10	Less than 1500	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	1500 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
11	Less than 1650	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	1650 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
12	Less than 1800	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	1800 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
14	Less than 2100	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	2100 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
16	Less than 2400	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
	2400 and over	550	740	920	1100	1290	1470	1660	1840	2020	2210	2390	2580
		Maximum Permissible Variation, mm											
		6	8	10	12	14	16	18	20	22	24	26	28

Intermediate Stiffeners on One Side Only of Web—Interior Girders

Thickness of Web, mm	Depth of Web, mm	Least Panel Dimension, mm											
		600	800										
8	Less than 800	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	800 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
9	Less than 900	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	900 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
10	Less than 1000	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	1000 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
11	Less than 1100	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	1100 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
12	Less than 1200	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	1200 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
14	Less than 1400	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	1400 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
16	Less than 1600	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
	1600 and over	400	540	670	800	940	1070	1210	1340	1470	1610	1740	1880
		Maximum Permissible Variation, mm											
		6	8	10	12	14	16	18	20	22	24	26	28

No Intermediate Stiffeners—Interior and Fascia Girders

Thickness of Web, mm	Least Panel Dimension, mm											
	900	1200	1500	1800	2100	2400	2700	3000	3300	3600	3900	4200
Any												
Maximum Permissible Variation, mm												
	6	8	10	12	14	16	18	20	22	24	26	28

Annex V

Terms and Definitions

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

The terms and definitions in this glossary are divided into three categories: (1) general welding terms compiled by the AWS Committee on Definitions and Symbols, (2) terms, defined by the AWS Structural Welding Committee, which apply only to ultrasonic testing, designated by (UT) following the term, and (3) other terms, preceded by asterisks, which are defined as they relate to this code.

A

***active flux (submerged arc welding).** A flux which contains small amounts of manganese or silicon, or both, added to improve the weld in certain single pass applications. Change in arc voltage or the number of weld passes can significantly change weld metal chemistry and mechanical properties.

***alloy flux (submerged arc welding).** A flux which contains alloy ingredients intended to modify the weld metal chemistry. Changes in arc voltage can significantly change weld metal chemistry.

***all-weld-metal test specimen.** A test specimen with the reduced section composed wholly of weld metal.

amplitude length rejection level (UT). The maximum length of discontinuity permitted by various indication ratings associated with weld size, as indicated in Tables 9.1 and 9.2.

angle of bevel. See preferred term **bevel angle**.

arc gouging. Thermal gouging that uses an arc cutting process variation used to form a bevel or groove.

as-welded. Pertaining to the condition of weld metal, welded joints, and weldments after welding, but prior

to any subsequent thermal, mechanical, or chemical treatments.

attenuation (UT). The loss in acoustic energy which occurs between any two points of travel. This loss may be due to absorption, reflection, etc. (In this code, using the shear wave pulse-echo method of testing, the attenuation factor is 2 dB per 25 mm of sound path distance after the first 25 mm.)

automatic welding. Welding with equipment that requires only occasional or no observation of the welding and no manual adjustment of the equipment controls. See also **machine welding**.

axis of a weld. See **weld axis**.

B

backgouging. The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

backing. A material or device placed against the back side of the joint, or at both sides of a weld in electroslag and electrogas welding, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal.

backing pass. A weld pass made for a backing weld.

backing ring. Backing in the form of a ring, generally used in the welding of pipe.

backing weld. Backing in the form of a weld.

back weld. A weld made at the back of a single-groove weld.

base metal. The metal or alloy to be welded, brazed, soldered, or cut.

bevel angle. The angle between the bevel of a joint member and a plane perpendicular to the surface of the member.

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

butt joint. A joint between two members aligned approximately in the same plane.

butt weld. A nonstandard term for a weld in a butt joint. See **butt joint**.

C

***caulking.** Plastic deformation of weld and base-metal surfaces by mechanical means to seal or obscure discontinuities.

complete fusion. Fusion over the entire fusion faces and between all adjoining weld beads.

complete joint penetration. A joint root condition in a groove weld in which weld metal extends through the joint thickness.

***complete joint penetration groove weld.** A groove weld which has been made from both sides or from one side on a backing having complete penetration and fusion of weld and base metal throughout the depth of the joint.

complete penetration. A nonstandard term for **complete joint penetration**.

***consumable guide electroslag or electrogas welding.** An electroslag or electrogas welding process variation in which filler metal is supplied by an electrode(s) and the guiding member(s).

continuous weld. A weld that extends continuously from one end of a joint to the other. Where the joint is essentially circular, it extends completely around the joint.

corner joint. A joint between two members located approximately at right angles to each other.

CO₂ welding. A nonstandard term for **gas metal arc welding (GMAW)**.

crater. A depression in the weld face at the termination of a weld bead.

D

decibel (dB) (UT). The logarithmic expression of a ratio of two amplitudes or intensities of acoustic energy.

decibel rating (UT). See preferred term **indication rating**.

defect. A discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability. See also **discontinuity** and **flaw**.

***defective weld.** A weld containing one or more defects.

defect level (UT). See preferred term **indication rating**.

defect rating (UT). See preferred term **indication rating**.

depth of fusion. The distance that fusion extends into the base metal or previous bead from the surface melted during welding.

discontinuity. An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

downhand. See preferred term **flat welding position**.

***drawings.** As used in this code, refers to plans, design, detail drawings and erection plans.

E

***effective length of weld.** The length throughout which the correctly proportioned cross section of the weld exists. In a curved weld, it shall be measured along the weld axis.

electrogas welding (EGW). An arc welding process that uses an arc between a continuous filler metal electrode, and the weld pool, employing approximately vertical welding progression with backing to confine the molten weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure.

weld metal for vertical position welding. The electrodes may be either flux cored or solid. Shielding

may or may not be obtained from an externally supplied gas or mixture.

electroslag welding (ESW). A welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces.

F

faying surface. The mating surface of a member that is in contact with or in close proximity to another member to which it is to be joined.

filler metal. The metal or alloy to be added in making a welded, brazed, or soldered joint.

fillet weld leg. The distance from the joint root to the toe of the fillet weld.

***flash.** The material which is expelled or squeezed out around the base of a stud weld.

***flat welding position.** The welding position used to weld from the upper side of the joint when the face of the weld is approximately horizontal.

flaw. An undesirable discontinuity. See also **defect** and **discontinuity**.

***flux.** A material used to hinder or prevent the formation of oxides and other undesirable substances in molten metal and on solid metal surfaces, and to dissolve or otherwise facilitate the removal of such substances. See also **active flux** and **neutral flux**.

flux cored arc welding (FCAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode with or without additional shielding from an externally supplied gas, and without the application of pressure.

fusion. The melting together of filler metal and base metal or of base metal only, to produce a weld. See also **depth of fusion**.

***fusion-type discontinuity.** Signifies slag inclusion, incomplete fusion, incomplete joint penetration, and similar discontinuities associated with fusion.

fusion zone. The area of base metal melted as determined on the cross section of a weld.

G

gas metal arc welding (GMAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.

***gas metal arc welding-short circuit arc (GMAW-S).** A gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits.

***gas pocket.** A cavity caused by entrapped gas.

***gouging (thermal).** The forming of a bevel or groove by material removal. See also **back gouging**, **arc gouging**, and **oxygen gouging**.

groove angle. The total included angle of the groove between workpieces.

groove face. That surface of a joint member included in the groove.

groove weld. A weld made in a groove between the workpieces.

H

heat-affected zone (HAZ). That portion of the base metal with mechanical properties or microstructure that have been altered by the heat of welding, brazing, soldering, or thermal cutting.

***horizontal welding position**

fillet weld. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface. See Figures 5.4, and 5.7(B).

groove weld. The position of welding in which the weld axis lies in an approximately horizontal plane and the weld face lies in an approximately vertical plane. See Figures 5.5 and 5.6(B).

horizontal reference line (UT). A horizontal line near the center of the ultrasonic test instrument scope to which all echoes are adjusted for dB reading.

I

***image quality indicator (IQI).** A device whose image in a radiograph is used to determine radiographic quality level. It is not intended for use in judging the size nor for establishing acceptance limits of discontinuities.

indication (UT). The signal displayed on the oscilloscope signifying the presence of a sound wave reflector in the part being tested.

indication level (UT). The calibrated gain or attenuation control reading obtained for a reference-line height indication from a discontinuity.

indication rating (UT). The decibel reading in relation to the zero reference level after having been corrected for sound attenuation.

inert gas metal arc welding. See preferred term **gas metal arc welding (GMAW)**.

intermittent weld. A weld in which the continuity is broken by recurring unwelded spaces.

***interpass temperature (welding).** In a multiple-pass weld, the temperature of the weld before the next pass is started.

J

joint. The junction of members or the edges of members that are to be joined or have been joined.

joint penetration. The distance the weld metal extends from the weld face into a joint, exclusive of reinforcement.

joint root. That portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, a line, or an area.

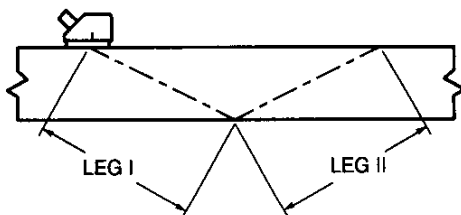
***joint welding procedure.** The materials and detailed methods and practices employed in the welding of a particular joint.

L

lap joint. A joint between two overlapping members in parallel planes.

***layer.** A stratum of weld metal or surfacing material. The layer may consist of one or more weld beads laid side by side.

leg (UT). The path the shear wave travels in a straight line before being reflected by the opposite surface of material being tested. See sketch below for leg identification. *Note: Leg I plus leg II equals one V-path.*



leg of a fillet weld. See **fillet weld leg**.

M

***machine.** To shape, plane, mill, saw, grind or otherwise finish by machine-operated tools.

***machine welding.** Welding with equipment which performs the welding operation under the constant observation and control of a welding operator. The equipment may or may not load and unload the workpieces. See also **automatic welding**.

manual welding. Welding with the torch, gun, or electrode holder held and manipulated by hand. Accessory equipment, such as part motion devices and manually controlled filler material feeders may be used. See **automatic welding**, **machine welding**, and **semiautomatic welding**.

N

neutral flux (submerged arc welding). A flux that will not cause a significant change in the weld metal composition when there is a large change in the arc voltage.

node (UT). See preferred term **leg**.

O

***overhead welding position.** The position in which welding is performed from the underside of the joint. See Figures 5.4, 5.5, 5.6(D) and 5.7(D).

***overlap (fusion welding).** The protrusion of weld metal beyond the weld toe or weld root.

oxygen cutting (OC). A nonstandard term for oxyfuel gas cutting.

oxygen gouging. Thermal gouging that uses an oxygen cutting process variation to form a bevel or groove.

P

***parallel electrode.** See **submerged arc welding (SAW)**.

partial joint penetration. Joint penetration that is intentionally less than complete.

pass. See preferred term **weld pass**.

peening. The mechanical working of metals using impact blows.

***piping porosity (electroslag and electrogas).** Elongated gas pores whose major dimension lie in a direction approximately parallel to the weld axis which is vertical during welding. When not controlled, piping porosity can be extensive, and very long pores or tunnels have been found in electroslag welds. This defect is difficult to evaluate by ultrasonic testing.

***piping porosity (general).** Elongated porosity whose major dimension lies in a direction approximately normal to the weld surface. (They generally grow vertically during welding before the weld metal has completely solidified.) Piping porosity is frequently referred to as *pin holes* when the porosity extends to the weld surface.

plug weld. A weld made in a circular hole in one member of a joint, fusing that member to another member. A fillet-welded hole is not to be construed as conforming to this definition.

***porosity.** Cavity-type discontinuities formed by gas entrapment during solidification.

***positioned weld.** A weld made in a joint that has been placed to facilitate making the weld.

***postweld heat treatment.** Any heat treatment after welding.

***preheating.** The application of heat to the base metal immediately before welding, brazing, soldering, thermal spraying, or cutting.

preheat temperature (welding). A specified temperature that the base metal must attain in the welding, brazing, soldering, thermal spraying, or cutting area immediately before these operations are performed.

procedure qualification. The demonstration that welds made by a specific procedure can meet prescribed standards.

procedure qualification record (PQR) (welding). A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld to qualify a WPS. See Form E-1.

Q

qualification. See preferred terms **welder performance qualification** and **procedure qualification**.

R

random sequence. A longitudinal sequence in which the weld bead increments are made at random.

reference level (UT). The decibel reading obtained for a horizontal reference-line height indication from a reference reflector.

reference reflector (UT). The reflector of known geometry contained in the IIW reference block or other approved blocks.

reinforcement of weld. See **weld reinforcement**.

***rejectable discontinuity.** See preferred term **defect**.

resolution (UT). The ability of ultrasonic equipment to give separate indications from closely spaced reflectors.

root face. That portion of the groove face within the joint root. See ANSI/AWS A3.0-94, Figure 5.

root of joint. See **joint root**.

root of weld. See **weld root**.

root opening. The separation at the joint root between the workpieces.

S

scanning level (UT). The dB setting used during scanning, as described in Tables 9.1 and 9.2.

***semiautomatic welding.** Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

shielded metal arc welding (SMAW). An arc welding process with an arc between a covered metal electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.

shielding gas. Protective gas used to prevent or reduce atmospheric contamination.

***single-welded joint (fusion welding).** In arc and gas welding, any joint welded from one side only.

size of weld. See **weld size**.

slot weld. A weld made in an elongated hole in one member of a joint fusing that member to another member. The hole may be open at one end. A fillet welded slot is not to be construed as conforming to this definition.

sound beam distance (UT). See preferred term **sound path distance**.

sound path distance (UT). The distance between the search unit test material interface and the reflector as measured along the centerline of the sound beam.

splatter. The metal particles expelled during fusion welding that do not form a part of the weld.

stringer bead. A type of weld bead made without appreciable weaving motion.

***stud arc welding (SW).** An arc welding process that produces coalescence of metals by heating them with an arc between a metal stud, or similar part, and the other workpiece. When the surfaces to be joined are properly heated, they are brought together under pressure. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used.

***stud base.** The stud tip at the welding end, including flux and container or metal insert, and 3 mm of the body of the stud adjacent to the tip.

submerged arc welding (SAW). An arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

***single electrode.** One electrode connected exclusively to one power source which may consist of one or more power units.

***parallel electrode.** Two electrodes connected electrically in parallel and exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. Welding current, when specified, is the total for the two electrodes.

***multiple electrodes.** The combination of two or more single or parallel electrode systems. Each of the component systems has its own independent power source and its own electrode feeder.

T

tack weld. A weld made to hold parts of a weldment in proper alignment until the final welds are made.

***tack welder.** A fitter, or someone under the direction of a fitter, who has been qualified to tack weld parts of a weldment to hold them in proper alignment until the final welds are made.

***tandem.** Refers to a geometrical arrangement of electrodes in which a line through the arcs is parallel to the direction of welding.

temporary weld. A weld made to attach a piece or pieces to a weldment for temporary use in handling, shipping, or working on the weldment.

throat of a fillet weld

theoretical throat. The distance from the beginning of the joint root perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.

actual throat. The shortest distance between the weld root and the face of a fillet weld.

throat of a groove weld. A nonstandard term for groove weld size.

T-joint. A joint between two members located approximately at right angles to each other in the form of a T.

toe of weld. See weld toe.

***transverse discontinuity.** A weld discontinuity whose major dimension is in a direction perpendicular to the weld axis "X."

U

undercut. A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

V

***vertical welding position.** The position of welding in which the axis of the weld is approximately vertical. See Figures 5.4, 5.5, 5.6(C) and 5.7(C).

V-path (UT). The distance a shear wave sound beam travels from the search unit test material interface to the other face of the test material and back to the original surface.

W

weave bead. A type of weld bead made with transverse oscillation.

weld. A localized coalescence of metals or non-metals produced either by heating the materials to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.

weldability. The capacity of a material to be welded under the imposed fabrication conditions into a spe-

cific, suitably designed structure and to perform satisfactorily in the intended service.

weld axis. A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

weld bead. A weld resulting from a pass. See **stringer bead** and **weave bead**.

welder. One who performs a manual or semiautomatic welding.

***welder certification.** Certification in writing that a welder has produced welds meeting prescribed standards. Certification is only effective when the welder or welding operator meets the currency requirements of section 5, Parts C and D.

welder performance qualification. The demonstration of a welder's ability to produce welds meeting prescribed standards.

weld face. The exposed surface of a weld on the side from which welding was done.

welding. A joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure alone, and with or without the use of filler metal. See the Master Chart of Welding Processes, ANSI/AWS A3.0.

welding machine. Equipment used to perform the welding operation. For example, spot welding machine, arc welding machine, and seam welding machine.

welding operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.

***welding procedure.** The detailed methods and practices including all joint welding procedures involved

in the production of a weldment. See **joint welding procedure**.

welding procedure specification (WPS). A document providing the required variables for a specific application to assure repeatability by properly trained welders and welding operators.

welding sequence. The order of making the welds in a weldment.

weldment. An assembly whose component parts are joined by welding.

weld pass. A single progression of welding along a joint. The result of a pass is a weld bead or layer.

weld reinforcement. Weld metal in excess of the quantity required to fill a joint.

weld root. The points, shown in cross section, at which the root surface intersects the base metal surfaces.

weld size

fillet weld size. For equal leg fillet welds, the leg lengths of the largest isosceles right triangle which can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.

groove weld size. The joint penetration of a groove weld.

weld tab. Additional material that extends beyond either end of the joint, on which the weld is started or terminated.

weld toe. The junction of the weld face and the base metal.

Annex VI

Manufacturer's Stud Base Qualification Requirements

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

VI1. Purpose

The purpose of these requirements is to prescribe tests for the stud manufacturer's certification of a stud base for welding under shop or field conditions.

VI2. Responsibility for Tests

The stud manufacturer shall be responsible for the performance of the qualification test. These tests may be performed by a testing agency satisfactory to the Engineer. The agency performing the tests shall submit a certified report to the manufacturer of the studs giving procedures and results for all tests including the information listed under VI10.

VI3. Extent of Qualification

Qualification of a stud base shall constitute qualification of stud bases with the same geometry, flux, and arc shield, having the same diameter and diameters that are smaller by less than 3 mm. For example, qualification of a 19 mm shank diameter stud base does not constitute qualification for a 16 mm shank diameter stud, but would constitute qualification for a stud base having a shank diameter of 17 mm. A stud base qualified with an approved grade of ASTM A108 steel shall constitute qualification for all other approved grades of A108 Steel (see 7.3.1) provided that all other provisions stated herein are complied with.

VI4. Duration of Qualification

A size of stud base with arc shield, once qualified, is considered qualified until the stud manufacturer makes any change in the stud-base geometry, material, flux, or arc shield which affects the welding characteristics.

VI5. Preparation of Specimens

VI5.1 Test specimens shall be prepared by welding representative studs to suitable specimen plates of Grade 250 steel or any of the other materials listed in 9.2. When studs are to be welded through decking, the stud-base qualification test shall include decking representative of that to be used in construction. Welding shall be done in the flat position (plate surface horizontal). Tests for threaded studs shall be on blanks (studs without threads).

VI5.2 Studs shall be welded with power source, welding gun, and automatically controlled equipment as recommended by the stud manufacturer. Welding voltage, current, and time (see VI6) shall be measured and recorded for each specimen. Lift and plunge shall be at the optimum setting as recommended by the manufacturer.

VI6. Number of Test Specimens

VI6.1 For studs 22 mm or less in diameter, thirty test specimens shall be welded consecutively with constant optimum time, but with current 10 percent above optimum. For studs over 22 mm diameter, 10 test specimens shall be welded consecutively with constant optimum time, but current and time shall be the midpoint of the

range normally recommended by the manufacturer for production welding.

VI6.2 For studs 22 mm or less in diameter, 30 test specimens shall be welded consecutively with constant optimum time, but with current 10 percent below optimum. For studs over 22 mm diameter, 10 test specimens shall be welded consecutively with constant optimum time, but with current 5 percent below optimum.

VI7. Tests

VI7.1 Tension Tests. Ten of the specimens welded in accordance with VI6.1 and ten in accordance with VI6.2 shall be subjected to a tension test in a fixture similar to that shown in Figure 7.2, except that studs without heads may be gripped on the unwelded end in the jaws of the tension testing machine. A stud base shall be considered as qualified if all test specimens have a tensile strength equal to or above the minimum specified in 7.3.1.

VI7.2 Bend Test Studs 22 mm or Less in Diameter. Twenty of the specimens welded in accordance with VI6.1 and twenty in accordance with VI6.2 shall be bend tested by being bent alternately thirty degrees from their original axis in opposite directions until failure occurs. Studs shall be bent in a bend testing device as shown in Figure VI-1A, except that studs less than 12 mm diameter, optionally, may be bent using a device as shown in Figure VI-1B. A stud base shall be considered as qualified if, on all test specimens, fracture occurs in the plate material or shank of the stud and not in the weld or heat-

affected zone (HAZ). All test specimens for studs over 22 mm will be tested only for tensile strength, Figure 7.2.

VI8. Retests

If failure occurs in a weld or the HAZ in any of the bend test groups of VI7.2 or at less than specified minimum tensile strength of the stud in any of the tension groups in VI7.1, a new test group (specified in VI6.1 or VI6.2, as applicable) shall be prepared and tested. If such failures are repeated, the stud base shall fail to qualify.

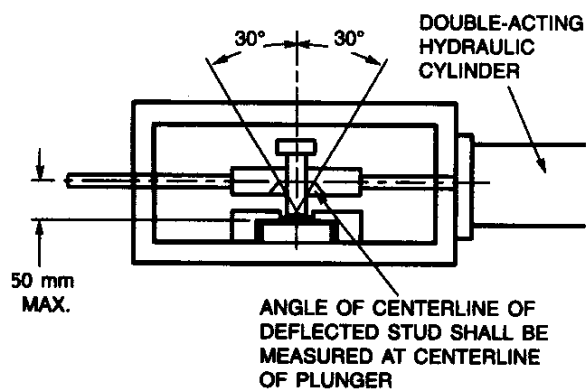
VI9. Acceptance

For a manufacturer's stud base and arc shield combination to be qualified, each stud of each group of 30 studs shall, by test or retest, meet the requirements prescribed in VI7. Qualification of a given diameter of stud base shall be considered qualification for stud bases of the same nominal diameter (see VI3, stud-base geometry, material, flux, and arc shield).

VI10. Manufacturer's Qualification Test Data

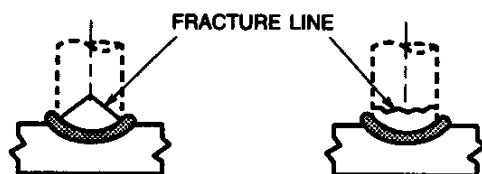
The test data shall include the following:

- (1) Drawings showing shapes and dimensions with tolerances of stud, arc shields, and flux
- (2) A complete description of materials used in the studs, including the quantity and type of flux, and a description of the arc shields
- (3) Certified results of required laboratory tests

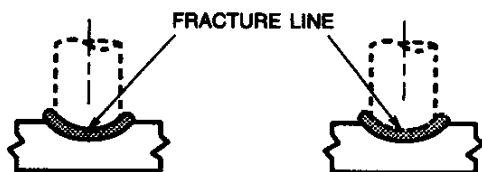


Notes:

1. Fixture holds specimen and stud is bent 30° alternately in opposite directions.
2. Load can be applied with hydraulic cylinder (shown) or fixture adapted for use with tension test machine.



TYPICAL FRACTURES IN SHANK OF STUD

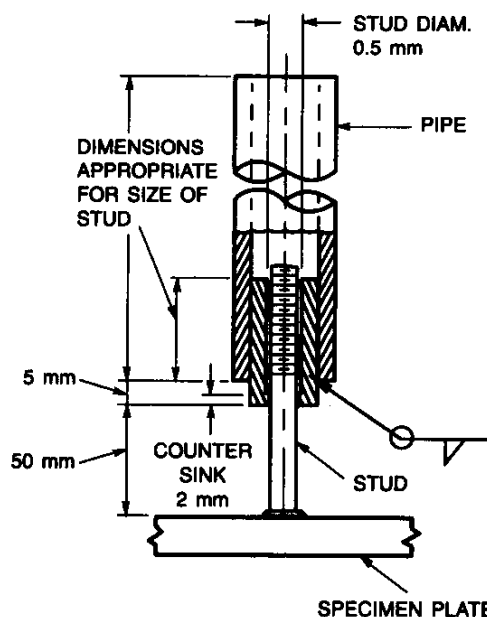


Note: Fracture in weld near stud fillet remains on plate.

Note: Fracture through flash torn from plate.

TYPICAL WELD FAILURES

**Figure VI-1A—Bend Testing Device
(see VI7.2)**



**Figure VI-1B—Suggested Type of Device for
Qualification Testing of Small Studs (see
VI7.2)**

Annex VII

Part A **Qualification and Calibration of the Ultrasonic Unit with Other Approved Reference Blocks (see Figure VII-1)**

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

VIIA1. Longitudinal Mode

VIIA1.1 Distance Calibration

VIIA1.1.1 The transducer shall be set in position

H on the DC block, or
M on the DSC block

VIIA1.1.2 The instrument shall be adjusted to produce indications at 25, 50, 75, 100 mm, etc., on the display.

