

# Bridge Welding Code

A Joint Publication of

AMERICAN ASSOCIATION  
OF STATE HIGHWAY AND  
TRANSPORTATION OFFICIALS

**AASHTO**



**American Welding Society®**



**Documents**

Document Sharing Hub

**AASHTO/AWS D1.5M/D1.5:2020**  
**An American National Standard**

**Approved by the**  
**American National Standards Institute**  
**April 24th, 2020**

# **Bridge Welding Code**

**8th Edition**

**Revises AASHTO/AWS D1.5M/D1.5:2015**

Prepared by the  
American Welding Society (AWS) D1 Committee on Structural Welding  
AASHTO Highway Subcommittee on Bridges and Structures

Under the Direction of the  
AWS Technical Activities Committee  
AASHTO Executive Committee

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

## **Abstract**

This code covers the welding requirements for welded bridges made from carbon and low-alloy constructional steels and designed to AASHTO or AREMA requirements. This 2020 edition contains dimensions in metric SI Units and U.S. Customary Units. Clauses 1 through 9 constitute a body of rules for the regulation of welding in steel construction. Clauses 10 and 11 do not contain provisions, as their analogue D1.1 sections are not applicable to the D1.5 code. Clause 14 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, DC 20001

**American Welding Society**  
8669 NW 36 St, # 130  
Miami, FL 33166

ISBN-Web: 978-1-64322-140-3

ISBN-Print: 978-1-64322-139-7

© 2020 by American Welding Society

All rights reserved

Printed in the United States of America

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

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

## Statement on the Use of American Welding Society Standards

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

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

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

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

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

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

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

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

This standard is subject to revision at any time by the AWS D1 Committee on Structural Welding. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D1 Committee on Structural Welding and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D1 Committee on Structural Welding to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

This page is intentionally blank.

# Personnel

## AWS D1 Committee on Structural Welding

|                               |                                                               |
|-------------------------------|---------------------------------------------------------------|
| A. W. Sindel, Chair           | <i>TRC Solutions</i>                                          |
| T. L. Niemann, Vice Chair     | <i>Fickett Structural Solutions, LLC</i>                      |
| R. D. Medlock, 2nd Vice Chair | <i>High Steel Structures, LLC</i>                             |
| J. Molin, Secretary           | <i>American Welding Society</i>                               |
| U. W. Aschemeier              | <i>Subsea Global Solutions</i>                                |
| E. L. Bickford                | <i>IISI</i>                                                   |
| T. W. Burns                   | <i>Thom Burns Consulting, LLC</i>                             |
| H. H. Campbell III            | <i>Pazazu Engineering</i>                                     |
| R. D. Campbell                | <i>Bechtel</i>                                                |
| B. Connelly                   | <i>Eustis Engineering, LLC</i>                                |
| R. B. Corbit                  | <i>APTIM (Retired)</i>                                        |
| M. E. Gase                    | <i>Midwest Steel, Incorporated</i>                            |
| M. A. Grieco                  | <i>MA Department of Transportation</i>                        |
| J. J. Kenney                  | <i>Shell International E &amp; P</i>                          |
| J. H. Kiefer                  | <i>ConocoPhillips (Retired)</i>                               |
| J. R. Kissell                 | <i>Trinity Consultants</i>                                    |
| B. Krueger                    | <i>Los Alamos National Laboratory</i>                         |
| V. Kuruvilla                  | <i>Lexicon, Incorporated</i>                                  |
| J. Lawmon                     | <i>American Engineering &amp; Manufacturing, Incorporated</i> |
| N. S. Lindell                 | <i>Project &amp; Quality Solutions</i>                        |
| D. R. Luciani                 | <i>Canadian Welding Bureau</i>                                |
| P. W. Marshall                | <i>Moonshine Hill Proprietary Systems Engineering</i>         |
| M. J. Mayes                   | <i>Terracon Consultants</i>                                   |
| D. L. McQuaid                 | <i>D. L. McQuaid and Associates, Incorporated</i>             |
| J. Merrill                    | <i>TRC Solutions</i>                                          |
| D. K. Miller                  | <i>The Lincoln Electric Company</i>                           |
| J. B. Pearson, Jr.            | <i>ALRV Consultant, LLC</i>                                   |
| D. D. Rager                   | <i>Rager Consulting, Incorporated</i>                         |
| T. J. Schlafly                | <i>American Institute of Steel Construction</i>               |
| R. E. Shaw, Jr.               | <i>Steel Structures Technology Center, Incorporated</i>       |
| M. M. Tayarani                | <i>Pennoni Associates, Incorporated</i>                       |
| P. Torchio, III               | <i>Williams Enterprises of GA, Incorporated (Retired)</i>     |