Note: This procedure establishes a 250 mm screen calibration and may be modified to establish other distances as permitted by 6.18.4.1.

VIIA1.2 Amplitude. With the transducer in position described in VIIA1.1, the gain shall be adjusted until the maximized indication from the first back reflection attains 50 to 75 percent screen height.

VIIA2. Shear Wave Mode (Transverse)

VIIA2.1 Sound Entry (Index) Point Check

VIIA2.1.1 The search unit shall be set in position J or L on the DSC block; or I on the DC block.

VIIA2.1.2 The search unit shall be moved until the signal from the radius is maximized.

VIIA2.1.3 The point on the search unit that is in line with the line on the calibration block is indicative of the point of sound entry.

Note: Use this sound entry point for all further distance and angle checks.

VIIA2.2 Sound Path Angle Check

VIIA2.2.1 The transducer shall be set in position:

K on the DSC block for 45° through 70°
N on the SC block for 70°
O on the SC block for 45°
P on the SC block for 60°

VIIA2.2.2 The transducer shall be moved back and forth over the line indicative of the transducer angle until the signal from the radius is maximized.

VIIA2.2.3 The sound entry point on the transducer shall be compared with the angle mark on the calibration block (tolerance ± 2 degrees).

VIIA2.3 Distance Calibration

VIIA2.3.1 The transducer shall be set in position L on the DSC block. The instrument shall be adjusted to attain indications at 75 mm and 180 mm on the display.

VIIA2.3.2 The transducer shall be set in position J on the DSC block (any angle). The instrument shall be adjusted to attain indications at 25 mm, 125 mm, and 230 mm on the display.

VIIA2.3.3 The transducer shall be set in position I on the DC block (any angle). The instrument shall be adjusted to attain indication at 25 mm, 50 mm, 75 mm, 100 mm, etc., on the display.

Note: This procedure establishes a 250 mm screen calibration and may be modified to establish other distances as permitted by 6.18.5.1.

VIIA2.4 Amplitude or Sensitivity Calibration

VIIA2.4.1 The transducer shall be set in position L on the DSC block (any angle). The maximized signal from the 0.8 mm slot shall be adjusted to attain a horizontal reference-line height indication.

VIIA2.4.2 The transducer shall be set on the SC block in position:

- N for 70° angle
- O for 45° angle
- P for 60° angle

The maximized signal from the 1.6 mm hole shall be adjusted to attain a horizontal reference-line height indication.

VIIA2.4.3 The decibel reading obtained in VIIA2.4.1 or VIIA2.4.2 shall be used as the "reference level, "b" on the Test Report Sheet (Annex VII, Part B, Form VII-11) in accordance with 6.16.1.

VIIA3. Horizontal Linearity Procedure

Note: Since this qualification procedure is performed with a straight beam search unit which produces longitudinal waves with a sound velocity of almost double that of shear waves, it is necessary to double the shear wave distance ranges to be used in applying this procedure.

VIIA3.1 A straight beam search unit meeting the requirements of 6.15.6 shall be coupled in position:

- G on the IIW block (Figure 6.5)
- T or U on the DS block (Figure 6.5)

VIIA3.2 A minimum of 5 back reflections shall be attained in the qualification range being certified.

VIIA3.3 The first and fifth back reflections shall be adjusted to their proper locations with use of the distance calibration and zero delay adjustments.

VIIA3.4 Each indication shall be adjusted to reference level with the gain or attenuation control for horizontal location examination.

VIIA3.5 Each intermediate trace deflection location shall be correct within ± 2 percent of the screen width.

Part B
Ultrasonic Equipment Qualification Procedures

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

This Annex contains examples for use of three forms, VII-8, VII-9, and VII-10, recording of ultrasonic test data. Each example of forms VII-8, VII-9, and VII-10 shows how the forms may be used during the ultrasonic inspection of welds. Form VII-11 is for reporting results of ultrasonic inspection of welds.

Ultrasonic Unit Certification

Ultrasonic unit
 Model UT77 Serial no. 00006
 Search unit
 Size 25 mm Type BT
 Frequency 2.25 MHz

Date 10-23-90
 By I. C. BLIPS
 ASNT Level II

TABULATION CHART					
No.	a dB Reading	b % Scale	c Corrected Reading	d dB Error	e Collective dB Error
1	6	69	7.1	-1.1	-2.3
2	12	75	12.4	-0.4	-1.2
3	18	75	18.3	-0.3	-0.8
4	24	77	24.1	-0.1	-0.5
5	30	77	30.1	-0.1	-0.4
6	36	77	36.1	-0.1	-0.3
7	42	77	42.1	-0.1	-0.2
8	48	78	48.0	-0.0	-0.1
9	54	77	54.1	-0.1	-0.1
10	60	78	60.0	0.0	0.0
11	66	79	65.9	+0.1	+0.1
12	72	80	71.8	+0.2	+0.3
13	78	81	77.7	+0.3	+0.6
14	84	86	83.1	+0.9	+1.5
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					

Average 78% —

Find the average % screen values from column b disregarding the first three and last three tabulations. Use this percentage as %₂ in calculating the Corrected Reading c.

The dB Error d is established by subtracting the Corrected Reading from the dB Reading a. Beginning with the tabulated dB Error d nearest to 0.0, collectively add the dB Error d values up and down placing the subtotals in column e (Collective dB Errors).

Moving vertically up and down from the Average % line, find the largest vertical span in which the top and bottom Collective dB Error figures remain at or below 2 dB. Count the number of vertical spaces of movement, subtract one, and multiply the remainder by six. This dB value is the acceptable range of the unit.

In order to establish the acceptable range graphically, Form VII-9 should be used in conjunction with Form VII-8 as follows:

- (1) Apply the collective dB Error "e" values vertically on the horizontal offset coinciding with the dB reading values "a".
- (2) Establish a curve line passing through this series of points.
- (3) Apply a 2 dB high horizontal window over this curve positioned vertically so that the longest section is completely encompassed within the 2 dB Error height.
- (4) This window length represents the acceptable dB range of the unit.

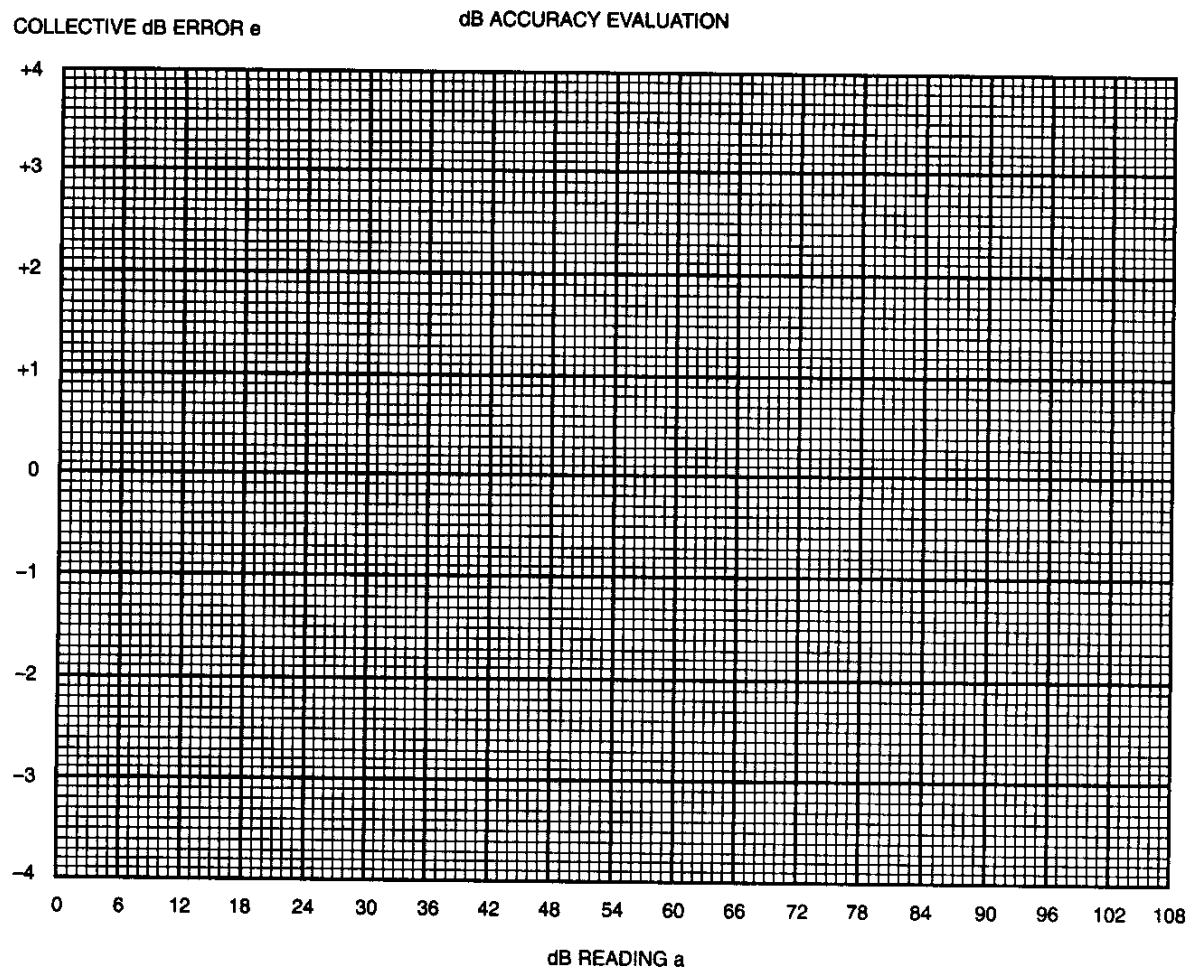
$$dB_2 = 20 \times \log (\%_2 \div \%_1) + dB_1$$

%₂ (Average) 78 %
 Total qualified range 12 dB to 78 dB = 66 dB
 Total qualified range 11 dB to 80 dB = 69 dB

Total error 1.8 dB
 Total error 2.0 dB

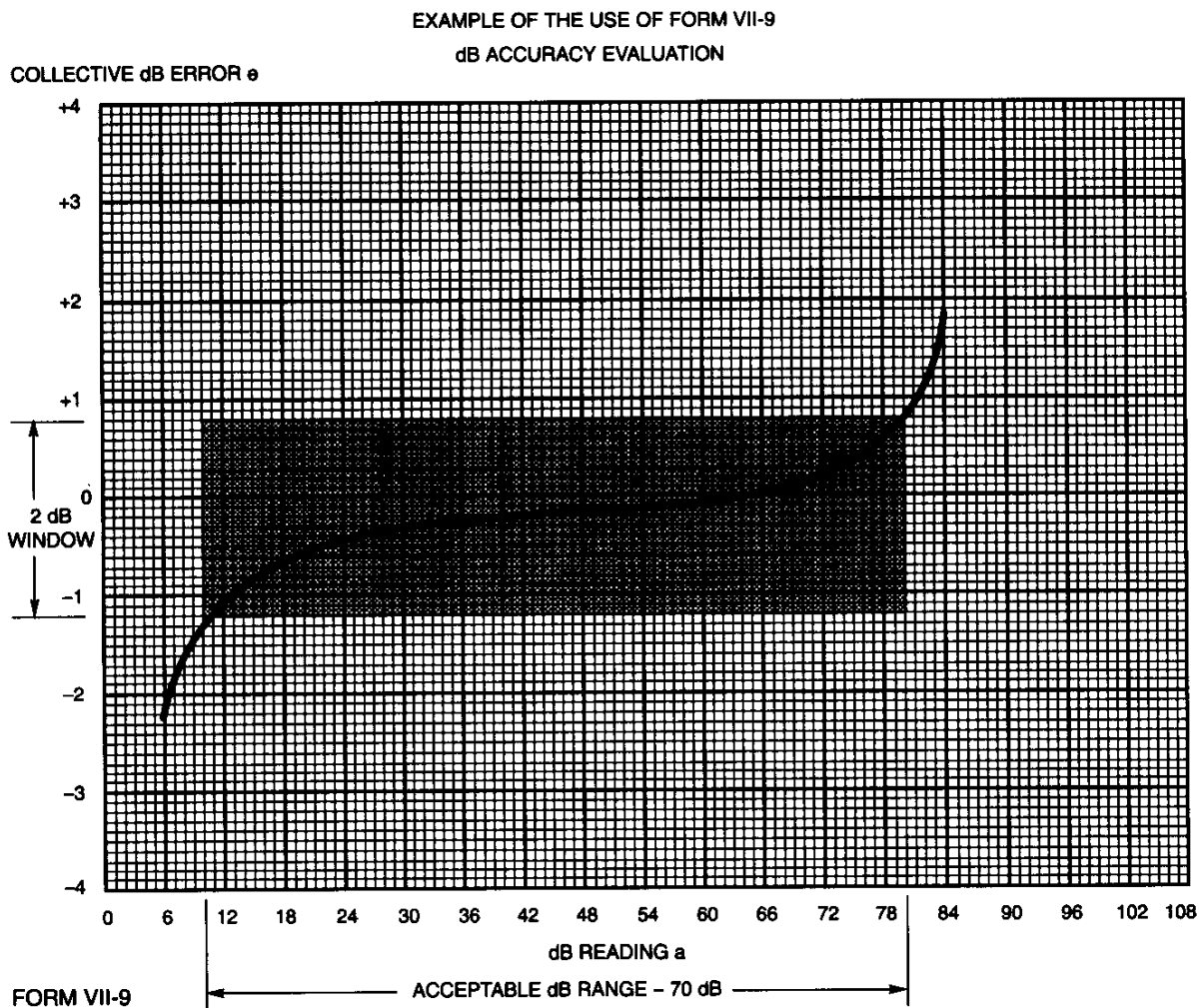
FORM VII-8

Figure VII-1—Example of the Use of Form VII-8 Ultrasonic Unit Certification



FORM VII-9

Figure VII-2—Example of Form VII-9



THE CURVE ON FORM VII-9 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM VII-9 (FIGURE VII-9).
 THE CROSS HATCHED ON FIGURE VII-9 SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS CODE.
 NOTE: THE FIRST LINE OF EXAMPLE OF THE USE OF FORM VII-9 IS SHOWN IN THIS EXAMPLE.

Figure VII-3—Example of the Use of Form VII-9

DECIBEL (ATTENUATION OR GAIN) VALUES NOMOGRAPH

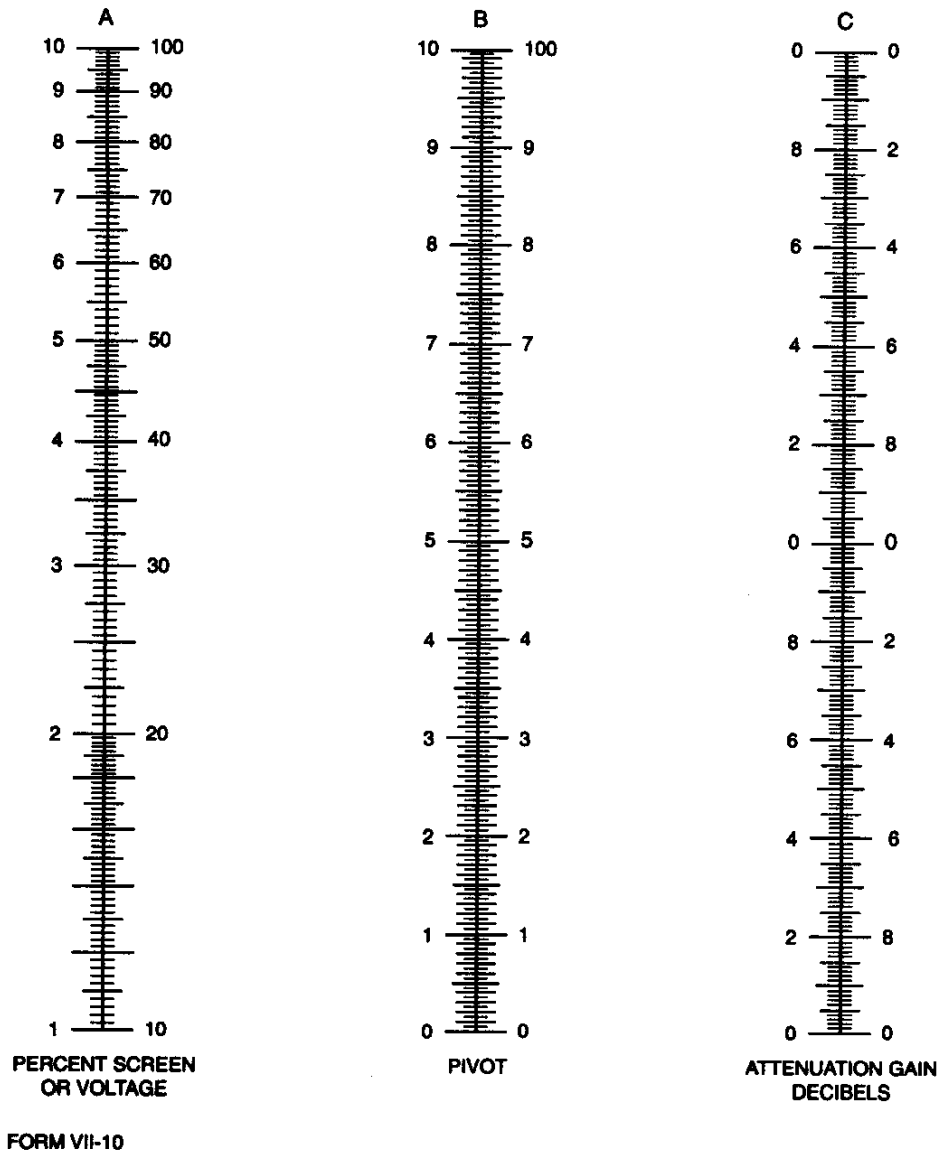


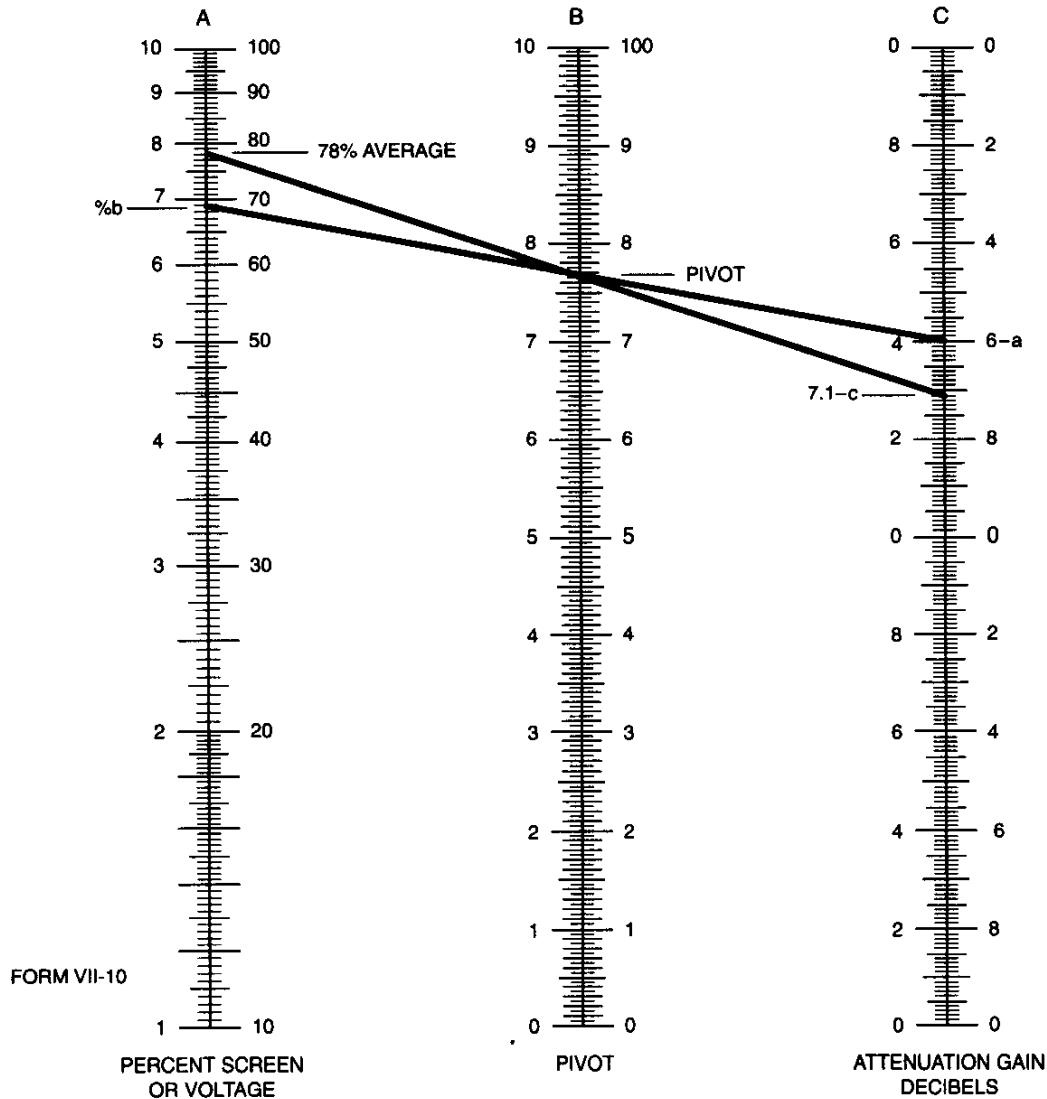
Figure VII-4—Example of Form VII-10

NOTES:

1. THE 6 dB READING AND 69% SCALE ARE DERIVED FROM THE INSTRUMENT READING AND BECOME dB "b₁" AND %₁ "c" RESPECTIVELY.
2. %₂ IS 78 - CONSTANT.
3. dB₂ (WHICH IS CORRECTED dB "d") IS EQUAL TO 20 TIMES X LOG (78/69) + 6 OR 7.1.

THE USE OF THE NOMOGRAPH IN RESOLVING LINE 3 IS AS SHOWN ON THE FOLLOWING EXAMPLE.

DECIBEL (ATTENUATION OR GAIN) VALUES NOMOGRAPH



THE CURVE ON FORM VII-7 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM VII-8 EXAMPLE. THE CROSS HATCHED AREA ON FORM VII-9 EXAMPLE SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS CODE.

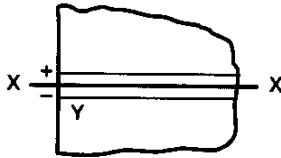
Notes: Procedure for using the Nomograph:

1. Extend a straight line between the decibel reading from Column a applied to the C scale and the corresponding percentage from Column b applied to the A scale.
2. Use the point where the straight line from Step 1 crosses the pivot line B as a pivot line for a second straight line.
3. Extend a second straight line from the average sign point on the A scale, through the pivot point developed in Step 2, and onto the dB scale C.
4. This point on the C scale is indicative of the corrected dB for use in Column C.

Figure VII-5—Example of the Use of Form VII-10

REPORT OF ULTRASONIC TESTING OF WELDS

Project _____ Report no. _____



Weld identification _____
 Material thickness _____
 Weld joint AWS _____
 Welding process _____
 Quality requirements—section no. _____
 Remarks _____

Line number	Indication number	Transducer angle	From Face	Leg*	Decibels				Discontinuity				Discontinuity evaluation	Remarks	
					Indication level	Reference level	Attenuation factor	Indication rating	Length	Angular distance (sound path)	Depth from "A" surface	Distance			
												From X			From Y
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															
26															

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of section 6, Part F of ANSI/AASHTO/AWS D1.5, (_____) Bridge Welding Code.
 (year)

Test Date _____ Manufacturer or Contractor _____

Inspected By _____ Authorized By _____

Notes: _____ Date _____

1. In order to attain Rating "d"

(A) With instruments with gain control, use the formula $a - b - c = d$.(B) With instruments with attenuation control, use the formula $b - a - c = d$.

(C) A plus or minus sign must accompany the "d" figure unless "d" is equal to zero.

2. Distance from X is used in describing the location of a weld discontinuity in a direction perpendicular to the weld reference line. Unless this figure is zero, a plus or minus sign must accompany it.

3. Distance from Y is used in describing the location of a weld discontinuity in a direction parallel to the weld reference line. This figure is attained by measuring the distance from the "Y" end of the weld to the beginning of said discontinuity.

4. Evaluation of Retested Repaired Weld Areas must be tabulated on a new line on the report form. If the original report form is used, R_n shall prefix the indication number. If additional forms are used, the R number shall prefix the report number.

*Use Leg I, II, or III. See glossary of terms (Annex V).

Figure VII-6—Form VII-11—Report of Ultrasonic Testing of Welds

Annex VIII

Guidelines on Alternative Methods for Determining Preheat

(Mandatory Information)

(This Annex is a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, and includes mandatory requirements for use in this standard.)

VIII.1. Introduction

The purpose of this guide is to provide some optional alternative methods for determining welding conditions (principally preheat) to avoid cold cracking. The methods are based primarily on research on small scale tests carried out over many years in several laboratories worldwide. No method is available for predicting optimum conditions in all cases, but the guide does consider several important factors such as hydrogen level and steel composition not explicitly included in the requirements of Table 4.4. The guide may therefore be of value in indicating whether the requirements of Table 4.4 are overly conservative or in some cases not sufficiently demanding.

The user is referred to the Commentary, ANSI/AWS D1.1, *Structural Welding Code—Steel*, for more detailed presentation of the background scientific and research information leading to the two methods proposed.

In using this guide as an alternative to Table 4.4, careful consideration must be given to the assumptions made, the values selected, and past experience.

VIII.2. Methods

Two methods are used as the basis for estimating welding conditions to avoid cold cracking:

- (1) Heat-affected zone (HAZ) hardness control
- (2) Hydrogen control

VIII.3. HAZ Hardness Control

VIII.3.1 The provisions included in this guide for use of this method are restricted to fillet welds.

VIII.3.2 This method is based on the assumption that cracking will not occur if the hardness of the HAZ is kept below some critical value. This is achieved by controlling the cooling rate below a critical value dependent on the hardenability of the steel. Hardenability of steel in welding relates to its propensity towards formation of a hard HAZ and can be characterized by the cooling rate necessary to produce a given level of hardness. Steels with high hardenability can, therefore, produce a hard HAZ at slower cooling rates than a steel with lower hardenability. Equations and graphs are available in the technical literature that relate the weld cooling rate to the thickness of the steel members, type of joint, welding conditions, and variables.

VIII.3.3 The selection of the critical hardness will depend on a number of factors such as steel type, hydrogen level, restraint and service conditions. Laboratory tests with fillet welds show that HAZ cracking does not occur if the HAZ Vickers Hardness No. (Vh) is less than 350 Vh even with high-hydrogen electrodes. With low-hydrogen electrodes, hardnesses of 400 Vh could be tolerated without cracking. Such hardnesses, however, may not be tolerable in service where there is an increased risk of stress corrosion cracking, brittle fracture initiation, or other risks for the safety or serviceability of the structure.

The critical cooling rate for a given hardness can be approximately related to the carbon equivalent of the steel (see Figure VIII-2). Since the relationship is only approximate, the curve shown in Figure VIII-2 may be conservative for plain carbon and plain-carbon-manganese steels and thus allow the use of the high hard-

ness curve with less risk. Some low-alloy steels, particularly those containing columbium (niobium), may be more hardenable than Figure VIII-2 indicates, and the use of the lower hardness curve is recommended.

VIII3.4 Although the method can be used to determine a preheat level, its main value is in determining the minimum heat input (and hence minimum weld size) that prevents excessive hardening. It is particularly useful for determining the minimum size of single-pass fillet welds that can be deposited without preheat.

VIII3.5 The hardness approach does not consider the possibility of weld metal cracking, but from experience it has been found that the heat input determined by this method is usually adequate to prevent weld metal cracking in most cases in fillet welds if the electrode is not a high-strength filler metal; generally, it should be a low-hydrogen type [e.g., low-hydrogen (SMAW) electrode, gas metal arc, flux cored arc, submerged arc].

VIII3.6 Because the method depends solely on controlling the HAZ hardness, the hydrogen level and restraint are not explicitly considered.

VIII3.7 This method is not applicable to Q & T steels. (See VIII5.2.3 for limitations.)

VIII4. Hydrogen Control

VIII4.1 The hydrogen control method is based on the assumption that cracking will not occur if the average quantity of hydrogen remaining in the joint after it has cooled down to about 50°C does not exceed a critical value dependent on the composition of the steel and the restraint. The preheat necessary to allow excessive hydrogen to diffuse out of the joint can be estimated using this method.

VIII4.2 This method is based mainly on results of restrained partial joint penetration groove weld tests; the weld metal used in the tests matched the parent metal.

There has not been extensive testing of this method on fillet welds; however, by allowing for restraint, the method has been suitably adapted for those welds.

VIII4.3 A determination of the restraint level and the original hydrogen level in the weld pool is required for the hydrogen method. In this guide, restraint is classified as high, medium, and low and the category must be established from experience.

VIII4.4 The hydrogen control method is based on a single low heat input weld bead representing a root pass and assumes that the HAZ hardens. The method is, therefore, particularly useful for high-strength, low-alloy steels having quite high hardenability where hardness control is not always feasible. Consequently, because it assumes

that the HAZ fully hardens, the predicted preheat may be too conservative for carbon steels.

VIII5. Selection of Method

The following procedure, for selection of the more appropriate method of VIII3 or VIII4, is suggested as a guide.

VIII5.1 Both the carbon content and carbon equivalent of the steel should be determined:

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

to locate the zone classification of the steel in Figure VIII-1. (See VIII6.1.1 for different ways to obtain the chemical analysis.)

VIII5.2 The performance characteristics of each zone and the suggested action are as follows:

VIII5.2.1 Zone I. Cracking is unlikely but may occur with high hydrogen or high restraint. The hydrogen control method should be used to determine preheat for steels in this zone.

VIII5.2.2 Zone II. The hardness control method should be used and Vh350 or Vh400 hardness number should be selected to determine the minimum energy input for single-pass fillet welds without preheat. If that energy input is not practical, the hydrogen method should be used to determine preheat.

(1) For groove welds, the hydrogen control method should be used to determine preheat.

(2) For steels with high carbon, a minimum energy to control hardness and a minimum preheat to control hydrogen both may be required, for fillet welds and for groove welds.

VIII5.2.3 Zone III. The hydrogen control method should be used. Where heat input is restricted to preserve the HAZ properties (e.g., some quenched and tempered steels), the hydrogen control method should be used to determine preheat.

VIII6. Detailed Computation Guide

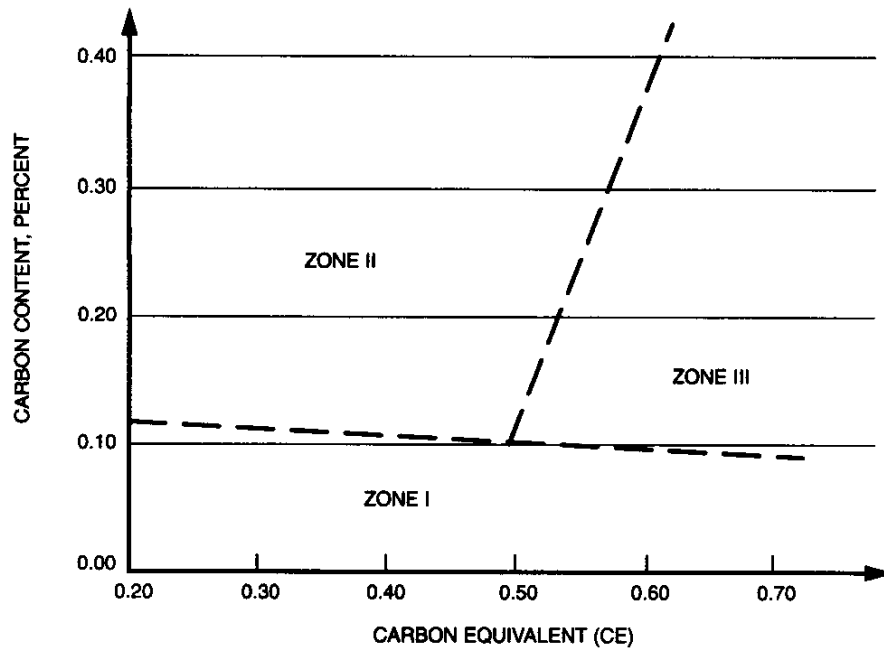
VIII6.1 Hardness Method

VIII6.1.1 Calculate the carbon equivalent as follows:

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

The chemical analysis may be obtained from the following:

- (1) Mill test certificates
- (2) Typical production chemical analysis (from the mill)



NOTES:

1. $CE = C + (Mn + Si)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$
2. SEE VIII5.2.1, VIII5.2.2 OR VIII5.2.3 FOR APPLICABLE ZONE CHARACTERISTICS.

Figure VIII-1—Zone Classification of Steels (see VIII5.1)

(3) Specification chemical analysis (using maximum values)

(4) User tests (chemical analysis)

VIII6.1.2 The critical cooling rate shall be determined for a selected maximum HAZ hardness of either 400 Vh or 350 Vh, from Figure VIII-2.

VIII6.1.3 Using applicable thicknesses for “flange” and “web” plates, the appropriate diagram from Figure VIII-3 shall be selected and the minimum input energy shall be determined for single-pass fillet welds. Keep in mind that this energy input applies to submerged arc welds.

VIII6.1.4 For other processes, the minimum energy input for single-pass fillet welds can be estimated by multiplying the energy estimated in VIII6.1.3 by the factors below:

Welding Process	Multiplication Factor
SAW	1
SMAW	1.50
GMAW, FCAW	1.25

VIII6.1.5 Figure VIII-4 may be used to determine fillet sizes as a function of energy input.

VIII6.2 Hydrogen Control Method

VIII6.2.1 The value of the composition parameter, P_{cm} , shall be calculated as follows:

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

The chemical analysis shall be determined as in VIII6.1.1.

VIII6.2.2 The hydrogen level shall be determined and defined as follows:

VIII6.2.2.1 H4 Extra-Low Hydrogen. Consumables thus labeled should have the following:

(1) A diffusible hydrogen content of less than 4ml/100g deposited metal when measured using the latest edition of ANSI/AWS A4.3, *Standard Procedures for Determination of Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding* or

(2) A moisture content of electrode covering of 0.2 percent maximum in accordance with ANSI/AWS A5.1 or A5.5.

This may be established by testing each type, brand, or wire/flux combination used after removal from the

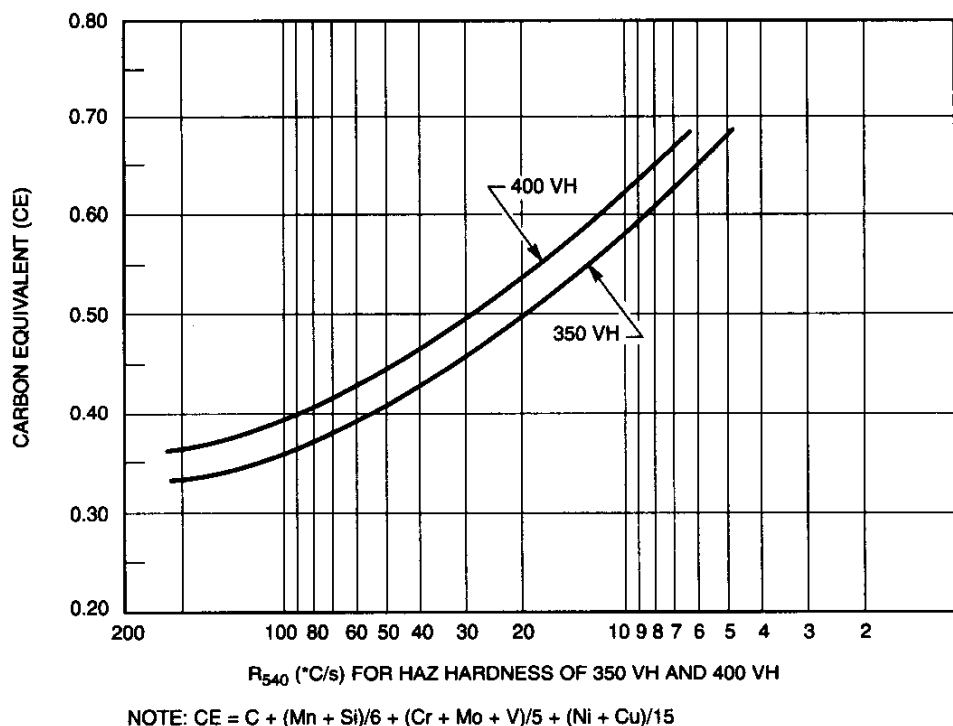


Figure VIII-2—Critical Cooling Rate for 350 VH and 400 VH (see VIII6.1.2)

package or container and exposure for the intended duration, with due consideration of actual storage conditions prior to immediate use. The following may be assumed to meet this requirement:

- (a) Low-hydrogen electrodes taken from hermetically sealed containers, dried at 370°C–425°C for one hour and used within two hours after removal
- (b) GMAW with clean solid wires

VIII6.2.2.2 H8 Low-Hydrogen. These consumables must have the following:

- (1) A diffusible hydrogen content of less than 8ml/100g deposited metal when measured using AWS A4.3 or
- (2) A moisture content of electrode covering of 0.4% maximum in accordance with AWS A5.1.

This may be established by a test on each type, brand of consumable, or wire/flux combination used. The following may be assumed to meet this requirement:

- (a) Low-hydrogen electrodes taken from hermetically sealed containers conditioned in accordance with 4.5.2 of the code and used within four hours after removal
- (b) Submerged arc welding with dry flux. Note that these consumables are expected to give a diffusible hydrogen content of "less than 16 ml/100 g," which may not meet this 8ml/100g definition.

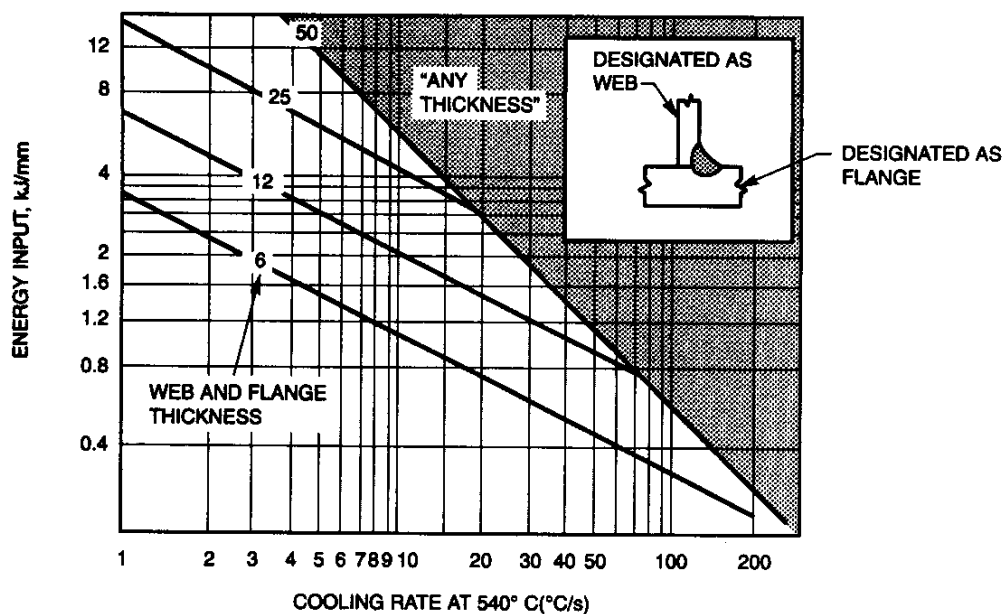
VIII6.2.2.3 H16 Hydrogen Limit. These other consumables do not meet the requirements of H4 or H8.

VIII6.2.3 The susceptibility index grouping from Table VIII.1 should be determined.

VIII6.2.3.1 Required minimum preheat levels and interpass temperatures are given in Table VIII.2 for three levels of restraint. The restraint level to be used shall be determined in conformance with VIII6.2.3.2.

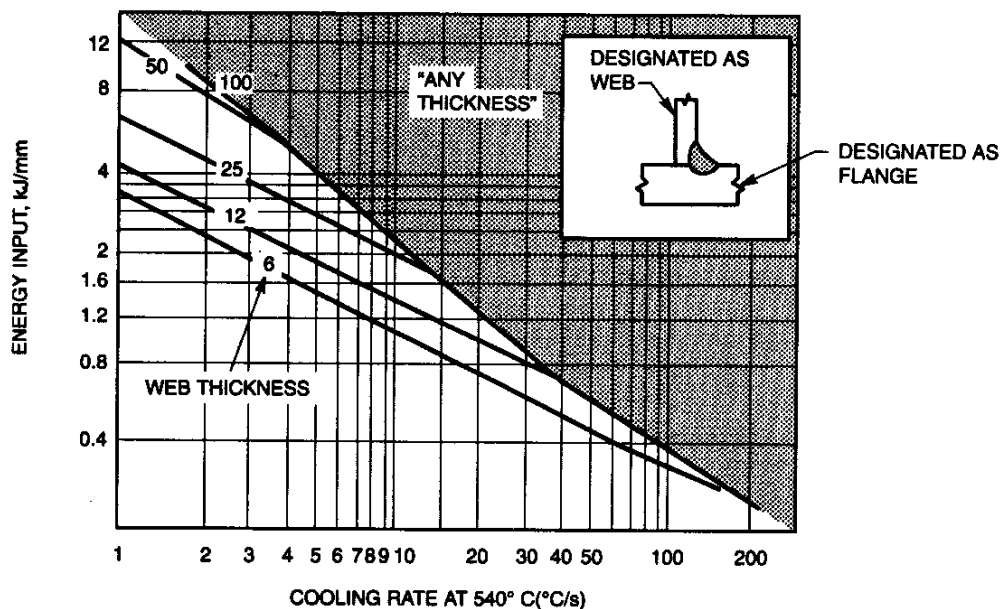
VIII6.2.3.2 Restraint. The degree of restraint of weld types should be determined on the basis of experience, engineering judgment, research, or calculation. Three levels of restraint have been provided:

- (1) *Low restraint.* This level describes common fillet and groove welded joints in which a reasonable freedom of movement of members exists.
- (2) *Medium restraint.* This level describes fillet and groove welded joints in which, because of members being already attached to structural work, a reduced freedom of movement exists.
- (3) *High restraint.* This level describes welds in which there is almost no freedom of movement for members joined (such as repair welds, especially in thick material).



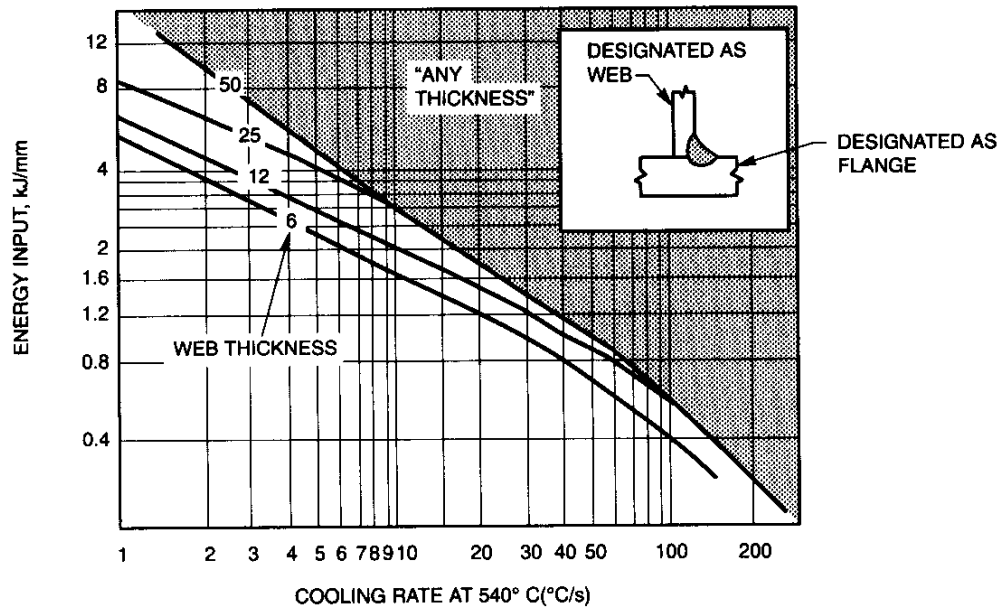
NOTE: ENERGY INPUT DETERMINED FROM CHART DOES NOT IMPLY SUITABILITY FOR PRACTICAL APPLICATIONS. FOR CERTAIN COMBINATION OF THICKNESSES MELTING MAY OCCUR THROUGH THE THICKNESS.

(A) SINGLE-PASS SAW FILLET WELDS WITH WEB AND FLANGE OF SAME THICKNESS



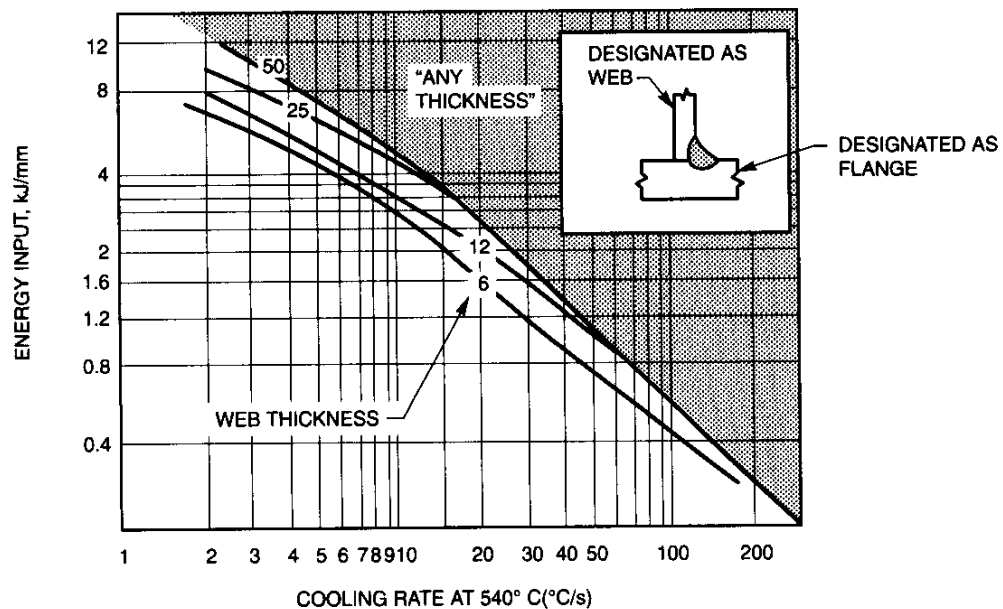
(B) SINGLE-PASS SAW FILLET WELDS WITH 6 mm FLANGES AND VARYING WEB THICKNESSES

**Figure VIII-3—Charts to Determine Cooling Rates
for Single-Pass Submerged Arc Fillet Welds (see VIII.6.1.3)**



NOTE: ENERGY INPUT DETERMINED FROM CHART DOES NOT IMPLY SUITABILITY FOR PRACTICAL APPLICATIONS. FOR CERTAIN COMBINATION OF THICKNESSES MELTING MAY OCCUR THROUGH THE THICKNESS.

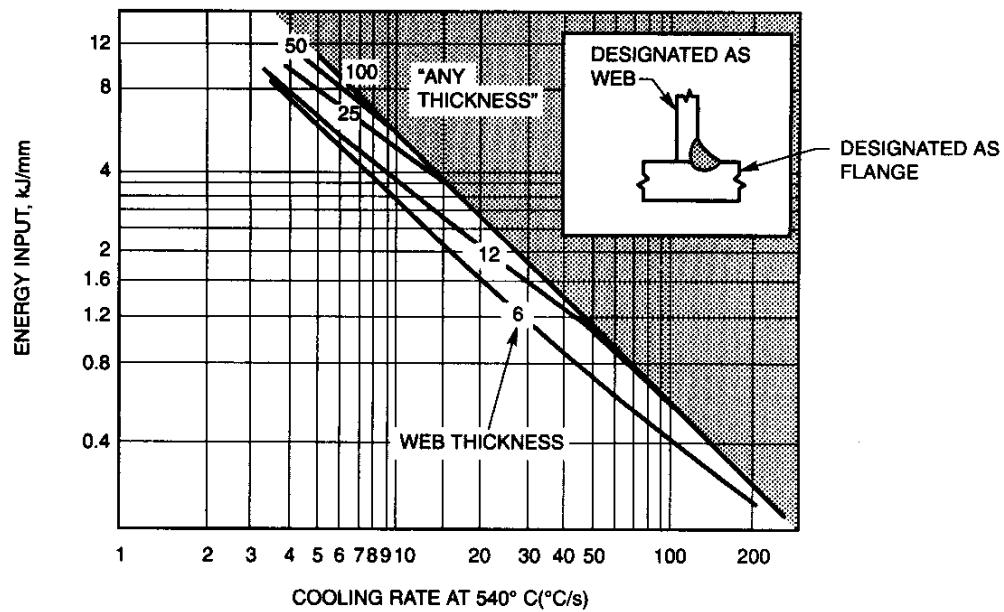
(C) SINGLE-PASS SAW FILLET WELDS WITH 12 mm FLANGES AND VARYING WEB THICKNESSES



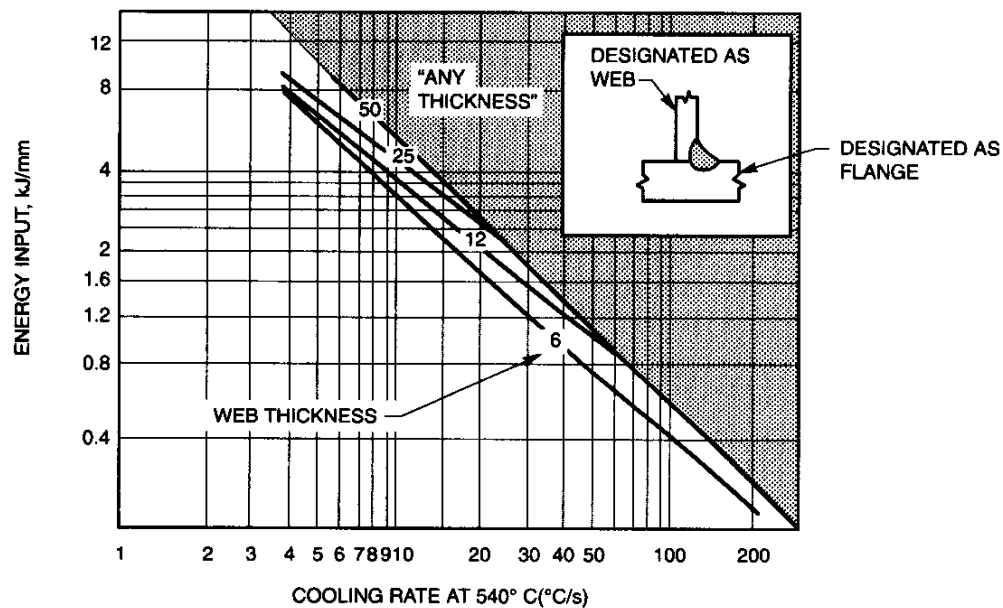
NOTE: ENERGY INPUT DETERMINED FROM CHART DOES NOT IMPLY SUITABILITY FOR PRACTICAL APPLICATIONS. FOR CERTAIN COMBINATION OF THICKNESSES MELTING MAY OCCUR THROUGH THE THICKNESS.