## Advisors to the D1 Committee on Structural Welding

|                  |                                               |
|------------------|-----------------------------------------------|
| N. J. Altebrando | <i>STV, Incorporated</i>                      |
| F. G. Armao      | <i>The Lincoln Electric Company</i>           |
| G. L. Fox        | <i>Consultant</i>                             |
| H. E. Gilmer     | <i>TUV</i>                                    |
| G. J. Hill       | <i>G. J. Hill &amp; Associates</i>            |
| M. L. Hoitomt    | <i>Consultant</i>                             |
| C. W. Holmes     | <i>Modjeski &amp; Masters, Inc. (Retired)</i> |
| P. G. Kinney     | <i>Sandia National Laboratories</i>           |
| G. S. Martin     | <i>Retired</i>                                |

### **Advisors to the D1 Committee on Structural Welding (Continued)**

|                |                                                |
|----------------|------------------------------------------------|
| J. W. Post     | <i>J. W. Post and Associates, Incorporated</i> |
| D. C. Phillips | <i>Retired</i>                                 |
| R. W. Stieve   | <i>Parsons Corporation</i>                     |
| K. K. Verma    | <i>Consultant</i>                              |

### **AASHTO Technical Committee for Metals Fabrication**

|                          |                                                   |
|--------------------------|---------------------------------------------------|
| A K. Bardow, Chair       | <i>Massachusetts Department of Transportation</i> |
| J. M. Walker, Vice Chair | <i>Mississippi Department of Transportation</i>   |
| X. H. Cheng              | <i>New Jersey Department of Transportation</i>    |
| L. Daugherty             | <i>Alaska Department of Transportation</i>        |
| J. F. Farris             | <i>Texas Department of Transportation</i>         |
| S. J. Jacobi             | <i>Oklahoma Department of Transportation</i>      |
| J. M. Ocel               | <i>Federal Highway Administration</i>             |
| A. N. Mongi              | <i>West Virginia Department of Transportation</i> |
| P. W. Sauser             | <i>US Army Corps of Engineers</i>                 |

### **Joint AASHTO/AWS Bridge Welding Subcommittee**

|                        |                                                |
|------------------------|------------------------------------------------|
| R. D. Medlock, Chair   | <i>High Steel Structures, LLC</i>              |
| N. M. Choy, Vice Chair | <i>California Department of Transportation</i> |
| P. Portela, Secretary  | <i>American Welding Society</i>                |

### **AASHTO Representatives**

|                   |                                                        |
|-------------------|--------------------------------------------------------|
| N. M. Choy        | <i>California Department of Transportation</i>         |
| M. A. Grieco      | <i>Massachusetts Department of Transportation</i>      |
| T. McCullough     | <i>Florida Department of Transportation</i>            |
| T. L. Niemann     | <i>Retired, Minnesota Department of Transportation</i> |
| R. J. Ringstmeyer | <i>Wyoming Department of Transportation</i>            |

### **AWS Representatives**

|               |                                                   |
|---------------|---------------------------------------------------|
| K. H. Frank   | <i>NSBA</i>                                       |
| B. Harris     | <i>W&amp;W AFCO Steel – AFCO Division</i>         |
| N. S. Lindell | <i>Project Quality Solutions</i>                  |
| D. L. McQuaid | <i>D. L. McQuaid and Associates, Incorporated</i> |
| R. D. Medlock | <i>High Steel Structures, LLC</i>                 |
| R. L. Mertz   | <i>HDR</i>                                        |

### **General Interest Representatives**

|               |                                                              |
|---------------|--------------------------------------------------------------|
| J. J. Edwards | <i>Department of Transportation Quality Services</i>         |
| H. E. Gilmer  | <i>TUV</i>                                                   |
| P. Huckabee   | <i>Gill Engineering Associates, Incorporated</i>             |
| D. K. Miller  | <i>The Lincoln Electric Company</i>                          |
| T. E. Rogers  | <i>Modjeski &amp; Masters</i>                                |
| R. Stachel    | <i>HRV—Conformance Verification Associates, Incorporated</i> |