(D) SINGLE-PASS SAW FILLET WELDS WITH 25 mm FLANGES AND VARYING WEB THICKNESSES

Figure VIII-3 (Continued)—Charts to Determine Cooling Rates for Single-Pass Submerged Arc Fillet Welds (see VIII.6.1.3)



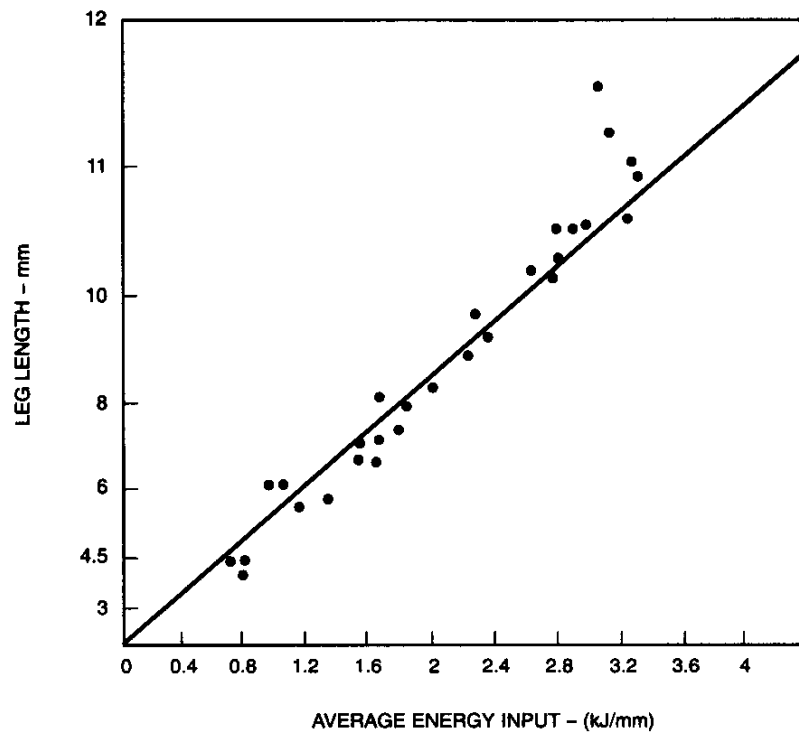
(E) SINGLE-PASS SAW FILLET WELDS WITH 50 mm FLANGES AND VARYING WEB THICKNESSES



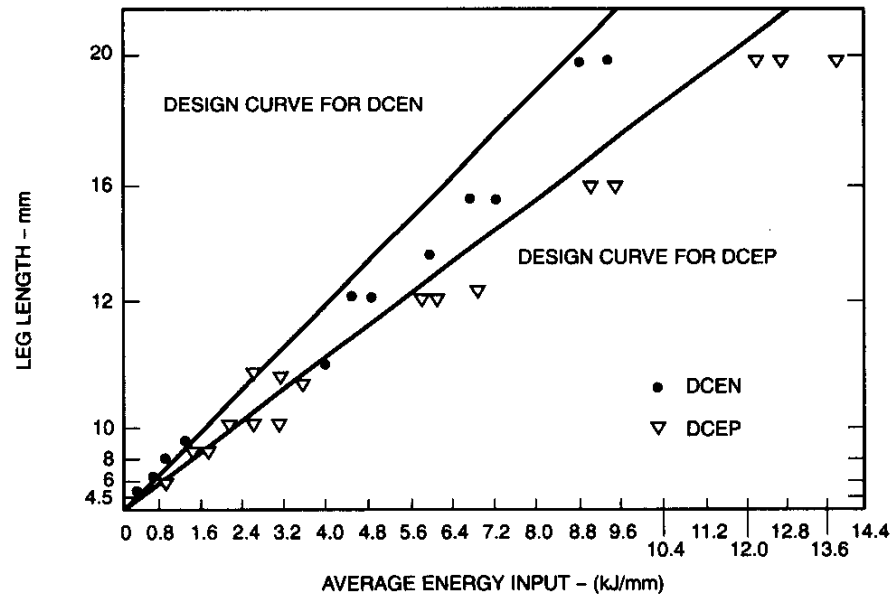
NOTE: ENERGY INPUT DETERMINED FROM CHART DOES NOT IMPLY SUITABILITY FOR PRACTICAL APPLICATIONS. FOR CERTAIN COMBINATION OF THICKNESSES MELTING MAY OCCUR THROUGH THE THICKNESS.

(F) SINGLE-PASS SAW FILLET WELDS WITH 100 mm FLANGES AND VARYING WEB THICKNESSES

**Figure VIII-3 (Continued)—Charts to Determine Cooling Rates
for Single-Pass Submerged Arc Fillet Welds (see VIII.6.1.3)**



(A) SHIELDED METAL ARC WELDING (SMAW)



(B) SUBMERGED ARC WELDING (SAW)

Figure VIII-4—Relation Between Fillet Weld Size and Energy Input (see VIII6.1.5)

Table VIII.1
Susceptibility Index Grouping as Function of Hydrogen Level "H"
and Composition Parameter P_{cm} (see VIII.6.2.3)

Hydrogen Level, H	Susceptibility Index ² Grouping				
	Carbon Equivalent = P_{cm}^1				
	< 0.18	< 0.23	< 0.28	< 0.33	< 0.38
H4	A	B	C	D	E
H8	B	C	D	E	F
H16	C	D	E	F	G

Notes:

1. $P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B$

2. Susceptibility index— $12 P_{cm} + \log_{10} H$.

3. Susceptibility Index Groupings, A through G, encompass the combined effect of the composition parameter, P_{cm} , and hydrogen level, H, in accordance with the formula shown in Note 2.

The exact numerical quantities are obtained from the Note 2 formula using the stated values of P_{cm} and the following values of H, given in ml/100g of weld metal (see VIII.6.2.2, a, b, c):

$$H4 < 4; H8 < 8; H16 < 16.$$

For greater convenience, Susceptibility Index Groupings have been expressed in the table by means of letters, A through G, to cover the following narrow ranges:

$$A = 3.0; B = 3.1-3.5; C = 3.6-4.0; D = 4.1-4.5; E = 4.6-5.0; F = 5.1-5.5; G = 5.6-7.0$$

These groupings are used in Table VIII.2.4 in conjunction with restraint and thickness to determine the minimum preheat and interpass temperature.

Table VIII.2
Minimum Preheat and Interpass Temperatures for Three Levels of Restraint (see VIII.6.2.3.1)

Restraint Level	Thickness* mm	Minimum Preheat and Interpass Temperature (°C)						
		Susceptibility Index Grouping						
		A	B	C	D	E	F	G
Low	< 10	< 20	< 20	< 20	< 20	60	135	150
	10-20	< 20	< 20	20	60	100	135	150
	20-40	< 20	< 20	20	180	110	135	150
	40-75	20	20	40	95	120	135	150
	> 75	20	20	40	95	120	135	150
Medium	< 10	< 20	< 20	< 20	< 20	70	135	160
	10-20	< 20	< 20	20	80	115	145	160
	20-40	< 20	20	75	110	135	150	160
	40-75	20	80	110	130	150	150	160
	> 75	95	120	135	150	160	160	160
High	< 10	< 20	< 20	< 20	40	110	150	160
	10-20	< 20	20	65	105	135	160	160
	20-40	20	85	115	135	150	160	160
	40-75	115	130	150	150	160	160	160
	> 75	115	115	150	150	160	160	160

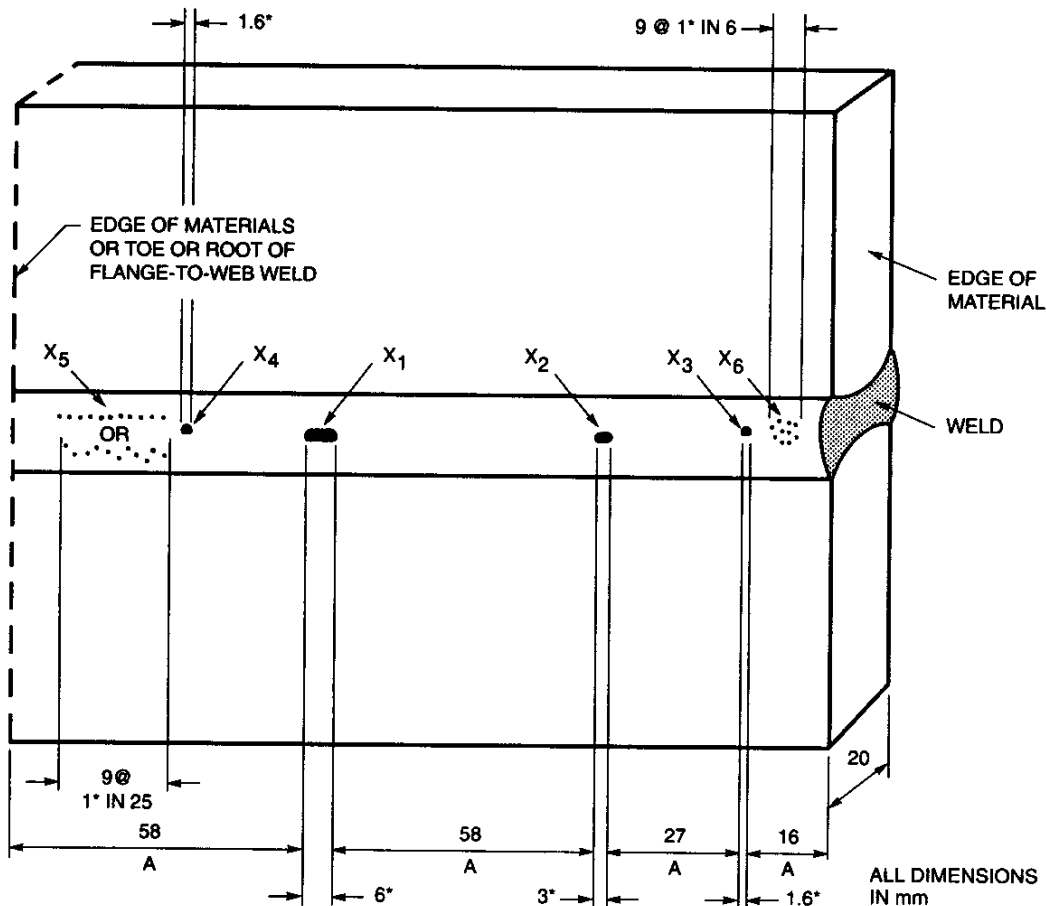
*Thickness is that of the thicker part welded

Annex A

Weld Quality Requirements for Tension Joints

(Nonmandatory Information)

(This Annex is not a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, but is included for information purposes only.)



Notes:

1. A — minimum clearance allowed between edges of porosity or fusion-type discontinuities 2 mm or larger. Larger of adjacent discontinuities governs.
2. X_1 — largest permissible porosity or fusion-type discontinuity for 20 mm joint thickness (see Figure 9.4)
3. X_2 , X_3 , X_4 — porosity or fusion-type discontinuity 2 mm or larger, but less than maximum permissible for 20 mm joint thickness.
4. X_5 , X_6 — porosity or fusion-type discontinuity less than 2 mm.

Interpretation:

1. Porosity or fusion-type discontinuity X_4 is not acceptable because it is within the minimum clearance allowed between edges of such discontinuities (see 9.21.2.1 and Figure 9.4)
2. Remainder of weld is acceptable.

*Discontinuity size indicated is assumed to be its greatest dimension.

Annex B

Description of Common Weld and Base Metal Discontinuities

(Reprinted with modification from
New York State Steel Construction Manual)

(Nonmandatory Information)

(This Annex is not a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, but is included for information purposes only.)

B1. General

This annex describes discontinuities which may or may not be classified as unacceptable under the provisions of this code. Except for cracks, discontinuities are unacceptable only if they exceed the specification requirements for type, size, distribution or location. All cracks are unacceptable discontinuities under the provisions of this code. Discontinuities may be found in the base metal, weld metal, or heat-affected zones (HAZs) in butt, T-, corner and lap-joint configurations. The following articles present a fairly comprehensive list of discontinuities which may be encountered in fabrication.

B2. List of Discontinuities

The most common types of discontinuities found in butt, T-, corner, and lap joints are listed in Table B1 and shown in Figures B1–B6.

Weld and base-metal discontinuities of specific types are more common when certain welding processes and joint details are used. High restraint and limited access to portions of a weld joint preparation may lead to a higher than normal incidence of weld and base metal discontinuities.

Each general type of discontinuity is discussed in detail in this annex. The *New York State Steel Construction Manual*, the *AWS Structural Welding Code—Steel*, and this *Bridge Welding Code* use the term *fusion-type dis-*

continuity as an all-encompassing term to describe slag inclusions, incomplete fusion, inadequate joint penetration, and similar generally elongated discontinuities in weld fusion.

Since this code requires all complete joint penetration welds without backing to be backgouged to sound metal before welding from the second side, inadequate joint penetration is technically impossible if all provisions of the code are met. Many codes consider fusion discontinuities less critical than cracks. The *Bridge Welding Code* reflects our agreement with this provision. Some codes specifically prohibit not only cracks but also any area of incomplete fusion or inadequate joint penetration. This code does not prohibit incomplete fusion or inadequate joint penetration, per se, even though these discontinuities are planar defects that in a fracture analysis will perform in a manner similar to cracks. Incomplete fusion and inadequate joint penetration defects are treated as fusion discontinuities, since they generally do not have the flaw tip acuity of a crack and because routine nondestructive tests generally cannot distinguish between the various types of fusion defects.

Specific joint types and welding procedures may have an effect on the type, location, and incidence of discontinuities. The conditions that may effect the formation of discontinuities are described in the following articles.

B2.1 Porosity. Porosity is created when gas is entrapped in solidifying metal. The discontinuity formed is gener-

Table B1
Common Types of Discontinuities (see B2)

Type of Discontinuity	Location	Remarks
1) Porosity a) Uniformly scattered b) Cluster c) Linear d) Piping	W	Weld only, as discussed herein. (Porosity is also commonly found in castings.)
2) Inclusions a) Non-metallic slag b) Metallic tungsten	W	
3) Incomplete fusion (also called lack of fusion)	W	Found at joint boundaries or between passes.
4) Inadequate joint penetration (also called lack of joint penetration)	W	Found at root of weld preparation.
5) Undercut	BM	Found at junction of weld and base metal at surface.
6) Underfill	W	Found at outer surface of joint penetration.
7) Overlap	W	Found at junction of weld and base metal at surface.
8) Laminations	BM	Found in base metal, generally near mid-thickness of section.
9) Delamination	BM	Found in base metal, generally near mid-thickness of section.
10) Seams and laps	BM	Found at base metal surface. Almost always longitudinal.
11) Lamellar tears	BM	Found in base metal near weld HAZ.
12) Cracks a) Longitudinal b) Transverse c) Crater d) Throat e) Toe f) Root g) Underbeat and Heat-Affected Zone h) Fissures	W, HAZ, BM W, HAZ, BM W W HZ W HAZ W	Found in weld or base metal adjacent to weld fusion boundary. Found in weld (may propagate from weld in HAZ and base metal). Found in weld at point where arc is terminated. Found at weld axis. Found at junction between face of weld and base metal. Found in weld metal at root. Found in base metal in HAZ (may propagate into unaffected base metal). Found in weld metal.

W — Weld
BM — Base Metal
HAZ — Heat Affected Zone

ally spherical but may be elongated. When there are gas discontinuities in ingots that are reduced to wrought products, gas voids in the ingot will appear as laminations in the finished product. This annex will only discuss porosity as a weld discontinuity. Unless porosity is gross (large or extensive, or both), it is not so critical a flaw as sharp, planar discontinuities that intensify stress. Porosity is a sign that the welding process is not being properly controlled or that the base metal is contaminated or of variable composition. Porosity is not caused exclusively by hydrogen, but the presence of porosity indicates that there is a possibility of hydrogen in the weld and HAZ that may lead to cracking.

(1) *Uniformly Scattered Porosity.* Uniformly scattered porosity is scattered pores distributed through a single weld pass, or throughout several passes of a multiple-

pass weld. Whenever uniformly scattered porosity is encountered, the case is generally faulty welding technique or materials. Porosity will only be present in a weld if the technique used, materials, or the conditions of the weld joint preparation lead to gas formation and entrapment. If the weld cools slowly enough to allow gas to pass to the surface before the weld solidifies, there will be no porosity in the weld.

(2) *Cluster Porosity.* Cluster porosity is a localized grouping of pores that usually results from improper initiation or termination of the welding arc.

(3) *Linear Porosity.* Linear porosity is porosity aligned along a joint boundary, the root of the weld, or an interbead boundary. Linear porosity is caused by contamination that leads to gas evolution at particular locations within the weld.

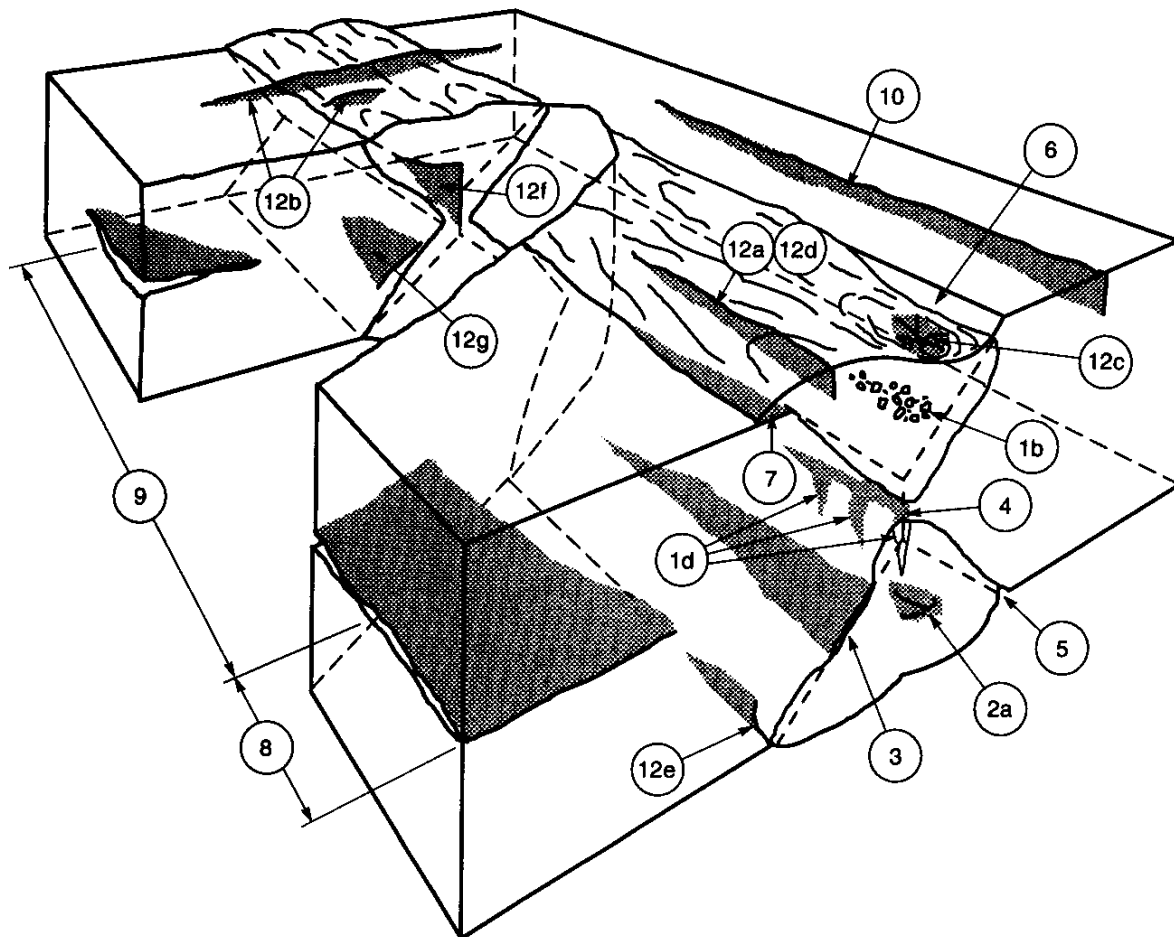


Figure B1—Weld in Butt Joint (see B2)

(4) *Piping Porosity.* Piping porosity is a term for elongated (cylindrical) gas discontinuities. Piping porosity in fillet welds extends from the root of the weld towards the surface of the weld. When one or two porosity discontinuities are seen in the surface of the weld, careful excavation will generally show that there are many subsurface piping porosity discontinuities interspersed among the exposed pores. Much of the piping porosity found in welds does not extend all the way to the surface. Piping porosity in electroslag and electrogas welds can become very extensive in number and length. Pores as long as 500 mm have been measured in some electroslag welds. Piping porosity is very difficult to evaluate by ultrasonic test.

B2.2 Inclusions

(1) *Nonmetallic Slag.* Slag inclusions result from non-metallic, solid material being entrapped in weld metal,

between weld passes, or between weld and base metal. Slag inclusions can be found in welds made by most arc welding procedures. In general, slag inclusions result from faulty welding technique, failure to clean properly between weld passes, and conditions that lead to limited access for welding within the joint. If allowed, molten slag will float to the top of the weld. Sharp notches in joint boundaries or between weld passes often cause slag to be entrapped under the molten weld metal.

(2) *Metallic Tungsten.* Tungsten inclusions are found only in welds made by the gas tungsten arc welding (GTAW) process. Since this process is not used under the provisions of this code, the discontinuity is listed for interest only. Tungsten inclusions may be found in aluminum welds made by the GTAW process. A nonconsumable tungsten electrode is used to establish a welding arc between the electrode and the base metal. If the tung-

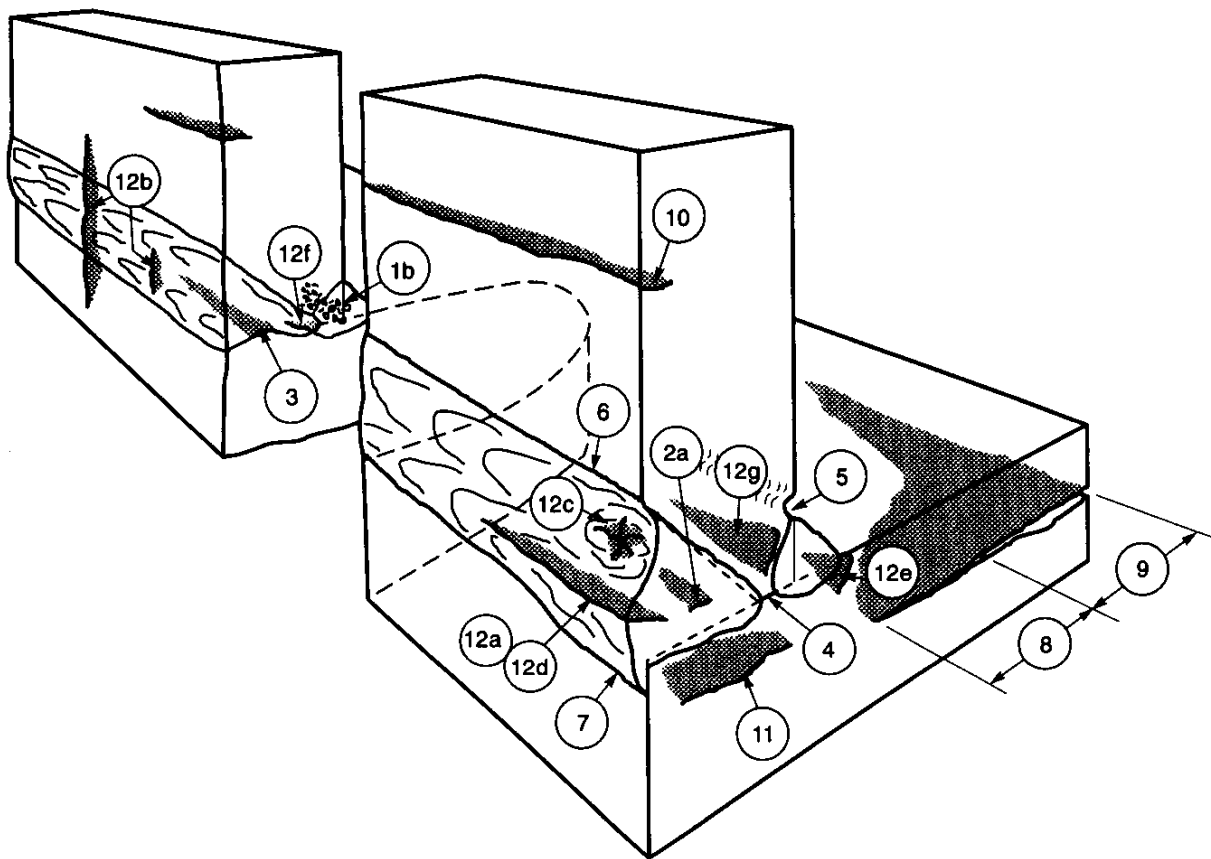


Figure B2—Weld in Corner Joint (see B2)

sten electrode is dipped into the molten metal, or if the current is set too high, tungsten droplets may be transferred from the electrode to the molten metal. Tungsten inclusions appear as light marks or areas in radiographs because the inspecting radiation has a higher absorption rate in tungsten than it does in steel or aluminum.

B2.3 Incomplete Fusion. Incomplete fusion may result from improper welding techniques, improper preparation of material for welding, or improper joint design. Deficiencies causing incomplete fusion include insufficient welding heat, improper electrode manipulation, and lack of access to all boundaries of the weld joint that are to be fused during welding. On rare occasions, weld metal may fail to fuse to the base metal even though the prepared joint surface has been melted beyond the original interface. Tightly adhering oxides will interfere with complete fusion, even when there is access for welding and proper welding procedures are used.

B2.4 Inadequate Joint Penetration. Inadequate joint penetration is penetration of the welding arc that is less than required. Technically, this discontinuity can only be present when the welding procedure specification requires penetration of the weld metal beyond the original joint boundaries and the weld deposit fails to penetrate the areas of weld joints that depend upon penetration for fusion. Inadequate joint penetration may result from insufficient welding heat, improper electrode manipulation or guidance, or improper joint design which requires melting of more base metal than the arc can penetrate. Some welding procedures have much greater penetrating ability than others.

This code requires that all complete joint penetration groove welds without backing be backgouged to sound metal before welding from the second side so that there is no possibility of inadequate joint penetration at the root of the weld. In bridge construction, weld joint designs call-

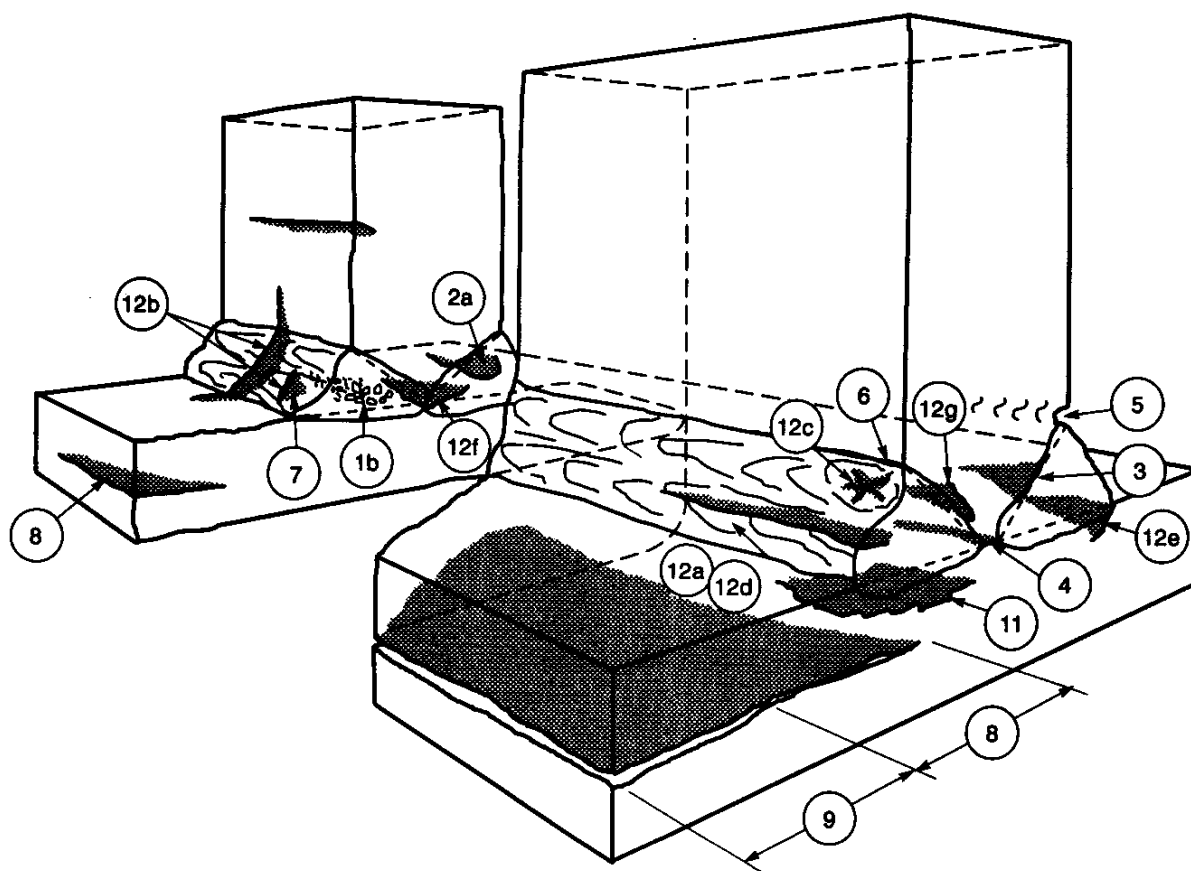


Figure B3—Weld in T-Joint (see B2)

ing for a specific root penetration that would produce complete joint penetration groove welds are not used.

B2.5 Undercut. Undercut considered to be a defect is generally the result of either an improper welding technique, excessive welding heat, or both. It is generally located at the junction of the weld and base metal, at the toe of fillet welds, or at the fusion line of groove welds. Undercut may also be encountered at the root of groove welds made from one side only. The most serious undercut is generally found in base metal surfaces that were vertical during welding. Undercut creates a mechanical notch at the fusion boundary of the weld. All welds have some undercut if examined carefully. Undercut is not considered an unacceptable weld discontinuity until the degree of undercutting exceeds the amount allowed by contract documents. Some undercut produces a sharp notch defect. Other undercutting may be more rounded. Some undercut may only be seen in metallographic tests where etched weld cross sections are examined under

magnification. The sharper and deeper the notch created by undercutting, the more serious the defect.

B2.6 Underfill. Underfill is a depression on the face of the weld extending below the surface of the adjacent base metal. Underfill results from failure of the welder or welding operator to completely fill the weld joint as required by the welding procedure specification.

B2.7 Overlap. Overlap is a sharp surface connected discontinuity that forms a severe mechanical notch because the weld metal protrudes or flows beyond the toe or face of the weld without fusion. It can occur as a result of failure to control the welding process, improper selection of welding materials, or improper preparation of the base metal prior to welding. Tightly adhering oxides on the base metal may interfere with fusion, and overlap may result.

B2.8 Laminations. Laminations are planar discontinuities elongated in the rolling direction. They are most

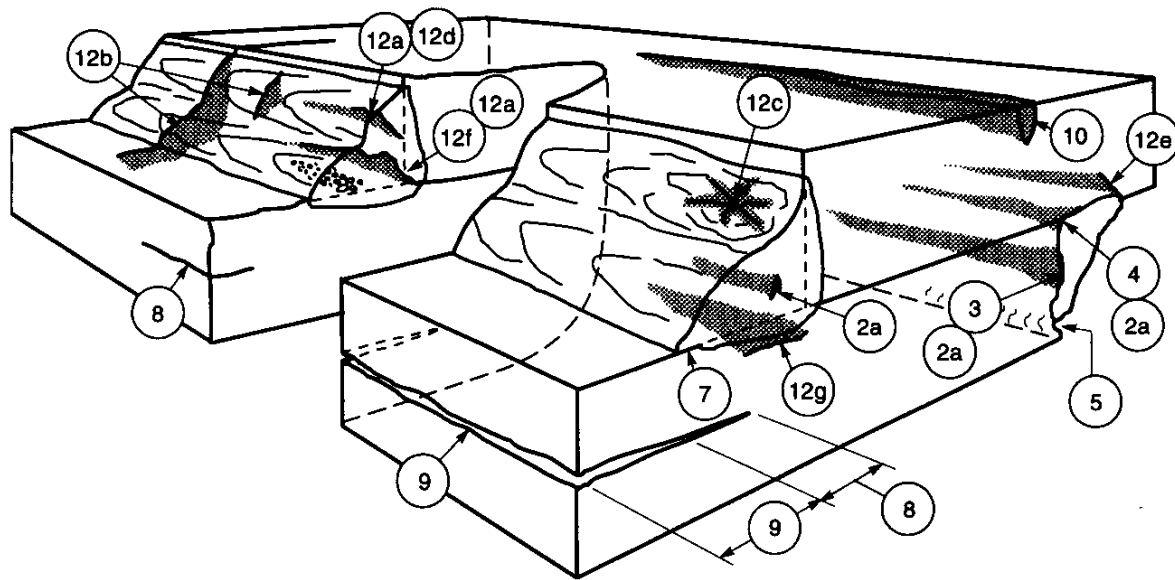


Figure B4—Weld in Lap Joint (see B2)

commonly found near the mid thickness of wrought products. Laminations may be completely internal and detectable only by nondestructive tests, or they may extend to an edge or end where they are visible at the surface. Laminations may be discovered when cutting or machining exposes internal metal structure.

Laminations are formed when gas voids (porosity), nonmetallics, or ingot shrinkage cavities are rolled flat. Laminations generally run parallel to the surface of rolled products and are most commonly found in shapes and plates. Some laminations are partially roll-forge welded along their interface by the high temperature and pressure of the rolling or forging operation. The soundness of the roll-forged weld depends upon the presence or absence of oxides or nonmetallics on the surfaces of the original voids. Laminations that are partially or completely roll-forge welded may conduct sound across the interface and therefore may not be accurately evaluated by ultrasonic tests. Metals containing laminations generally cannot be relied upon to transmit tensile stresses in the through-thickness direction. Laminations may be a source of gas voids and cracks in adjacent butt welds.

B2.9 Delamination. Delamination is the separation of a partially or completely roll-forge welded lamination under stress. The stress may be residual stress from welding or applied stress. Delaminations may be found visually at the edges or ends of pieces or may be discovered by ultrasonic tests.

B2.10 Seams and Laps. Seams and laps are longitudinal base-metal discontinuities that may be found in rolled products. When seams and laps are located parallel to the principal stress, they are generally not considered unacceptable discontinuities. When seams or laps are perpendicular to the applied or residual stresses, they will often propagate as cracks. Seams and laps are surface-connected discontinuities that result from cracks in the surface of the ingot or mechanical deformations caused by the manufacturing process. These discontinuities are modified during rolling so that the bottom of a seam is generally not so sharp as the original ingot- or slab-crack. They may be masked by mill scale or by the surface texture of the finished product. Welding over seams and laps can lead to cracking.

B2.11 Lamellar Tears. Lamellar tears are somewhat terrace-like separations in the base metal adjacent to the HAZ, typically caused by thermally induced shrinkage stresses resulting from welding. Lamellar tearing is a form of fracture resulting from high stress in the short-transverse (through-thickness) direction, which may extend over long distances. The tears are roughly parallel to the surface of the rolled product and generally initiate in regions of the base metal having a high incidence of coplanar, stringer-like nonmetallic inclusions. These inclusions are usually manganese sulfides in areas of the base metal subject to high residual stress. The fracture usually propagates from one lamellar plane to another by shear

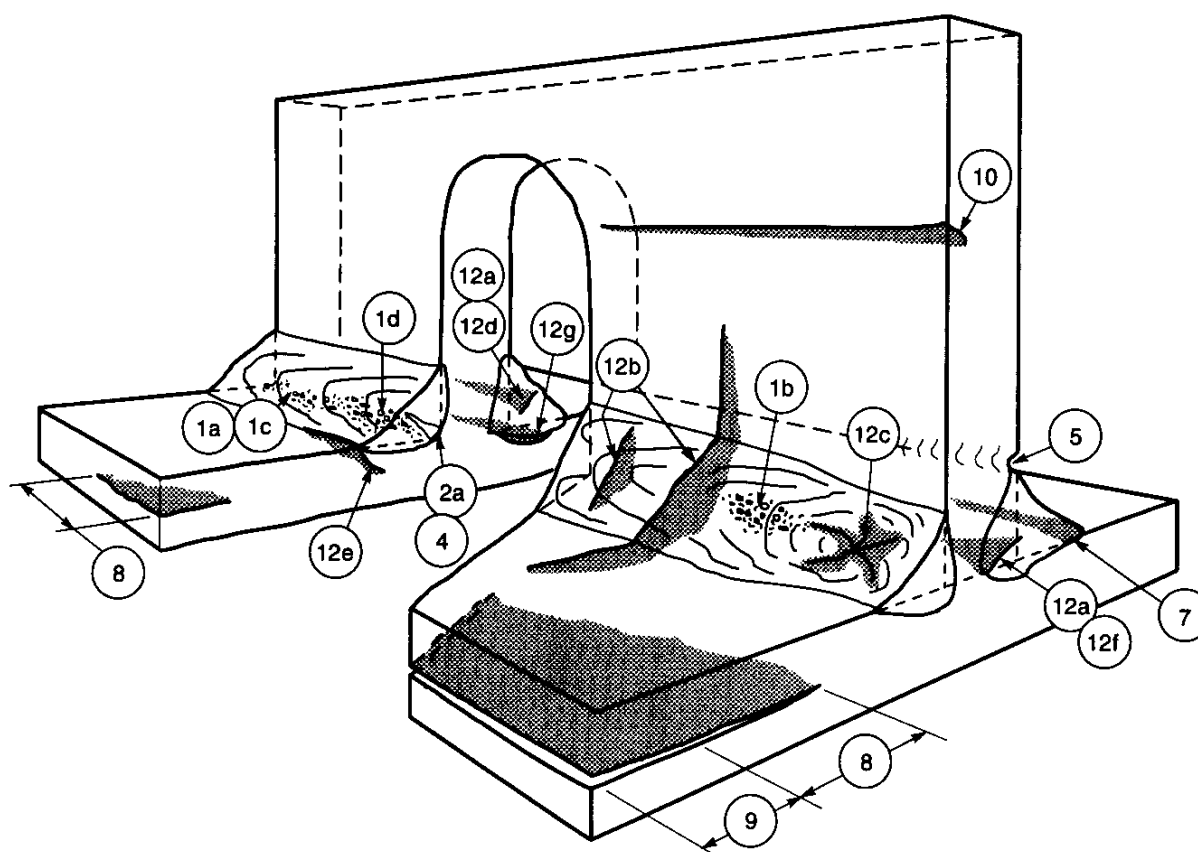


Figure B5—Single-Pass Fillet Weld in T-Joint (see B2)

along lines that are roughly normal to the rolled surface. Lamellar tearing is exacerbated by hydrogen and may be thought of as a form of hydrogen cracking. Low-sulfur steels and steels with controlled sulfur morphology have improved resistance to lamellar tearing.

B2.12 Cracks. Weld and base-metal cracks exclusive of fatigue cracks occur in weld and base metal when localized stresses exceed the ultimate strength of the material. Cracking is generally associated with stress amplification near discontinuities in welds and base metal, or near mechanical notches associated with weldment design. High residual stresses are generally present, and hydrogen embrittlement is often a contributor to crack formation. Welding-related cracks are generally brittle in nature, exhibiting little plastic deformation at the crack boundaries.

Cracks can be classified as either hot or cold cracks. Hot cracks develop at elevated temperatures. These commonly form upon solidification of the metal at tempera-

tures near the melting point. Cold cracks, sometimes called *delayed cracks* or *hydrogen cracks*, can form hours and even months after the completion of welding and are commonly associated with hydrogen embrittlement. Cold cracks propagate both between and through the grains. Cracks may be termed longitudinal or transverse, depending upon their orientation. All cracks result from tensile stress, which may be a combination of residual, secondary, and applied stress. Crack initiation and propagation is greatly influenced by the presence of discontinuities that concentrate stress.

B2.12.1 Longitudinal Cracks. When a crack is parallel to the axis of the weld, it is called a longitudinal crack regardless of whether it is along the centerline of the weld metal, or in the HAZ of the base metal. Longitudinal cracks in submerged arc welds, made by automatic welding procedures, are often associated with high welding speeds and sometimes are aggravated by segregation of weld metal constituents or by extensive porosity that does not show on the surface of the weld. Longitudinal

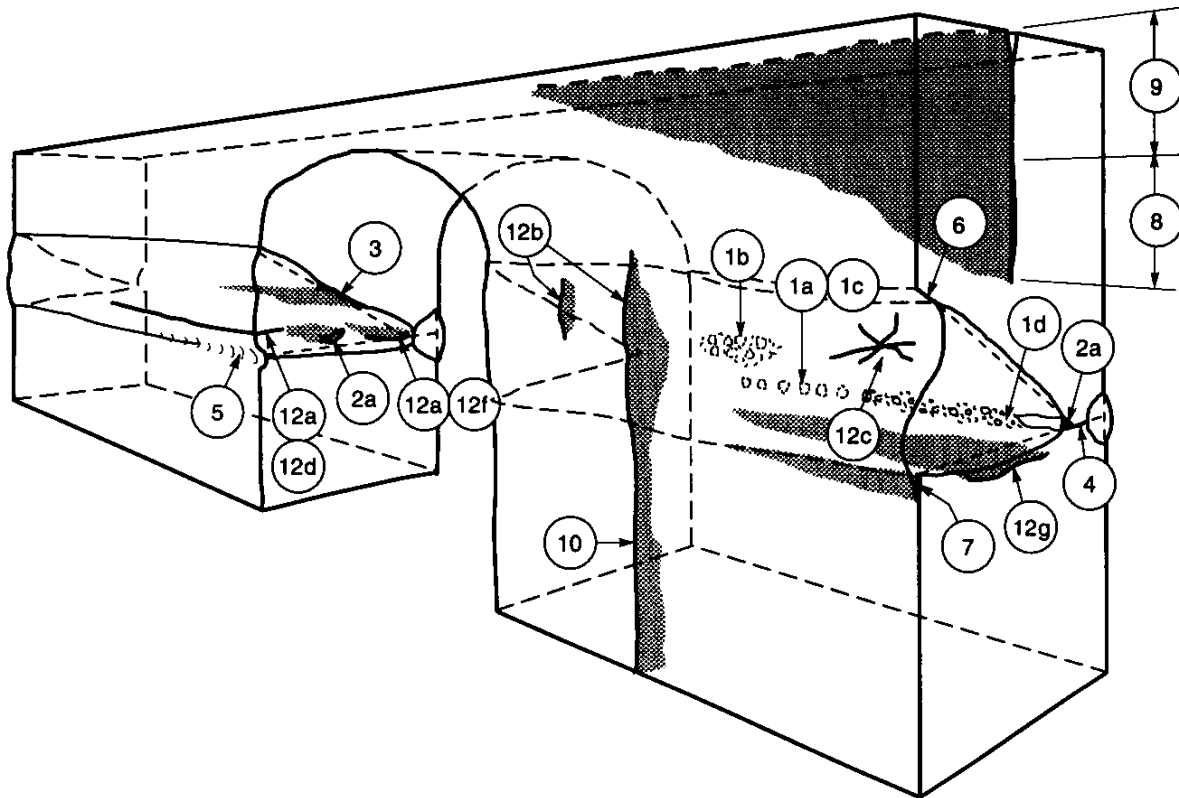


Figure B6—Single-V-Groove Weld in Butt Joint (see B2)

cracks in small welds between heavy sections are often the result of high cooling rates and high restraint.

B2.12.2 Transverse Cracks. Transverse cracks are perpendicular to the axis of the weld. They may be in weld metal, base metal, or both. Transverse cracks may be limited in size and contained completely within the weld, or may propagate from the weld metal into the adjacent HAZ and into the unaffected base metal. Transverse cracks initiating in weld metal are commonly the result of longitudinal shrinkage stresses acting upon excessively hard (brittle) weld metal. Transverse cracks initiating in the HAZ are generally hydrogen cracks.

B2.12.3 Crater Cracks. Crater cracks are cracks that form in the crater or depression that is formed by improper termination of the welding arc. Crater cracks are shallow, hot cracks that usually form a multipointed star-like cluster, although they may have other shapes.

B2.12.4 Throat Cracks. Throat cracks are longitudinal cracks that are generally located in the center of the

weld bead. These are generally, but not always, hot cracks.

B2.12.5 Toe Cracks. Toe cracks are generally cold cracks. These initiate or propagate from the toe of the weld where restraint stresses are highest. Toe cracks initiate approximately normal to the base-metal surface but more accurately normal to the tensile stress acting at that location and propagate to various depths in the base metal depending upon the residual stress and toughness of the base metal.

B2.12.6 Root Cracks. Root cracks are generally longitudinal cracks in the root of the weld. Root cracks are generally hot cracks.

B2.12.7 Underbead and Heat-Affected Zone (HAZ) Cracks. Underbead and HAZ cracks are almost always cold cracks that form in the HAZ. These are generally short cracks but may join to form much larger continuous cracks. Underbead and HAZ cracks generally

align themselves with weld boundaries that concentrate residual stresses. Underbead cracking and all other hydrogen cracks can become a serious problem when three elements are present: a susceptible microstructure, high residual stress, and hydrogen.

B2.12.8 Fissures. The term *fissure* is used to describe small to moderate size separations along prior austenite grain boundaries. This discontinuity is commonly found in electroslog and electrogas welds. Fissures occur in other welds, but they are easier to detect in electroslog welds because of the much larger prior austenite grain size. When electroslog welds are subject to high restraint, and hydrogen is present, fissuring may become a major problem. Fissuring in electroslog and electrogas welds is generally restricted to the center portion of the weld that is subject to high tensile residual stress resulting from solidification. Fissures can be either hot or cold cracks, although cold cracking is more common. The term *microfissure* is used for cracks that are so small that magnification must be used to detect the separation. The term *macrofissure* is used when the separation is large enough to be seen with the unaided eye.

B2.13 Fatigue Cracks. Fatigue cracks are different from the cracks listed in B2.12 of this Annex in that they represent cumulative damage from repeated applications of load. Fatigue cracks may extend preexisting cracks of any origin or may develop as new cracks from stress concentrations resulting from weld flaws or structural details.

The process of fatigue cracking left unchecked can propagate subcritical cracks to critical size at which point, brittle fracture will occur. The difference between weld quality standards for buildings and those specified for bridges is based upon the knowledge that bridge members subject to significant stress range and cycles of load are subject to fatigue crack initiation and growth; statically loaded structures are not.

Fatigue life of a structural member is the sum of initiation life plus propagation life until critical crack size is reached and failure occurs. Initiation life is generally much greater than propagation life, so it is essential that structures not be placed in service with known preexisting cracks. See *Fracture and Fatigue Control in Structures—Applications of Fracture Mechanics*, 2nd Edition, by Barsom and Rolfe, Prentice-Hall Inc.

Annex C

Short Circuiting Transfer

(Nonmandatory Information)

(This Annex is not a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, but is included for information purposes only.)

Gas metal arc welding (GMAW), using short circuiting transfer is not authorized for the construction of bridge members except by written approval of the Engineer. See 1.3.4 and 2.10.1.1.

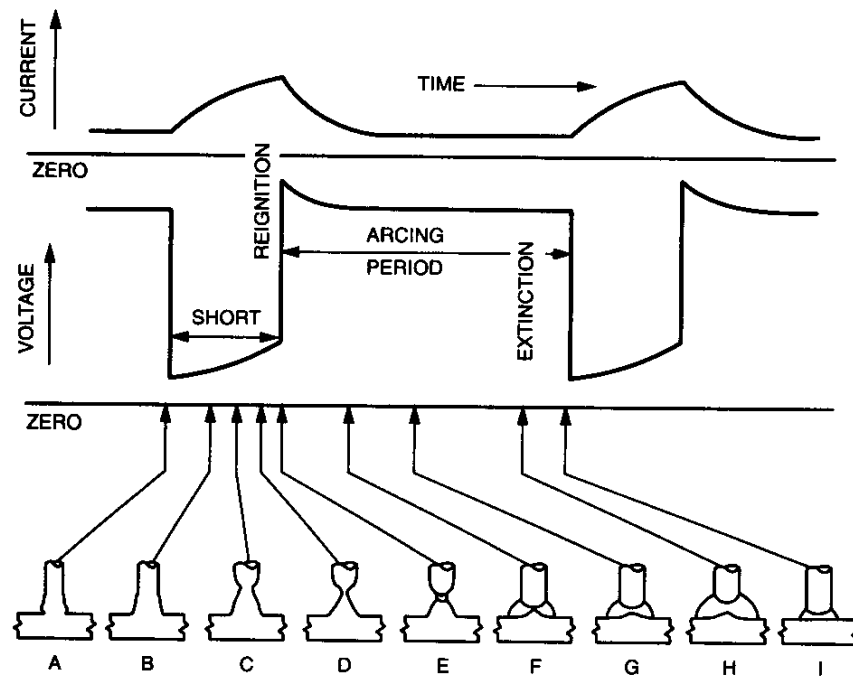


Figure C1—Oscillograms and Sketches of Short Circuiting Arc Metal Transfer

Annex D

Guidelines for Preparation of Technical Inquiries for the Joint AASHTO/AWS Subcommittee on Bridge Welding

(Nonmandatory Information)

(This Annex is not a part of ANSI/AASHTO/AWS D1.5-96, *Bridge Welding Code*, but is included for information purposes only.)

D1. Introduction

The AWS Board of Directors has adopted a policy whereby all official interpretations of AWS standards will be handled in a formal manner. Under that policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

D2. Procedure

All inquiries must be directed to the following:

Managing Director, Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries must contain the name, address, and affiliation of the inquirer and they must provide enough information for the committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and should also be in the format used here.

D2.1 Scope. Each inquiry must address one single provision of the code, unless the point of the inquiry involves two or more interrelated provisions. That provision must be identified in the Scope of the inquiry, along with the edition of the code that contains the provisions or that the Inquirer is addressing.

D2.2 Purpose of the Inquiry. The purpose of the inquiry must be stated in this portion of the inquiry. The purpose can be either to obtain an interpretation of a code requirement, or to request the revision of a particular provision in the code.

D2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to quickly and fully understand the point of the inquiry. Sketches should be used, when appropriate, and all paragraphs, figures, and tables (or the annex), which bear on the inquiry must be cited. If the point of the inquiry is to obtain a revision of the code, the inquiry must provide technical justification for that revision.

D2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry, or the wording for a proposed revision, if that is what inquirer seeks.

D3. Interpretation of Code Provisions

Interpretations of code provisions are made by the Structural Welding Committee. The secretary of the committee refers all inquiries to the co-chairs of the joint

AASHTO/AWS subcommittee. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire Structural Welding Committee for review and approval. Upon approval by the committee, the interpretation will be an official interpretation of the Society, and the Secretary will transmit the response to the inquirer.

D4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal*.

D5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning the *Bridge Welding Code* should be limited to questions of a general nature or to matters directly related to the use of the code. The Board of Directors' Policy requires that all Staff members respond to a telephone request for

an Official Interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. The Headquarters Staff can not provide consulting services. The Staff can, however, refer a caller to any of those consultants whose names are on file at AWS Headquarters.

D6. The Structural Welding Committee

The Structural Welding Committee's activities, in regard to interpretations, are limited strictly to the Interpretation of Code provisions or to consideration of revisions to existing provisions on the basis of new data or technology. Neither the Committee nor the Staff is in a position to offer interpretive or consulting services on: (1) specific engineering problems, or (2) code requirements applied to fabrications outside the scope of the code or points not specifically covered by the code. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Index

A

AASHTO/AWS
fracture control plan, 12
interpass temperature control, 12.14,
Tables 12.3, 12.4, 12.5
temperature zone, 12.4.5
Acceptance criteria
bend tests, 5.15.2, 5.25.2, 5.26.1
liquid penetrant testing, 9.21.4
macroetch test, 5.19.3, 5.26.3.4
magnetic particle testing, 9.21.2
per FCP, 12.3.3.2
radiography, 9.21.2
reduced section tension test, 5.15.1
stud welding, 7.8
ultrasonic testing, 9.21.3
visual, 5.17, 5.19.6, 5.27.1, 9.21.1
Air carbon arc process
cutting, 3.2.6
gouging, 3.2.3.3(2), 3.2.6, 3.7.1,
12.17.6(3)
Alignment, 3.3.3
jigs and fixtures for, 3.3.6
offset, 3.3.3
welds in butt joints, 3.3.3
Allowable stresses, 9.3 (not applicable)
All-weld-metal test, 5.16.3, 5.18.4,
5.19.4, Fig. 5.9
Ambient temperature, 3.1.3, 4.2.6, 7.5.4,
12.16.4
American Bureau of Shipping (ABS),
12.6.1.1(1)
American Society of Mechanical
Engineers, (ASME), 12.6.1.1(3)
Anti-spatter compound, 3.2.1
Ancillary products, 1.3.6
Application, 1.1, 7.6, 9.1
Approved procedures, 5.1
of weld repairs, 12.17.4
Arc shield, 7.2.2, 7.4.4, 7.4.6, Annex VI
Arc strikes, 3.10
ASNT Recommended Practice,
SNT-TC-1A, 6.1.3.4
Assembly, 3.3

Atmospheric corrosion resistance
base metals for, 4.1.4
electrodes for, 4.1.4
Attachments, (FCM), 12.2.2.1
Attenuation, 6.19.6
Attenuator, see Gain control

B

Backgouging, 2.10.1, 3.2.6, 12.17.2,
12.17.3(2)
air carbon arc, 3.2.6, 12.17.6(3),(6)
chipping, 3.2.6
grinding, 3.2.6
Backing, 2.10.1, 3.3.2.1, 3.13, 3.13.3,
4.7.6, 4.7.8, 4.14.2, 5.24.2.3, 9.2.4,
9.8.2,
Backing, removal of, 3.13.4, 3.13.5,
6.10.3.2, 6.10.3.3
Backing thickness, 3.13.3
Baking, drying
of flux, 12.6.6.3
of electrodes, 12.6.7.4, 12.6.7.6
Base metal, 1.2, 3.2, 5.4, 5.21.3, 7.2.1, 9.2
approval of repair, 12.17.4, 12.17.6(4)
discontinuities, 6.13.4, 12.10.3,
12.10.4, 12.11
edges, 3.2.3, 3.2.3.1, 12.10, 12.10.3
FCAW electrodes for, 12.6.7
identification of, 12.4.6
inspection, 3.2.2.3, 12.9, 12.16.5.1
limitations, 9.2.5
low-sulphur requirements, 12.4.4.1
optional requirements, 12.4.4
oxygen cutting, 3.2.6
postheat temperature limitations for,
12.15.2.3, 12.17.6(11),(13)
preparation, 3.2, 4.2.8, 5.13, 9.18
records, 12.16.5.1
rejection of, 12.12
removal, 3.2.2, 3.7, 12.12, 12.13.3
repair, 3.2.2, 3.2.3, 3.2.7, 3.3.4.1, 3.7,
12.11, 12.11.3, 12.17, 12.17.2
critical, 12.17.3, 12.17.4
noncritical, 12.17.2.1, 12.17.6

rotation of, 12.11.1
replacement, 12.11.4
requirements for FCMs, 12.4
SAW electrodes for, 12.6.7
SMAW electrodes for, 12.6.2.3
specifications, 9.2
substitution, 12.11.4
surfaces, 3.2.1, 3.2.2
testing, 12.15.2.5
thicknesses, 3.2.2
through-thickness requirements,
12.4.4.1
unlisted, 9.2.3
weldability, 4.2.3, 9.2.3, 9.2.3.1,
9.2.3.2, 12.12
weld tabs, 9.2.4
Beams, 9.17
built-up edges, 3.2.7
camber, 3.5.1.3
depth, 3.5.1.8
splices, 9.14
straightness, 3.5.1.2
tilt, 3.5.1.7
warpage, 3.5.1.7
Bearing at points of loading, 3.5.1.9
bearing stiffeners, 3.5.1.9, 3.5.1.12
tolerances, 3.3.2.2, 3.5.1.9, 3.5.1.12
Bend test requirements, 5.20.1
procedure qualifications, 5.19.2
welder qualification, 5.26.1, 5.27.3,
12.8.2
welding operator qualification, 12.8.2
Bidders, 9.19.4
Bolt holes, mislocated, restoration by
welding, 3.7.7
Bolts, 9.10
Boxing, 2.3.2.1, 9.11.1, Annex V
Bracing, 3.5.1.4
Break test, fillet welds, 5.26.3.1, 5.26.3.2,
5.27.4, 5.27.5
Bridges, 9
backing, 9.2.4, 9.8(2)
base metal, 9.2
beams, 9.17
non-continuous, 9.4
splices, 9.14, 9.2.4

bolts, 9.10
 built-up members, 9.15
 combination of welds, 9.9
 compression members, 9.13, 9.14,
 9.21.3.1(2)
 corner joints, 9.7
 dimensional tolerances, 9.19
 eccentricity of connections, 9.12
 fillet weld details, 9.11
 interrupted, 9.11.2
 fillet welds, 9.11
 flatness of girder webs, 9.19.1, 9.19.2,
 Annex IV
 floor systems, 9.5
 girders, 9.17
 splices, 9.17.1, 9.17.2
 web flatness, Annex IV
 inspection, 9.21.1
 lap joints, 9.6
 material preparation, 9.18
 noncontinuous beams, 9.4
 plug welds, 9.13
 prohibited welds, 9.8
 quality of welds, 9.21
 acceptance criteria, 9.21.1, 9.21.2,
 9.21.3, 9.21.4
 liquid penetrant testing, 6.7.7,
 9.21.4
 magnetic particle testing, 6.7.6,
 9.21.2
 radiographic testing, 6.7.5, 9.21.2
 ultrasonic testing, 9.21.3
 visual inspection, 9.21.1
 rivets, 9.10
 splices, 9.13, 9.14
 structural details, 9 Part B
 supplementary requirements, 9 Part D
 T- and corner joints, 9.7
 temporary welds, 9.20
 tension members, 9.13, 9.21.3.1(1),
 Annex A
 timing of tests, 9.21.5
 T-joints, 9.7
 transition of thickness or width in butt
 joints, 9.16
 compressive stresses, 9.16.2
 radius transition, 9.16.3
 shear stresses, 9.16.2
 tensile stresses, 9.16.1, 9.16.3
 undercut, 9.21.1.5
 welds, rivets, and bolts, 9.14
 workmanship, 9 Part C
 Bursts, 7.2.5

C

Calibration, ultrasonic, 6.17, 6.18, 6.22,
 Annex VII
 angle beam, 6.23.2
 angle check, Annex VII, A2.2

block (IIW), 6.16
 corner reflector (prohibited), 6.16.2
 dB accuracy, 6.22.2
 equipment, 6.15, 6.17, 6.21
 horizontal linearity, 6.21.1, Annex
 VII-A3
 longitudinal mode, 6.23.1, Annex
 VII-A1
 nomograph, Annex VII-B10
 shear wave mode, 6.23.2, Annex
 VII-A2
 Camber, Tables 3.2, 3.3, 3.2.7, 3.2.8,
 3.5.1.2, 3.5.1.3, 12.12, 12.15.2
 beams, 3.5.1.3
 girders, 3.5.1.3
 quenched and tempered steel, 3.2.8
 Canadian Welding Bureau, Level I or
 Level II, 6.1.3.1(2)
 Carbon equivalent, 5.4.2, Annex VIII,
 6.1.1
 Caulking, 3.9
 Certification, 4.8.2
 records, 12.16.5
 Charpy impact test, 5.16.3, 5.18.5, 5.19.5,
 Fig. 5.13
 Charpy V-notch (CVN) toughness values,
 12.4.4.2, Table 12.1
 for groove welds, 12.6.4.1, 12.7.2
 yield strength, undermatching, 12.6.4.2
 Chipping, 3.2.6, 4.14.2
 Cleaning, 3.11, 5.21.5.1, 5.21.5.3, 7.4.1
 weld spatter, 3.11.2
 Clipping control (UT), 6.18.1, 6.19.6
 Code interpretations, vii, Annex D
 Cold bending, 12.12
 Columns, variation from straightness,
 3.5.1.1
 Combination of welds, 9.9, 9.10
 Compression members, acceptance,
 9.21.2.2
 splices, 9.13, 9.14
 stresses, 9.21.3.1, Table 9.2
 Component (FCM), member, 12.2.2
 Concavity, 3.6.1, 3.7.2.2, 4.11.4
 Consumables, welding, 5.5, Table 5.1
 diffusible hydrogen limits for, 12.6.2.4
 exemptions, 12.6.1.1
 heat or lot testing of, 12.6.1, 12.6.2.1
 requirements for FCMs, 12.6
 Containers, sealed
 for electrodes
 for SMAW, 12.6.5.2
 for SAW, 12.6.6.3
 production usage, 12.6.5.10
 recovery of flux, 12.6.6.9
 Contract documents, 6.7.1.2(d), 12.3,
 12.3.3.1, 12.4.4, 12.4.4.1, 12.4.4.2,
 12.4.5.1, 12.5.3, 12.6.3, 12.9,
 12.10.1, 12.16.1, 12.16.5.1,
 12.16.5.2
 acceptance, 12.3.3.2

as fracture critical, 12.1
 designation of FCMs, 12.3.2
 postweld thermal treatments, 12.15.1
 Contractor, 3.4.3, 3.7.2, 4.2.4, 4.5.5,
 4.7.5, 4.8.2, 4.12.3, 4.15.1, 5.2.4,
 5.7.2, 5.7.3, 5.7.4.1, 5.7.7, 5.13.3,
 5.21.6.1, 5.21.7, 5.23.1.3, 5.23.2.4,
 5.25.1, 6.6, 7.1.1, 7.2.6, 7.3.3,
 7.5.5, 7.6.2, 7.6.4, 7.8.6, 7.8.7,
 12.3.3.1, 12.3.3.2, 12.6.6.10,
 12.7.4, 12.8, 12.11, 12.11.4,
 12.16.1, 12.16.5.2, 12.17.1.1,
 12.17.2.1
 competence, 12.8.1
 obligations of, 6.6
 requalification, 12.8.2
 Convexity, 3.6.1, 3.6.2, 3.7.2.1, 5.27.3
 Cooling rates, Annex VIII, Figs. VIII-2,
 VIII-3
 Cooling times prior to inspection, 12.16.4
 Cope holes, 3.2.4
 Corner joints, 2.9.5, 2.10.5, 9.7, 9.11,
 12.16.2.2
 Corner reflector (prohibited), 6.16.2
 Correction of deficiencies, 6.6.2
 Cracks, 3.7.2.4, 3.7.4, 3.8.1, 5.27.5.1,
 9.21.1.1, 9.3, 9.21.2, Annex B: B2.12,
 B2.13
 Craters, 3.3.7.1(2), 3.7.2.2, 9.21.1.3,
 Annex B: B2.12
 Current and voltage, maximum, 4.7.3,
 5.12.1, 5.12.1.3, 5.12.1.4
 Curving, heat steel, 12.12

D

Decibel calculating equation, 6.22.2.1
 Deficiencies in the work, 6.6.2
 Definitions, 1.4, 2.10.1, 4.9.1, 4.10.1,
 Annex V
 Delamination, Annex B: B2.9
 Delayed inspection, 9.21.1.9
 Dew point, 4.13, 4.18
 Diagrammatic weld, 2.3.2.4, 2.3.4
 Dimensional tolerances, 2.9.2, 2.10.2,
 3.3, 3.5, 9.19
 Discontinuities, 3.2.3.3, 3.3.7.1(2), 3.6.2,
 4.20.6, 5.18.3.1, 5.26.1.1, 5.27.2,
 5.27.3, 6.7.1.2, 6.11, 6.19.6.3,
 6.19.8, 6.24.1, 6.24.2, 7.4.7,
 9.21.2, 9.21.2.1, 12.9, 12.10.2,
 12.11.2, Annex B, Figs. 9.4, 9.5
 acceptance criteria, 6.11, 9.21,
 12.10.4, 12.17.6
 dimensions, 9.21.2.1, 9.21.2.2, Figs.
 9.4, 9.5
 noncritical, 12.17.2, 12.17.6
 no repair, 3.2.3.7(3)
 repair, 3.2.3, 3.7, 6.11, 12.17,
 12.17.1.1, 12.17.1.2, 12.17.1.3

Disposition of radiographs, 6.12.3
 Distortion, 3.4.3, 3.7.3, 9.3
 control, 3.4
 straightening, 3.7.3
 Drawings, 2.1, 2.10.3, 6.5.1, 7.2.1,
 7.6.7.1, 9.11.1, 9.20
 Drying
 arc shields, 7.4.4
 electrodes, 4.5.2, 4.5.3, 4.5.4, 12.6.7.6
 flux, 4.8.3, 12.6.6.3
 ovens, 4.5.2, 12.6.5.4, 12.6.5.5
 Ductility requirements, 12.6.3, 12.15.2.5
 Dye penetrant testing, 6.7.7
 Dyes, low stress, for stamping, 12.4.6

E

Eccentricity, 9.12
 Edges, 3.2.6, 3.2.7, 3.2.8, 3.2.9
 Effective throat, see also effective weld
 size, 2.3, 2.3.2, 2.3.2.3, 2.3.2.4,
 Annex I, Annex II
 diagrammatic weld, 2.3.2.4, 2.3.4
 Effective weld area, 2.3.1, 2.3.2, 2.3.3
 Effective weld length, 2.3.1.1, 2.3.2.2,
 2.3.2.3
 Effective weld size, 2.3.1.3, 2.3.1.5,
 Table 2.2
 Electrodes, 4.1.1, 4.1.4, 4.5, 4.8, 4.9,
 4.10, 4.11, 4.12, 4.14, 4.17, 4.20.3,
 5.12.1.1, 5.24.2.1, 5.24.3.2,
 5.24.4.1, 7.5.5.2, 12.6, S9.30.2,
 Table 5.3
 approved brands, 4.5.6
 certification, 4.8.2
 drying, 4.5.2, 12.6.5.4
 drying temperature
 for FCAW, 12.6.7.6
 for SMAW, 12.6.5.4
 electrogas, 4.15.2, 4.17, 5.14
 electroslag, 4.15.2, 4.17, 5.14
 exposure requirements SMAW),
 12.6.5.9, 12.6.5.10
 flux cored arc, 4.1.5.4, 4.12.2.2, 4.14,
 12.6.7, Tables 4.1, 4.3
 flux packaging, 12.6.6.2
 for atmospheric corrosion resistance,
 4.1.4, 12.6.5.6, Table 4.3
 for tack welding, 12.6.2.2
 gas metal arc, 4.1.5.3, 4.12, 4.14
 low hydrogen, 3.2.2.1, 4.1.5.4, 4.5.2,
 4.7.8, 7.5.5.2, 7.7.5, Tables 4.1, 4.7
 manufacturer's certification, 4.5.5,
 4.8.2, 7.2.6.2, 7.3.3, Annex VI
 nonmoisture resistant (SMAW),
 12.6.5.7, 12.7.1, Table 4.7
 optional R designators
 for tack welding, 12.6.2.2
 for SMAW, 12.6.5.8, 12.7.1
 packages for FCAW, 12.6.7.2

production usage of, 12.6.5.10
 requirements
 for tack welding, Table 12.2
 optional, for tack welding, 12.6.2.2
 optional, for welding, 12.6.2.3
 minimum and maximum, Tables
 12.2, 12.3, 12.4, 12.5
 sealed containers for, 12.6.5.2
 shielded metal arc, 4.5.1, 12.6.2.3,
 12.6.5.1, 12.6.5.6, 12.6.5.9, Tables
 4.1, 4.3
 stickout, 5.12.1.2, 5.12.2.2
 storage, 4.1.3, 4.5.2, 12.6.5.3, 12.6.7.4
 storage ovens for, 12.6.5.8, 12.6.7.4
 submerged arc, 4.1.5.2, 4.8.1, 12.6.6,
 Tables 4.1, 4.3
 time limit extensions for, 12.6.7.5
 usage, 4.1.5, 4.5.2, 4.6, 4.8, 4.9, 4.12
 Electrogas welding, 1.3.2, 4 Part E, Table
 5.4, Fig. 5.25
 all-weld-metal tension test, 4.16
 electrodes, 4.17, 5.12.1
 flux, 4.19
 guide to tubes, 4.17
 impact strength, Annex B
 impact tests, 4.15.3, Annex B
 joint details, 4.15.1, 5.24.3.2
 mechanical properties, 4.16
 procedures, 4.20
 procedure qualification, essential
 variables, 4.15.1, 5.14.2
 procedure specification, 4.15.1
 protection, 4.20.2
 qualification, 4.15.1
 quenched and tempered steels, 4.15.2
 restrictions for FCMs, 12.5.2
 shielding gas, 4.18
 Electroslag welding, 1.3.2, 4 Part E,
 Table 5.4, Fig. 5.25
 electrodes, 4.16, 4.17
 flux, 4.19
 guide tubes, 4.17
 impact strength, Annex B
 impact tests, 4.15.3, Annex B
 joint details, 4.15.1
 previous qualifications, 4.20.1
 procedures, 4.20, 5.13, 5.7.4, 5.7.5
 procedure specification, essential
 variables, 4.20.1, 5.13.3
 qualification, 4.15, 5.14.2
 quenched and tempered steels, 4.15.2
 restrictions for FCMs, 12.5.2
 End returns, see Boxing
 Energy input, Annex VIII
 Engineer, 1.1.3, 2.6.2, 3.2.3.6, 3.2.8,
 3.3.4, 3.3.7.3, 3.4.3, 3.5.1.13, 3.7.4,
 3.7.5, 3.7.7.1(2), 3.8.1, 3.13.2.2, 4.5.6,
 4.7.5, 4.8.2.2, 4.10.6, 4.12.4, 4.18,
 4.26.2, 5.2.3, 5.2.4, 6.1.1.2, 6.6.4,
 6.12.2, 6.12.3, 7.2.7, 7.3.1.1, 7.3.3,
 7.3.4, 7.8.6, 9.2.1, 9.2.3.1, 9.2.3.4(1),

9.18.2, 9.20, S9.25.3, S9.27.3, 12.3.1,
 12.3.3.1, 12.3.2, 12.3.3.1, 12.3.3.2,
 12.4.1, 12.4.4.1, 12.4.4.2, 12.5.2,
 12.5.3, 12.6.1, 12.6.6.7, 12.6.7.5,
 12.7.5, 12.8, 12.8.2, 12.11.2, 12.11.4,
 12.12, 12.13.1.1, 12.13.2, 12.15.1,
 12.15.2.1, 12.15.2.5, 12.16.1,
 12.16.5.2, 12.17.1.1, 12.17.3(2),
 12.17.6(5),(11),(12), Annex VI, Table
 12.2

Equipment

ultrasonic testing, 6.15
 welding, 3.1.2, 6.3.2, 7.2.1, 7.5.1
 Erection marks, for weld reports,
 12.16.5.1
 Essential variables, WPS qualification,
 5.13.3
 electrogas welding, 5.14.2, Tables 5.3,
 5.4
 electroslag welding, Tables 5.3, 5.4
 flux cored arc welding, Tables 5.3, 5.4
 gas metal arc welding, Tables 5.3, 5.4
 position, 5.8
 shielded metal arc welding, Table 5.3
 submerged arc welding, 5.7.5, 5.14.1,
 Table 5.3
 tack welder qualification, 5.27.5
 welder qualification, 5.26.3.1
 welding operator qualification,
 5.26.3.2, 5.28.1
 Extension bars, see Weld tabs

F

Fabricator, see also contractor
 Face-bend test, 5.18.3, 5.19.2, 5.26.1,
 5.26.2.1, 5.27.3, Fig. 5.12
 Fatigue, 9.17.2
 Fatigue cracks, Annex B: B2.13
 Faying surfaces, 3.3.1.1, 3.6.3, 3.13
 Field welds, 2.1.1
 Filler metals, 4.1, 4.2, 12.7, Tables 4.1,
 4.2, 5.3
 electrode-flux, 4.1.1
 electrodes, 4.1.1, Table 4.1
 granular, Table 5.3
 hydrogen control, Annex VIII,
 12.6.2.4
 matching requirements, 4.1.4, 4.1.5,
 4.1.6, 9.2.4
 powdered, Table 5.3
 storage, 4.1.3, 4.5.2
 welder group designation, 5.21
 Fillers, 2.4, 3.3.1.2
 Fillet welds, 5.10, 5.27.6.1, Figs. 5.4, 5.7,
 5.8, 5.22
 along an edge, 2.7.1.2
 assembly tolerances, 3.3
 boxing, 2.3.2.1, 9.11.1, Annex V

- break test, 5.26.3, 5.26.3.1, 5.26.3.2, 5.27.4, 5.27.5
 - concavity, 3.6.1
 - convexity, 3.6.1
 - cooling times for, 12.16.4(1),(2)
 - curved, effective length, 2.3.2.2
 - details, 2.7, 9.11
 - effective length, 2.3.2.1, 2.3.2.2
 - effective throat, 2.3.2.4
 - energy input, Annex VIII: Table VIII-2, Fig. VIII-4
 - in holes, 2.7.1.3
 - in lap joints, in slots, 2.7.1.3, 2.7.1.6, 2.8
 - in lap joints, intermittent, 2.7.1.5, 9.8(4)
 - interrupted, 9.11.2
 - inspection by magnetic particle (MT), 6.7.2.3, 12.16.2.3
 - macroetch test for, 5.21.5.1, 5.21.5.2, Fig. 5.8
 - maximum size, 2.7.1.2, 4.1.5, 4.1.5.3, 4.1.5.4, tolerance, 3.1.4
 - minimum size, 2.7.1.1 tolerance, 3.1.4
 - prequalified, 2.7.1, Fig. 2.3
 - profiles, 3.6, 5.27.6.1
 - repairs by MT, 12.16.2.3
 - skewed joints, 2.7.1.4, Annex II, Fig. 2.3
 - soundness test, Figs. 5.3, 5.8
 - tests, 5.10, 5.18.2, 5.19.3, 5.23.1.4, 5.23.2.4, 5.23.3, 5.26.3, 6.7.2
 - test plates, 5.23.1.4, 5.24.3.1
 - WPS Qualification, 12.7.3
 - undersize, 3.1.4, 9.21.1.7
 - Fine-grain practice, 12.4.2
 - Fissures, Annex B: B2.12
 - Flaw size evaluation, 6.23
 - angle beam testing, 6.23.2
 - straight beam testing, 6.23.1
 - Floor system, 9.5
 - Flux, 4.8, 4.19, 7.2.3, 12.7
 - certification, 4.8.2
 - condition, 4.8.3, 4.19
 - damaged packages, 4.8.3, 4.19
 - drying (baking), 4.8.3, 4.19, 12.6.6.3, 12.6.6.4
 - electrode combination, 4.8.1
 - fused, 4.8.4
 - gravity feed delivery systems for, 12.6.6.11
 - handling of, for SAW, 12.6.6.7
 - hoppers, discharge and refill of, 12.6.6.5
 - open-top systems, for SAW, 12.6.6.6
 - packing, 4.8.3, 4.19, 12.6.6.2
 - pneumatic delivery systems for, 12.6.6.8
 - reclamation, 4.8.4
 - recovery, 12.6.6.9, 12.6.6.10
 - replacement, time limits for, 12.6.6.7
 - storage, 4.19, 12.6.6.3, 12.6.6.5
 - submerged arc welding, 4.8, 12.6.6.2, 12.6.6.3, 12.7.1
 - Flux cored arc welding, 1.3, 4 Part D, 4.1.5.4, 4.12.2.2, 5.21, 12.6.7, S9.25.1, Figs. 2.4, 2.5 Note A
 - backing, 4.14.3
 - electrodes, 4.12.1, 4.12.2.2, 4.14.1.1, 4.14.1.5, 12.6.7.1
 - layer thickness, 4.14.1.5
 - prequalified WPSs, 4.14.1, 4.14.3, 4.14.4
 - progression of passes, 4.14.1.7
 - protection, 4.14.3
 - repair of FCMs, 12.5.1
 - shielding gas, 4.13
 - WPS qualification, 5.1.1
 - essential variables, Tables 5.3, 5.4
 - Forging, manufacturing requirements, 12.4.4.2
 - Forms, Annex III
 - Fracture Control Plan (FCP), 12, 12.2.1
 - Fracture Critical Member (FCM), 12, 12.2.2, 12.12
 - individual competence, 12.8.1
 - limits, 12.3.2
 - member components, 12.1
 - nonredundant members, 12.1
 - steel bridge members, 12.1
- ## G
- Gain control (attenuator), 6 Part C
 - Gamma ray, 6.10.1
 - Gas metal arc welding, 1.3.1, 2.7.1, 2.8.1, 2.10.1.1, 4.1.5.3, 4.12.2.1, 4.14, 5.21, S9.25.1, Figs. 2.4, 2.5 Note A
 - backing, 4.14.2
 - electrodes, 4.12.1, 4.12.2.2, 4.14.1.1, 4.14.1.2, Tables 4.1, 4.2
 - layer thickness, 4.14.1.4
 - prequalified procedures, 4.14.1
 - procedure qualification, 5.1.1, 5 Part A
 - essential variables, 5, Tables 5.3, 5.4
 - progression of passes, 4.14.1.7
 - properties of electrodes for, 4.12.2.1
 - protection, 4.14.3
 - restrictions for FCMs, 12.5.2
 - shielding gas, 4.13, 4.14.3, 4.14.4
 - short circuiting transfer, 2.7.1, 2.8.1, Annex C, Figs. 2.4, 2.5 Note A
- ## H
- Girders
 - camber, 3.5.1.3, Tables 3.2, 3.3
 - depth, 3.5.1.8
 - splices, 9.17.1, 9.17.2
 - stiffeners, 9.19.2
 - straightness, 3.5.1.2
 - sweep, 3.5.1.4
 - testing of, 6.7.2.1
 - tilt, 3.5.1.7
 - warp, 3.5.1.7
 - web flatness, 3.5.1.6, 9.19.1, 9.19.2
 - Gouging, see Backgouging
 - Grinding, 3.2.4, 3.8.1
 - Groove welds
 - assembly tolerances, 2.9.2, 3.3
 - backing, 2.9.2, 3.13, 9.2.4
 - bevel, 5.23.1.2, 5.23.1.3, 9.12.5
 - complete joint penetration, 6.7.1, Fig. 2.4
 - cooling times for, 12.16.4(3),(4)
 - details, 5.23.1.2, 5.23.1.3, Figs. 2.4, 2.5, 5.5, 5.6
 - dimensional tolerances, 2.9.2, 2.10.2, 3.3.4
 - effective length, 2.3.1.1, 2.10.3
 - effective weld size, 2.3.1, 2.10.3, 2.12.3, Table 2.2
 - intermittent, 9.8(3)
 - NDT requirements, 12.16.2.2
 - partial joint penetration, 2.5, 2.10, 5.9.1, 6.7.2, Fig. 2.5
 - prequalified, 2.9, 2.10, Figs. 2.4, 2.5
 - profiles, 3.6.2, Fig. 3.3
 - size and length, 2.10.3, 3.1.4, Table 2.2
 - termination, 3.12
 - UT testing for, 12.16.2.2
 - yield strength for, 12.6.4.1
 - WPS qualification, 12.7.2, 12.8.2, 12.10.3
 - Groove weld test plate, 5.23.1.2, 5.23.1.3, Figs. 5.5, 5.6
 - Guided bend test jig, 5.26.1, Figs. 5.14, 5.15, 5.16
 - Guide tubes, 4.17
- ## H
- Hardness, 4.10.6, 4.11.6
 - determinations, 4.10.6.1, 4.11.6.1
 - grinding prior to testing for, 4.10.6.1, 4.11.6.1
 - Heat-affected zones (HAZ)
 - failure in, Annex VI: VI7.2
 - hardness control, 3.3.7.4, Annex VIII-3, 12.13.3
 - hardness of, 4.10.6, 4.11.6
 - testing of, 4.10.6.1, 4.11.6.1, 5.18.3, 4.4.1
 - Heat input, 4.3, 5.12.1, 5.12.2, 7.4.3, Tables 12.3, 12.4, 12.5
 - Heat-shrink method, 3.7.3, 12.12
 - controls, 12.15.2.4
 - testing, 12.15.2.5
 - Heat testing
 - exemptions from, 12.6.1.1

for diffusible hydrogen, 12.6.2.1
 of weld consumables, 12.6.1
 postheating, 12.15, 12.17.6(11)
 reports, 12.16.5.1
 Heat treatment, 4.4, 5.7.8, 12.4.4.2
 Hermetic containers, 4.5.2
 Hole-type IQI, 6.10.3.3, 6.10.7, Table
 6.1, Fig. 6.1E
 design, 6.10.4, Table 6.1
 essential hole size, Table 6.1
 location, 6.10.7, Fig. 6.1
 number required, 6.10.7
 radiographic testing, using, 12.16.3
 thickness, 6.10.7.2, 6.10.7.3
 Holes, unacceptable, bolt or punched
 appearance, 3.7.7
 approved welding procedure, 3.7.7(5)
 quenched and tempered steels,
 3.7.7.3(4)
 restoration by welding, 3.7.7.1,
 3.7.7.2, 3.7.7.3
 subject to other stresses, 3.7.7(1)
 subject to tensile stresses, 3.7.7(2)
 tests required, 3.7.7(1),(3)
 Hoppers, flux, 12.6.6.5, 12.6.6.11,
 open top, 12.6.6.6
 Hydrogen control, Annex VIII: VIII.6.2
 Hydrogen, diffusible, of weld metal,
 12.6.2
 for FCAW, 12.6.7, 12.6.7.5
 for SAW, 12.6.5
 for SMAW, 12.6.6.1, 12.6.6.7
 for tack welding, 12.6.6.2
 testing for, 12.6.2.1
 welding, for, 12.6.2.3

I

IIW ultrasonic reference block, 6.16.1,
 6.21, Fig. 6.4A
 Image quality indicator, 6.10.1, 6.10.3.3,
 6.10.7, Annex V, Table 6.1, Table
 6.1A, Fig. 6.1F
 Impact test, 5.18.5, 5.19.5, Tables 4.1,
 4.2, Fig. 5.13
 Inadequate joint penetration, 3.6,
 Annex B: B2.3
 Incomplete fusion, 3.7.2.3, Annex B:
 B2.3, Fig. 3.3
 Inspection
 certified reports, 12.16.5
 delay, 9.21.1.9
 dye penetrant, 6.7.7, 9.21.4
 equipment, 6.3
 general, 6.1
 liquid penetrant, 6.7.7, 9.21.4
 magnetic particle, 6.7.6, 9.21.2
 nondestructive testing, 5.16.2, 5.17,
 6.7, 7.8.1, 9.21.2
 of materials, 6.2

QA/QC, 12.17.5
 radiographic, 6 Part B, 9.21.2
 records, 6.5, 12.16.5
 studs, 7.4.1, 7.4.2, 7.5.5.6, 7.8, 7.8.6,
 Annex VI: VI.7.2
 ultrasonic, 6 Part C, 9.21.2
 verification, 6.1.1
 visual, 7.5.5.6, 7.7.1.3, 7.8.1, 9.21.1,
 9.21.1.8
 weld, 12.16, 12.16.1.1
 welder qualification, 6.4
 welding procedure qualification, 6.3,
 12.16
 work, 6.5
 Inspector, 6 Part A, 6.1.2, 6.1.3, 6.6.6
 ASNT qualification, 6.1.3.4,
 12.16.1.1, 12.16.1.2
 AWS Certified welding, 6.1.3.1
 assistant inspector, 6.1.3.3
 Canadian inspectors, 6.1.3.1
 fabrication/erection, 6.1.1, 6.1.2
 identification of accepted welds, 6.5.5
 Lead, 12.16.1.1, 12.16.5.2
 Quality Assurance, 12.16.5.2, 12.12.1.1
 technician, 6.1.3.1(3)
 verification, 6.6.2
 vision requirements, 6.1.3.7
 Intermittent welds, 2.7.1.5, 9.8(3),(4)
 Interpass temperature, 3.4.7, 4.2, 4.11.6,
 5.7.1, 5.7.1.1, 12.6.2, 12.14,
 12.15.2.2, 12.17.6(8), Tables 4.2,
 12.3, 12.4, 12.5
 Interpretation of code provisions, vi
 Isotope radiation, 6.9.1

J

Jig, wraparound, 5.18.3.3, Figs. 5.14,
 5.15, 5.16
 Joint root openings, 2.9.4
 Joint WPS, 5 Part A, 5.25.3
 limitation of variables, 5.13.3
 prequalified, 5.11, Figs. 2.4, 2.5 Note A
 WPS qualification, 4.15.1, 5 Part A
 WPS qualification by tests, sample
 form, Annex III
 Joints
 corner, 9.7
 nonstandard, 5.7.7
 prequalified, 2.7, 2.8, 2.9, 2.10
 transition in thickness and width, 9.16

L

Lamellar tearing, 4.2.4, 9.3, 12.15.1,
 Annex B
 Laminations, Annex B: B2.8
 Lap joints, 9.6

Limitation of variables, WPS
 qualification, 5.13.3
 electroslag and electrogas welding,
 5.14.2, Table 5.3
 flux cored arc welding, Table 5.3
 gas metal arc welding, Table 5.3
 shielded metal arc welding, Table 5.3
 submerged arc welding, Table 5.3
 Limitation of variables, tack welders,
 5.24.1, 5.24.4
 base metals, 5.24.1.1
 electrodes, 5.24.1.1, 5.24.3.2
 position, 5.24.2.2, 5.24.3.3
 welding process, 5.24.1.2
 Limitation of variables, welder, 5.24
 base metals, 5.24.1.1
 electrodes, 5.24.4.1, 5.24.1.3
 progression of welding, 5.24.2.2
 position, 5.24.2.2
 qualification, 5.24.1.1
 welding process, 5.24.1.2
 Limitation of variables, welding operator,
 5.24.1
 base metals, 5.24.1.1
 electrodes, 5.24.1.3, 5.24.3.2
 position, 5.24.2.2, 5.24.3.3
 qualification, 5.24.1.1
 Liquid penetrant testing, 6.7.7, 9.21.4
 Lloyd's Register of Shipping, 12.6.1.1(2)
 Longitudinal cracks, Annex B: B2.12a
 underbead cracking test report, S9.2.51
 Lot testing
 exemptions from, 12.6.1.1
 for diffusible hydrogen, 12.6.2.1
 of welding consumables, 12.6.1
 Low-hydrogen electrodes, 3.2.2.1,
 4.1.5.1, 4.5.2, 4.5.2.2, 4.7.8,
 7.5.5.2, 7.7.5, Table 4.5.2
 approved, 4.5.2.1
 atmospheric exposure, Table 4.7
 condition, 4.5.2
 redrying, 4.5.4
 restrictions, 4.5.3
 storage, 4.5.2

M

Machining, 3.2.5, 3.7.1
 Macroetch test, 5.18.2, 5.26.3, 5.26.3.2,
 5.26.3.4, Fig. 5.8
 Macroetch test specimen, 5.10.3, 5.18.2,
 5.26.3.4, 5.38.4, Figs. 5.21, 5.23
 Magnetic particle testing, 6.7.6, 9.21.2,
 12.15.2.5, 12.16.4, 12.17.6(5)
 sample form, test report form,
 Annex III, Form E-8
 Yoke method of, 6.7.6.2, 12.10.2
 Mandatory Annexes, Annex I through
 Annex VIII
 Manufacturer, 4.5.5, 5.5, 7.2.6.2, 12.6.1

electrode certification, 4.5.5, 4.8.2, 4.12.3, 4.16
 electrodes for SMAW, 12.6.5.9
 shielding gas certification, 4.13, 4.18
 stud certification, 7.1, 7.2.6.2, 7.3.3
 ultrasonic equipment certification, 6.21
 Mechanical testing, 5.17
 Melt-thru, see melting-through
 Melting-through, 3.13.3, 4.7.6
 Method of testing, 5.18, 5.26, 5.26.3.3
 Mill scale, 3.2.1, 3.11.1, 4.19, 7.4.3, 7.5.5.4
 Mill test reports, 12.16.5.1
 Mill orders, 12.4.3, 12.4.4, 12.4.5, 12.10
 for Charpy V-notch requirements, 12.4.5.2
 Mill repairs, 12.4.3
 Misalignment, 3.3.3
 Mislocated holes, 3.7.7
 Multiple arc, 4.7.1, 4.11
 Multiple electrodes, 4.11
 Multiple pass, 3.3.7.2, 5.10.3(1)

N

NDT Technicians, 12.16.1
 weld types, 12.16.2
 weld repair, 12.17.6(1)
 NDT, weld requirements, 12.16.2
 butt welds, repaired, 12.16.2.1
 noncritical, 12.17.2(2)
 corner joints, 12.16.2.2
 fillet weld repairs, 12.16.2.3
 groove welds, repaired, 12.16.2.2, 12.17.2(4)
 inspection reports, 12.16.5
 tension, butt joints, 12.16.2.1
 T-joints, 12.16.2.2
 Nomograph, ultrasonic attenuation, Annex VII, Fig. VII-10, Form VII-11
 Noncontinuous beams, 9.4
 Nondestructive testing, 5.16.2, 5.17, 6.6.5, 6.7, 6 Parts B and C, 9.21, Annex VII
 liquid penetrant, 6.7.7, 9.21.4
 magnetic particle, 6.7.6, 9.21.2, 12.17.6(5)
 personnel qualification, 6.1.3
 radiographic testing, 6 Part B
 SNT-TC-1A, 6.1.3.4
 timing, 9.21.5
 ultrasonic testing, 6 Part C
 unlisted base metals, 9.2.3
 Nonfusion, see Incomplete fusion
 Nonredundant members, 12

O

Offset, 3.3.3, 3.5.1.7
 Optional code provisions or requirements, 1.1.3, 3.1.5, 6.1.1, 6.1.3, 6.7
 Ovens, storage (drying) see storage ovens
 Overlap, 3.6.5, 3.7.2.1, Annex B: B2.7
 Owner, 1.1.4, 3.5.1.13, 6.6.5, 6.20.2
 Oxygen cutting, 3.2.6
 plate preparation, 3.2

P

Paint, removal of, 3.2.1, 6.19.3
 Parallel electrodes, 4.7.1, 4.10
 Peening, 3.8, 12.17.6(10)
 slag removal, 3.8.2
 unacceptable peening, 3.8.1
 use of vibrating tools, 3.8.2
 Penetrameters, see hole-type IQI
 Personnel qualification for NDT, 6.1.3.4
 Piping porosity, 6.13.3, 9.21.1.6, Annex B: B2.1d
 Plug welds, 2.3.3, 2.8, 3.3.1.1, 4.21, 5.2.1.4, 5.27.6.2, 9.13
 depth of filling, 2.8.7
 effective area, 2.3.3
 macroetch test, 5.26.3.4, Fig. 5.23
 qualification tests, 5.23.1.5, Fig. 5.23
 size, 2.8.2
 spacing, 2.8.3
 technique for making, 4.21
 Porosity, 3.7.2.3, 6.13.3, 9.21.1.6, 9.21.2.1, Annex B: B2.1
 Position of welding, 5.8, 5.22, 5.22.1, 5.24.3.3, 5.28.2, 7.6.1, 7.6.3.2
 Postheating, see Postweld thermal treatments
 Postweld thermal treatments (PWHT), 12.15, 12.15.1, 12.17.6(11),(13)
 approval of, 12.15.2.1
 controls, 12.15.2.1
 definition of, 12.15.2
 limitations, 12.15.2.3
 minimum temperatures, 12.15.2.2
 testing, 12.15.2.5
 Preheat, 3.3.7.1(1), 4.2, 4.10.6, 4.11.6, 7.5.5.5, 12.14, 12.15.2.2, 12.17.6(8), Annex VIII: Table VIII-2, Tables 4.4, 12.2
 effect on hardness, 4.10.6, 4.11.6
 Prequalified joint details, 2.7.1, 2.8.1, Figs. 2.4, 2.5
 Prequalified WPS, 5.11
 weld metal limitations, 5.15
 Pretest definition, 5.7.2
 Procedure specification, see Welding procedure specification (WPS)
 Processes not in Code, 1.3.5

Production weld thickness, 5.6, Table 5.2
 Profiles, weld, 3.6, 9.21.1.4
 Progression of welding, 4.6.8, 4.14.1.7, 5.24.2.2
 Prohibited welded joints, 9.8
 Protective coatings, 3.2.1, 3.11.2, 7.4.1, 7.4.2
 Punched holes, repair, 3.7.7, 12.17.3(6)

Q

Qualification, 5
 combined procedures, 5.7.9
 exempt procedures, 5.7.6
 forms, Annex III
 general requirements, 5 Part A, 5.7, 12.16
 nonconforming WPS, 5.11, NDT, 6.7.7
 prequalified WPS, 5.11, 5.11.1
 previously qualified WPS, 5.7.2
 records, 5.16, 5.32, 5.43, 5.51
 required tests, 5.12.1, 5.12.2, 5.15
 retests, 5.20, 5.28, 5.28.1, 5.28.2
 stud application, 7.6
 tack welders, 5 Part B
 ultrasonic unit, Annex VII
 verification testing, 5.7.3
 welders, 5 Part B, 5.3, 5.23.1.1
 welding operators, 5 Part B, 7.7.4
 WPS, 5 Part A, 5.9, 5.21.3, 9 Part D (S9.27), Figs. 5.1, 5.2
 Quality Assurance/Quality Control, 12.16.1, 12.16.5.2, 12.17.5, 12.17.6
 Quality of welds, 7.7, 9.21, 12.16

R

Radiographic Inspection, see Radiographic testing
 Radiographic testing procedure, 6.10
 Radiographic testing, 5.25.1, 5.26.1.2, 5.26.1.3, 5.27.2, 6.7.1.1, 6.7.1.2, 9.21.2, 12.8.2, 12.16.2.1, 12.16.5.1
 backscattered radiation, 6.10.8.3
 extent of testing, 6.7, 6.8
 film type, 6.10.4
 film width, 6.10.9
 gamma ray sources, 6.10.6
 general, 6.10.1, 6.10.8, 12.16.4
 image quality indicators, 6.10.1, 6.10.7, 6.10.7.5, Tables 6.1, 6.1A, Figs. 6.1A through Fig. 6.1F
 hole-type IQI, 6.10.7, Table 6.1, Fig. 6.1E
 radiograph illuminator, 6.12.1
 requirements, 12.16.3
 safety, 6.10.2
 source location, 6.10.5

S

- sources, 6.10.6
- surface preparation, 6.10.3
- wire IQI, 6.10.7, 6.10.7.4, 6.10.7.5, Table 6.1A, Fig. 6.1A through D
- x-ray unit size, 6.10.6
- Radiographic tests, 5.15, 5.16.2, 5.17, 5.21, 5.26.1, 5.26.1.2, 5.27.2, 6 Part B, 9.21.2
- acceptance, 5.12.5, 5.26.1.2, 6.11, 9.21.2
- Radiographs, 5.21.5.3, 5.26.1.2, 6.10.1, 6.10.5, 6.10.7, 9.21.2, Figs. 6.10.5A through D
- contractor's obligation, 6.12
- density limitations, 6.10.11
- density measurements, 6.10.11.1, 6.10.11.2
- identification of, 6.10.12
- quality, 6.10.10
- submitted to owner, 6.12.3
- supplement to ultrasonic testing, 6.13.3
- Records, 5.2.4, 5.21.7, 5.28.2, 6.5, 12.16.5
- Reduced-section tension tests, 5.15.1(1), 5.16.3
- test specimen, Fig. 5.10
- Re-entrant corners, 3.2.4
- Reference block, ultrasonic testing IIW, 6.16.1, Fig. 6.4A
- other approved designs, 6.16.1, Annex VII, Fig. 6.4B
- Reinforcement, 3.6.2, 3.6.3, 6.10.3
- removal of, 3.6.3
- Reject control (UT), 6.18.1, 6.19.6
- Repair, 3.2.2, 3.2.7, 3.3.4, 3.7.2, 3.7.7, 12.16, 12.16.5.1, Table 3.1
- of cracks, 3.7.2.4
- of fillet welds, 12.16.2.3
- of plate, 3.2.3
- of studs, 7.7.3, 7.7.5
- welding, definition of, 12.17
- critical, 12.17, 12.17.3
- noncritical, 12.17, 12.17.2, 12.17.2.1
- Report forms, Annex III
- Reports, 6.12, 6.20
- Responsibility of contractor, 5.2, 5.21.6.1, 6.6, 12.8
- Restoration by welding, of holes, 3.7.7
- Restraint, Annex VIII: VIII.6.2.5
- Retests, 5.20, 5.28, 5.28.1, 5.28.2
- Rivets, 9.10
- Root-bend test, 5.16.3, 5.25.2, 5.26.2.1, 5.27.3, Figs. 5.12, 5.13, 5.22
- Root face, 3.3.4
- Root opening, 2.9.4, 3.3.1, 3.3.4, 3.3.4.1
- build-up of, 3.3.4.1
- Run-off plates, see Weld tabs
- Rust-inhibitive coating, 3.2.1
- Safety, 1.6, 6.10.2
- Sample report forms, Annex III
- Sequence, 3.4.3
- Shear connectors, 7.2.5, 12.10, Fig. 7.1
- Shielded metal arc welding, 1.3.1, 2.7.1, 2.8.1, 4.1.5.1, 4.5, 4.6, 5.24.4.1, 7.5.5, 9.25.1, 12.6.5, S9.25.1
- electrodes, 4.1.1, 4.5.1, 12.6.5.1, 12.6.5.9
- atmospheric exposure, 4.5.2.1, 12.6.5.6, 12.6.5.8
- containers for, 12.6.5.3
- non-moisture-resistant electrodes for, 12.6.5.7
- optional moisture-resistant designator electrodes for, 12.6.5.8
- layer thickness, 4.6.5, 4.6.7
- maximum fillet weld size, 4.6.6
- of studs, 7.5.5
- prequalified procedures, 4.6
- root pass, 4.6.5
- stud welding, 7.5.5
- WPS qualification, 5 Part A
- essential variables, Tables 5.3, 5.4
- repair of FCMs, 12.5.1
- storage of, 12.6.5.3
- Shielding gas, 4.13, 4.14.3, 4.14.4, 4.18
- dew point, 4.13, 4.18
- electrode gas welding, 4.18
- flux cored arc welding, 4.13, 12.6.7.3
- gas metal arc welding, 4.13
- manufacturer, 4.13, 4.18
- wind protection, 4.14.3
- Shop drawings, 2.1, 12.3.3, 12.3.3.1, 12.3.3.2, 12.11.2, 12.11.4, 12.16.5.1
- for weld repair, 12.17.1.2
- Shop splices, 3.4.6
- Shop welds, 2.1.1
- Short circuiting transfer, 1.3.4, 2.10.1.1, 4.14.4, Annex C, Figs. 2.4, 2.5 Note A
- Shrinkage, 3.4
- due to cutting, 3.2.7
- due to welding, 3.2.7
- Side-bend test, 5.15.1, 5.16.3, 5.25.2, 5.26.2, 5.26.2.1, 5.27.3, Fig. 5.11
- Size effects, 2.3
- Slag, 3.11.1
- Slag inclusion, 3.7.2.3
- Slag removal, required, 3.11.2
- use of slag hammers, 3.8.2
- use of vibrating tools, 3.8.2
- Slot welds, 2.3.3, 4.22
- cleaning, 3.11.1
- effective area, 2.3.3
- ends, 2.8.5
- length, 2.8.4
- operator qualification, 5.23.2.3
- prequalified condition, 2.8.1.1
- size, 2.8.6
- spacing, 2.8.6
- technique for making, 4.22
- thickness, 2.8.2
- welder qualification, 5.23.1.1
- SNT-TC-1A qualification, 6.1.3.4
- Splatter, 3.11.2
- Splice plates, 9.17.3
- Splices, 9.13, 9.14
- Steels
- approved, 9.2.1, 12.4.1
- cambering, 12.12
- cold bending, 12.12
- heat curving, 12.12
- other than M270M Grades 100/100W, 3.2.2.1
- straightening, 12.12
- Steels, quenched and tempered, 3.2.6, 3.7.3, 4.3
- camber correction, 3.2.7
- heat input control, 4.3
- WPS qualification, 5.1.1, 5.13.2
- Stiffeners, 12.10
- bearing, 3.5.1.9, 3.5.1.12
- fit, 3.5.1.10
- intermediate, 3.5.1.10, 9.17.2
- straightness, 3.5.1.11
- Storage ovens
- for electrodes
- for FCAW, 12.6.7.4
- for SAW, 12.6.6.3, 12.6.6.4
- for SMAW, 12.6.5.3, 12.6.5.4, 12.6.5.5, 12.6.5.9
- drying temperatures for, 12.6.5.4
- Straightening, 3.7.3, 12.12, 12.15.2
- Straightness, 3.5.1.1
- Stress relief, 4.4
- alternate temperatures, 4.4.3
- cooling, 4.4.2.2
- heating, 4.4.2.2
- quenched and tempered steels, 4.4.2.3
- temperature, 4.4.2
- Structural details, 9 Part B
- beams, 9.17
- built-up members, 9.15
- eccentricity, 9.12
- fillet welds, 9.6
- girders, 9.17
- lap joints, 9.6
- noncontinuous beams, 9.4
- participation of floor systems, 9.5
- T-and corner joints, 9.7
- transition of thickness, 9.16
- transition of width, 9.16
- Studs
- acceptance, Annex VI
- application qualification, 7.1, 7.6
- base qualification, 7.2.4, 7.2.6, 7.3, 7.4, 7.5, 7.6, 7.6.5, 7.6.6.1, 7.7, 7.8, Annex VI: VI.7.2, VI.8, VI.9, Figs. VII.2A, VI.7.2B

- certification, 7.2.6.2, 7.3.3.1, 7.3.3.2
 - cracks, 7.2.5
 - decking, 7.6.1.2
 - description, 7.3.1, 7.4.7
 - design, 7.2.1
 - finish, 7.2.5
 - length of studs, 7.2.1, Fig. 7.1
 - manufacturers, 7.1, 7.2.6.2, 7.6.2, Annex VI
 - materials, 7.3.1
 - mechanical requirements, 7.1, 7.3, Fig. 7.2
 - moisture, 7.4.1, 7.4.3
 - not prequalified, 7.6.1.2
 - oil, 7.4.1, 7.4.4
 - operator qualification, 7.7.4
 - removal, 7.7.5
 - rust, 7.4.1, 7.4.3
 - scale, 7.4.1, 7.4.3
 - shear connectors, 7.4.5, 7.8.5
 - tensile requirements, 7.3.1.1, Annex VI: VI.7.1, Fig. 7.2
 - torque testing, 7.6.6.2, 7.8.3, Fig. 7.3
 - type A, Table 7.1, 7.8.5
 - type B, Table 7.1, 7.4.5, 7.8.5
 - Stud welding
 - application qualification requirements, 7.6
 - arc shields, 7.2.2, 7.4.4, 7.4.6, Annex VII: VII.3
 - automatically timed welding equipment, 7.2.1, 7.5.1, 7.5.2
 - certification, 7.2.6.2
 - decking, 7.4.3
 - fabrication inspection, 7.7.3, 7.8
 - ferrule, 7.7.2, 7.4.4, 7.4.6
 - fillet welded studs, 7.5.5
 - electrode diameters, 7.5.5.2
 - inspection, 7.5.5.6, 7.8
 - low hydrogen electrodes, 7.5.5.2
 - minimum size, 7.5.5.1, Table 7.2
 - preheat requirements, 7.5.5.5, Table 4.4
 - flash, 7.4.7, 7.7.1.3, 7.7.3, 7.8.1
 - flux, 7.2.3
 - general requirements, 7.2, 7.5.5.6, 7.7.1.3, 7.7.1.4, 7.7.1.5, 7.8
 - inspection, 7.5.5.6, 7.7.1.3, 7.7.1.4, 7.7.1.5, 7.8
 - length of studs, 7.2.1, Fig. 7.1
 - moisture, 7.4.1, 7.4.3, 7.4.4
 - operator qualification, 7.7.4
 - pre-production testing, 7.7.1
 - production control, 7.7
 - production welding, 7.7.2
 - repair, 7.7.3
 - removal, 7.7.5
 - rust, 7.4.1, 7.4.3
 - scale, 7.4.1, 7.4.3
 - shielded metal arc process, 7.5.5
 - stud base qualification, 7.2.4, 7.2.6, Annex VI: VI.3, VI.4
 - technique, 7.5
 - torque tests, 7.6.6.2, 7.8.1, Fig. 7.3
 - workmanship, 7.4
 - Submerged arc welding
 - diffusible hydrogen for, 12.6.6.1
 - drying (baking), 12.6.6.3
 - electrode diameter, 4.7.3
 - electrodes and fluxes, 4.7.1, 4.8, 12.6.2.2, 12.6.2.3, 12.6.6
 - flux handling, 12.6.6.3
 - flux reclamation, 4.8.4
 - general requirements, 4.7
 - hardness testing, 4.10.6, 4.10.6.2, 4.11.6, 4.11.6.2
 - heat input, 4.7.2
 - interpass temperature, 4.10.6, 4.10.6.2, 4.11.6.2
 - layer thickness, 4.10.3, 4.11.3
 - macroetch test specimens, 4.7.5, 4.10.6.1(1), 4.11.6.1(1)
 - maximum current, 4.7.3, 4.10.4.1, 4.11.4.1
 - multiple arcs, 4.7.1
 - multiple electrodes, 4.7.1, 4.11
 - definition, 4.11.1
 - hardness determination, 4.11.6.1
 - parallel electrodes, 4.7.1, 4.10, 5.19.3.2
 - definition, 4.10.1
 - hardness determination, 4.10.6.1
 - position, 4.10.2
 - reduction of preheat and interpass temperatures, 4.10.6
 - restriction on fillet welds, 4.10.6.2
 - tack weld requirements for, Table 12.2
 - weld layer thickness, 4.10.3
 - welding current limitations, 4.10.4.1, 4.10.5
 - with GMAW root pass, 4.10.5
 - position, 4.11.2
 - preheat, 4.10.6, 4.11.6
 - prequalified WPS, 4.9, 4.10, 4.11
 - reduction of preheat and interpass temperatures, 4.11.6
 - repair of FCMs, 12.5.1
 - restriction on fillet welds, 4.11.6.2
 - weld current limitations, 4.11.4.1
 - weld layer thickness, 4.11.3
 - with GMAW root pass, 4.11.5
 - sample joint, 4.10.6.1, 4.11.6.1
 - single electrodes, 4.9, 4.11.4.1, 5.19.3.2
 - definition, 4.9.1
 - tack welds, 4.7.8
 - WPS qualification, 5 Part A
 - essential variables, Tables 5.3, 5.4
 - Surface preparation, 3.2.1, 3.11
 - Surface roughness, 3.2.1, 3.6.3, 3.6.4, 12.13.3
 - Surface roughness guide, 3.2.2
- ## T
- Tack welder qualification, 5 Part B
 - eligibility, 5.22.4
 - fillet weld break test, 5.423.3, Figs. 5.14, 5.26, 5.27, 5.28
 - limitation of variables, 5.24
 - method of testing specimens, 5.26.3.3, Figs. 5.28, 5.29
 - period of effectiveness, 5.21.4
 - records, 5.21.7
 - test report form, Annex III
 - retests, 5.28.2
 - requirements, 12.13.1.2, Table 12.2
 - test results, 5.27
 - test specimens, 5.25.3, Figs. 5.28, 5.29
 - tests, 5.26.3.3
 - Tack welders, 5 Part B, 5.24.1, 6.4, Figs. 5.28, 5.29, 12.8.2
 - qualification variables, 5.24.4
 - Tack welds, 3.3.7, 9.24
 - designator requirements for, 12.6.2.2
 - discontinuities, 3.3.7.1(2)
 - in final weld, 3.3.7.2
 - location, 12.13.1.1
 - minimum temperatures, 4.2.1
 - multiple pass, 3.3.7.2
 - preheat, 3.3.7.1
 - interpass temperatures, Tables 12.3, 12.4, 12.5
 - quality, 3.3.7.1
 - removal, 3.3.7.3, 3.3.7.4, 12.13.3
 - size, 4.7.8
 - temporary, 12.13.2
 - Tacker, see Tack welder
 - Technical inquiries, vi, Annex D
 - Temporary welds, 9.20
 - Temperature variation, 4.4.2
 - Tensile strength, 12.4.4.1, 12.10
 - FCM not subject to, 12.2.2
 - weld removal, 12.13.3
 - Tension
 - components, 12.2.2
 - and repaired butt welds, 12.16.2.1
 - noncritical repair of butt welds, 12.17.2(2)
 - zone, 12.2.2.1
 - Tension members, 9.13, 12.2.2
 - acceptance, Annex A
 - repair, 3.2.3
 - retest, 5.20.1
 - splices, 9.13
 - stress, 9.21.2.1, 9.21.3.1, 9.21.3.1, Table 9.1
 - Tension specimens, Figs. 5.9, 5.10

Tension test, stud weld, 7.6.6.3
 Tension test fixture studs, Fig. 7.2
 Terms, 7.6.2
 Testing agency, 7.6.2, Annex VI: VI2
 Testing frequency, 5.3, 12.7.4
 Testing, magnetic particle, 12.10.2
 Test plates, welded
 heat treatment, 5.7.8
 procedure qualification, Figs. 5.1, 5.2, 5.3, 5.8
 tack welder qualification, Fig. 5.28
 thermal cutting, 9.18.2, 12.10
 welder qualification, Figs. 5.17, 5.18, 5.19, 5.20, 5.21, 5.22, 5.23
 welding operator qualification, 7.7.4, 12.8.2, Figs. 5.17 through 5.23
 Test results, 5.19, 5.27, 5.28.1, 12.6.1
 Testing procedures, S9.20
 Test specimens, 5.16, 5.25, 5.26, Table 5.5, Figs. 5.1, 5.2, 5.2, 5.6, 5.7, 5.8, and Figs. 5.14 through 5.28
 Tests in excess of code, 5.2.4
 Tests, welding variables, 4.24
 Test weld positions, 5.21
 Thermal cutting, 12.10, 12.11.2
 edge requirements (TCES), 12.10.1
 Throat cracks, Annex B: B2.12d
 T-joints, 9.7, 12.16.2.2
 Toe cracks, Annex B: B2.12e
 Tolerances
 alignment, 3.3.3, 3.5.1.8, 3.5.1.11
 bearing joints, 3.3.2.2
 camber, 3.5.1.3, Tables 3.2, 3.3
 dimensional, 2.9.2, 2.10.2, 3.3.4, 3.5, 9.19
 flatness, 3.5.1.5, 9.19
 offset, 3.5.1.5
 variation from straightness, 3.5.1.1
 warpage, 3.5.1.7
 Torque testing, 7.6.6.2, 7.8.3, Fig. 7.3
 Toughness, see weld metal toughness
 of base metal, 12.4.5, Table 12.1
 supplementary requirements, 12.4.5.1
 Transducer calibration, 6.21
 Transducer specifications, 6.15.6, 6.15.7
 Transitions of thickness or widths, 9.16, Figs. 9.2, 9.3
 Transverse cracks, Annex B: B2.12a

U

Ultrasonic testing, 6 Part C, 12.16.2.1, 12.16.2.2, 12.16.4
 acceptance criteria, 9.21.3, Tables 9.1, 9.2
 amplitude, Annex VII: VIIA1.2
 attenuation factor, 6.19.5.4
 base metal discontinuities, 6.13.4, 12.15.2.5
 calibration, 6.16, 6.17, 6.18, 6.21
 calibration for angle beams, 6.18.5,

Annex VII: VIIA2.2
 distance, 6.18.5.1
 horizontal sweep, 6.18.5.1
 zero reference level sensitivity, 6.18.5.2
 calibration for longitudinal mode, 6.21.1, Annex VII: VIIA2.2
 calibration for shear mode, 6.21.2, Annex VII: VIIA2
 amplitude calibration, 6.21.2.4, Annex VII: VIIA1.2
 distance calibration, 6.21.2.3, Annex VII: VIIA2.3
 resolution, 6.21.2.5
 sound entry point 6.21.2.1
 sound path angle, 6.21.2.2
 transducer positions, Fig. 6.5
 crossing patterns, 6.19.6.2
 calibration for straight beam, 6.18.4
 horizontal sweep, 6.18.2, 6.18.4.1, 6.18.5.1
 sensitivity, 6.18.4.2
 calibration for testing, 6.18
 angle beam, 6.15.7.7
 distance, 6.18.5.1
 horizontal sweep, 6.18.5.1
 zero reference level sensitivity, 6.18.5.2
 equipment, 6.15
 gain control, 6.15.4
 horizontal linearity, 6.15.2, 6.22.1
 search units
 angle beam, 6.15.7
 straight beam, 6.15.6
 equipment qualification, 6.17
 calibration block, 6.17.4
 certification, 6.17.3
 dB accuracy, 6.22.2
 gain control, 6.17.2
 horizontal linearity, 6.17.1, Annex VII: VIIA3
 internal reflections, 6.22.3
 examples, 6.25
 extent of testing, 6.14
 flaw length determination, 6.19.7
 flaw size evaluation procedures, 6.23, 6.25.2
 angle beam testing, 6.23.2
 straight beam testing, 6.23.1
 indication length, 6.19.7
 indication rating, 6.19.6.3, 6.19.6.5
 laminar reflector, 6.19.5.1
 longitudinal mode calibration, 6.21.1
 nomograph, Annex VII: Fig. VII-10
 operator requirements, 6.14.2
 personnel qualification, 6.7
 procedures, equipment qualification, 6.22, Annex VII
 horizontal linearity, 6.22.1, Annex VII: VIIA.3
 internal reflectors, 6.22.3

 vertical linearity, 6.22.2.1
 procedures, flaw size evaluation, 6.23
 angle beam testing, 6.23.2
 straight beam testing, 6.23.1
 radiographic supplement, 6.13.3
 reference blocks IIW, 6.15.7.7, 6.16, 6.16.1, Figs. 6.4A, 6.4B
 other approved blocks, 6.16.1, Fig. 6.4B
 repairs, 6.19.10
 report forms, Annex III, Annex VII
 information on, 6.19.6.3, 6.19.6.4, 6.19.6.5, 6.20.1
 reports, 6.19.6.4, 6.19.6.5, 6.19.9, 6.20
 disposition, 6.20.3
 examples forms, 6.25
 examples of, 6.25.1, 6.25.2
 reporting repairs, 6.19.9, 6.19.9.1
 requirements, 6.7.1.2
 scanning patterns, 6.24, Fig. 6.6
 electroslag and electrogas welds, 6.24.3
 longitudinal discontinuities, 6.24.1
 transverse discontinuities, 6.24.2
 search units
 amplitude, 6.21.2.4
 angle beam, 6.15.7, 6.19.6, 6.23.2
 dimensions, 6.15.6, 6.15.7.6
 distance calibration, 6.21.2.3
 resolution, 6.21.2.5
 sensitivity, 6.21.2.4
 shear wave mode, 6.21.2
 sound entry point, 6.21.2.1
 sound path angle, 6.22.2.2
 straight beam, 6.16.6, 6.19.5, 6.23.1
 testing procedure, 6.19, Table 6.2
 cleanliness of surfaces, 6.19.3
 couplant materials, 6.19.4
 flaw length, 6.19.7
 testing repair welds, 6.19.9.1
 thickness limitations, 6.13.1
 transducer size, 6.15.6, 6.15.7.2
 weld identification, 6.19.1, 6.19.2
 underbead cracking, 9 Part D, S9.25, Annex B: B2.12g
 undercut, 3.3.7.1, 3.7.2.2, 4.9.4, 5.27.4.1, 5.28.5, 9.21.1.5, Annex B: B2.5, Fig. 3.3
 underfill, Annex B: B2.6
 Undercut, repair of weld, 12.17.2
 Unlisted base metal, 8.2.3.3

V

Verification inspection, 6.1.1
 Verification test
 definition, 5.7.3
 procedure test, Figs. 5.1, 5.2

Vertical position welding
 prequalified, 4.6.8, 4.14.1.7
 restrictions on, 4.6.8, 4.14.1.7, 5.8.2.3, 5.24.2.2
 Visual inspection, 3.2.3, 5.19.6, 5.27.1, 6.5.5, 6.6.2, 7.5.5.6, 7.7.1.3, 7.7.1.5, 7.8.1, 9.21.1, 12.16.4, 12.16.5.1
 Voltage, maximum, 4.7.3, 5.12.1.4

W

Warpage, 3.4, 3.5.1.7
 Web flatness, Annex IV
 Web-to-flange welds, 9.21.3.3
 Weldability investigation, 9.2.3.1, 9 Part D, S9.22, S9.23
 Weldable steels, S9.28
 Weld cleaning, 3.11, 5.21.5
 completed welds, 3.11.2
 in-process cleaning, 3.11.1
 use of manual hammers, 3.8.2
 use of lightweight vibrating tools, 3.8.2
 Welded joint details, see joints
 Welder qualification, 5 Part B, 5.24.2
 fillet weld tests, 5.23.1.4, 5.27.4, Figs. 5.4, 5.7, 5.8, 5.21, 5.22
 groove weld tests, 5.23, 5.23.1.2, 5.23.1.3
 limitation of variables, 5.24.2
 limited thickness, 5.23.1.3
 method of testing, 5.26
 period of effectiveness, 5.21.4
 plug welding tests, 5.23.1.5, 5.26.3.4, Fig. 5.23
 position, 5.8.1, 5.22.1
 preparation, 5.23.1.5
 records, 5.21.7
 retest, 5.28.1
 semiautomatic, 5.24.3.4
 test plates, see most Figs. in 5, fillet welds, Figs. 5.4, 5.7, 5.21, 5.26
 groove welds, Figs. 5.5, 5.6
 macroetch, Figs. 5.8, 5.23, 5.26
 test results, 5.19, 5.27
 bend tests, 5.27.3
 fillet weld break tests, 5.26.3.1, Figs. 5.21, 5.26, 5.27, 5.28
 macroetch test, 5.26.3.4, Figs. 5.8, 5.23, 5.26
 radiographic test, 5.26.1.2
 visual, 5.27.3, 5.27.6
 test specimens, 5.25
 Welders, 3.1.2, 5 Part B, 5.24.1, 6.4, 12.8.2
 Welding
 at low temperatures, 3.1.3, 4.2, 7.5.4
 designator requirements for, 12.6.2.3
 equipment, 3.1.2, 4.26.1, 6.3
 processes, 12.5
 progression, 3.4.2, 4.6.8, 4.14.1.7
 restrictions, 12.5.2, 12.5.3
 sequence, 3.4.2
 test plate thickness, 5.6, Table 5.2, Figs. 5.17, 5.18, 5.19, 5.20, 5.24
 Welding consumables, 5.5, Table 5.1,
 Welding operators, 5 Part B, 5.24.1.3, 5.21.4, 6.4, 7.7.4, 12.8.2
 Welding operator qualification, 5 Part B, 5.23.2, 7.7.4, Figs. 5.17, 5.18, 5.19, 5.20, 5.21
 electroslog/electrogas weld tests, 5.23.3.1, 5.23.2.2
 fillet weld tests, 5.4.2, 5.23.2.4, 5.27.4, Figs. 5.7, 5.8, 5.22
 groove weld tests, 5.23.2.1, Figs. 5.5, 5.6
 limitations of variables, 5.24, Fig. 5.6
 method of testing, 5.26
 period of effectiveness, 5.21.4
 plate weld tests, Figs. 5.17, 5.18
 preparation of test specimens, 5.25
 retests, 5.28.1
 stud welds, 7.7.4
 test report form, Annex III
 test results required, 5.27
 bend tests, 5.27.3
 fillet weld break tests, 5.26.3.2, Fig. 5.21
 macroetch tests, 5.26.3.4, Figs. 5.21, 5.23
 radiographic tests, 5.26.1.3
 visual, 5.27.1
 test specimens, 5.26, Table 5.5
 Welding procedure specification (WPS), 5 Part A, 5.21.2, 9 Part D, S9.27, 12.3.3.1, 12.17.1, Tables 5.3, 5.4, Figs. 5.1, 5.2
 contractor requirements for, 12.8
 qualification for
 fillet welds, 12.7.3
 groove welds, 12.7.2
 previous, 12.7.5
 SMAW, 12.7.1
 period of effectiveness, 12.7.4
 requalification, 12.8.2
 sample forms, Annex III
 Welding sequences, 3.4.2
 Welding symbols, 1.5
 Weld inspection, 6, 12.16
 inspectors, 12.16.1.1
 NDT technicians, 12.16.1.2
 Quality Assurance/Quality Control, 12.16.1, 12.16.1.1
 Weld metal removal, 3.7.6, 12.13.3
 Weld metal strength, 12.6.3, 12.11.4
 heat treatment, 12.15.2.5
 requirements of, Tables 4.1, 4.2
 toughness of, Table 12.1
 Weld metal toughness
 for groove welds, 12.6.4.1
 requirements, 12.6.4
 testing, 12.15.2.5

Weld profiles, 3.6.1, 3.6.2, 3.6.3, Fig. 3.6

Welds

acceptability, 9.21
 accessibility, 3.7.6
 cleaning, 3.11
 inspection, 12.16.5
 multiple pass, 3.3.7, 4.6.7, 4.9.3, 4.11.3, 4.14.1.4 through 4.14.1.7, 5.10.3(1)
 NDT requirements for, 12.16.2
 painting, 3.11.2
 profiles, 3.6, 9.21.1.4
 quality, 9.21
 record keeping of, 12.16.5
 soundness, Fig. 5.3
 surfaces, 3.6.3
 removal, 12.13.3, 12.17
 tack, 3.3.7
 temporary, 9.20, 12.17.6(7)
 to FCMs, 12.2.2.2
 termination, 3.12
 yield strength, undermatching, 12.6.4.2
 Weld spatter, removal of, 3.11.2
 Weld tabs, 3.12.1, 3.12.2, 6.10.3.1
 Wind velocity, 3.1.3, 4.14.3, 4.20.2
 Workmanship, 3, 3.7.1, 7.4, 9 Part C
 alignment, 3.3
 bridges, see Bridges
 control of distortion and shrinkage, 3.4, 3.7.3
 general requirements, 3
 inspection, 6.4.2, 6.5.4, 6.5.5, 7.8.6
 repairs, 3.7
 tolerances, 3.5, 9.19
 visual inspection, 3.2.3, 6.5.5, 7.5.5.6, 9.21.1
 weld profiles, 3.6, 9.21.1.4
 WPS, see Welding procedure specification
 WPS qualification, 5 Part A, 9 Part D (S9.27)
 limitation of variables, 5.5.2, 5.13, pretest, Figs. 5.1, 5.2
 records, 5.2.4
 results required, 5.19
 retests, 5.20
 tests, 5.12, 5.12.1.1, 5.13.3, 5.15
 test weld positions, 5.8

Y

Yield strength, 12.17.6
 for cooling times of welds, 12.16.4
 for flux cored arc welding, 12.6.7.1
 for groove welds, 12.6.4.1
 for shielded metal arc welding, 12.6.5.8
 for submerged arc welding, 12.6.6.1
 undermatching, 12.6.4.2
 Yoke method, of magnetic-particle testing, 12.10.2

~

~

~