**Advisors to the Joint AASHTO/AWS Bridge Welding Subcommittee**

|                  |                                                  |
|------------------|--------------------------------------------------|
| S. Anderson      | <i>Intermech, Incorporated</i>                   |
| N. J. Altebrando | <i>STV, Incorporated</i>                         |
| S. M. Duke       | <i>Florida Department of Transportation</i>      |
| C. Hanson        | <i>ADF Group, Incorporated</i>                   |
| C. W. Holmes     | <i>Modjeski and Masters, Incorporated</i>        |
| B. P. Horn       | <i>Consultant</i>                                |
| D. M. Ison       | <i>Tampa Tank— Florida Structural Steel</i>      |
| W. M. Kavicky    | <i>Trans Bay Steel Corporation</i>               |
| S. W. Kopp       | <i>High Steel Structures, LLC</i>                |
| K. Ledford       | <i>Georgia Department of Transportation</i>      |
| J. Mellinger     | <i>Pennoni Associates, Incorporated</i>          |
| J. Merrill       | <i>AMEC E&amp;I</i>                              |
| K. Nelson        | <i>Missouri Department of Transportation</i>     |
| J. M. Ocel       | <i>Federal Highway Administration</i>            |
| D. C. Phillips   | <i>Retired</i>                                   |
| D. D. Rager      | <i>Rager Consulting, Incorporated</i>            |
| P. Rimmer        | <i>Greenman Pedersen, Incorporated</i>           |
| B. Roberds       | <i>Consultant</i>                                |
| N. Shrawder      | <i>Pennsylvania Department of Transportation</i> |
| T. J. Schlafly   | <i>American Institute of Steel Construction</i>  |
| R. W. Stieve     | <i>Retired</i>                                   |
| M. M. Tayarani   | <i>Pennoni Associates, Incorporated</i>          |

This page is intentionally blank.

# Foreword

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

The original preparation of this specification was undertaken in response to a need for a common welding specification for the fabrication of steel highway bridges across the country. Prior to its publication, the departments of highways and transportation that make up the American Association of State Highway and Transportation Officials (AASHTO) had routinely used other specifications of the American Welding Society (AWS) Structural Welding Committee, with various unique modifications, to produce contract documents suitable for the construction of bridges. The proliferation of disparate requirements resulted in the need for a single specification that could facilitate uniformity and improved economy in steel 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 CVN testing, and a further Circular Memorandum, dated August 19, 1966, modified provisions of the 1966 Edition of AWS D2.0-66, *Specification for Welded Highway and Railway Bridges*.

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 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 AWS D1.1. The *Bridge Welding Code* is the result of an agreement between AASHTO and AWS to produce a joint AASHTO/AWS *Bridge Welding Code* for steel bridges that addresses essential AASHTO needs and makes AASHTO revisions mandatory.

The first edition of the *Bridge Welding Code*, published in 1988, provided for the qualification of welding procedures by test to assure that welds have 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 HAZs 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.

**Changes in Code Requirements.** Underlined text in the clauses, subclauses, tables, figures, or forms indicates a change from the 2015 edition. A vertical line in the margin of a table or figure also indicates a change from the 2015 edition.

The publication of AASHTO/AWS D1.5M/D1.5:2020 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 most significant revisions in the 2020 edition:

| Summary of Changes        |                                                                                                                                                                                                                                                                                                                                                            |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Clause/Table/Figure/Annex | Modification                                                                                                                                                                                                                                                                                                                                               |
| Clause 1                  | Revisions were made to the approved base metals and grades.                                                                                                                                                                                                                                                                                                |
| Clause 2                  | This is a new clause listing normative references. It replaces Annex P from the previous edition.                                                                                                                                                                                                                                                          |
| Clause 3                  | This is a new clause that provides terms and definitions specific to this standard. It replaces Annex D from the previous edition. New definitions were added.                                                                                                                                                                                             |
| Clause 4                  | Clause 4 was presented as Clause 2 in the previous edition. Revisions were made to the symbols (S) and (E) for alignment with AWS A2.4.                                                                                                                                                                                                                    |
| Clause 5                  | Clause 5 was presented as Clause 3 in the previous edition. Revisions were made to base metal cleanliness, tack welds, chipping and brushing language, assembly, and dimensional tolerances. Instances of “grind” or “mill” were changed to “finish”.                                                                                                      |
| Clause 6                  | Clause 6 was presented as Clause 4 in the previous edition. Revisions were made to FC provisions. Instances of “grind” or “mill” were changed to “finish”.                                                                                                                                                                                                 |
| Clause 7                  | Clause 7 was presented as Clause 5 in the previous edition. Revisions were made to the renaming of electrodes, and mismatch qualification. New tables, 7.1 and 7.2, were added.                                                                                                                                                                            |
| Clause 8                  | Clause 8 was presented as Clause 6 in the previous edition. Revisions were made to nondestructive testing, flaw and discontinuity language, digital radiography, and QA/QC language. Instances of “grind” or “mill” were changed to “finish”. New table, 8.1 was added. Table 8.3 was updated for backgouging. Clause 8 from the 2015 edition was deleted. |
| Clause 9                  | Clause 9 was presented as Clause 7 in the previous edition. Revisions were made to failed stud repairs. Clause 9 from the 2015 edition was deleted.                                                                                                                                                                                                        |
| Clause 10                 | No changes were made to Clause 10.                                                                                                                                                                                                                                                                                                                         |
| Clause 11                 | No changes were made to Clause 11.                                                                                                                                                                                                                                                                                                                         |
| Clause 12                 | Revisions were made to sole plates and fracture critical criteria. New table, 12.2, was added.                                                                                                                                                                                                                                                             |
| Annex A                   |                                                                                                                                                                                                                                                                                                                                                            |
| Annex B                   |                                                                                                                                                                                                                                                                                                                                                            |
| Annex C                   |                                                                                                                                                                                                                                                                                                                                                            |
| Annex D                   | Annex D was presented as Annex E in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex E                   | Annex E was presented as Annex F in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex F                   | Annex F was presented as Annex G in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex G                   | Annex G was presented as Annex H in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex H                   | Annex H was presented as Annex I in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex I                   | Annex I was presented as Annex J in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex J                   | Annex J was presented as Annex K in the previous edition. Revisions were made to flaw and discontinuity language, personnel requirements, and the testing of welds.                                                                                                                                                                                        |
| Annex K                   | Annex K was presented as Annex L in the previous edition.                                                                                                                                                                                                                                                                                                  |
| Annex L                   | Annex L was presented as Annex M in the previous edition. Revisions were made to flaw and discontinuity language.                                                                                                                                                                                                                                          |
| Annex M                   | Annex M was presented as Annex N in the previous edition.                                                                                                                                                                                                                                                                                                  |

(Continued)

### Summary of Changes (Continued)

| Clause/Table/Figure/Annex | Modification                                                                                                                                             |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Annex N                   | Annex N was presented as Annex O in the previous edition.                                                                                                |
| Annex O                   | Annex O was presented as Annex Q in the previous edition. Annex P from the previous edition was deleted.                                                 |
| Annex P                   | Annex P was presented as Annex R in the previous edition.                                                                                                |
| Commentary                | Revisions were made to numbering due to the movement of clauses and annexes, addition of text, deletion of text, and addition of new tables and figures. |

**Commentary.** The Commentary is nonmandatory and is intended only to provide insightful information into provision rationale.

**Normative Annexes.** These annexes address specific subjects in the code and their requirements are mandatory requirements that supplement the code provisions.

**Informative Annexes.** These annexes are not code requirements but are provided to clarify code provisions by showing examples, providing information, or suggesting alternative good practices.

**Index.** As in previous codes, the entries in the Index are referred to by subclause number rather than by page number. This should enable the user of the Index to locate a particular item of interest in minimum time.

**Errata.** It is the Structural Welding Committee's Policy that all errata should be made available to users of the code. Therefore, any significant errata will be published in the Society News Section of the *Welding Journal* and posted on the AWS web site at: <http://www.aws.org/technical/d1/>.

**Suggestions.** Your comments for improving AWS D1.5M/D1.5:2015, *Bridge Welding Code* are welcome. Submit comments to the Managing Director, Standards Development Division, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166; telephone (305) 443-9353; fax (305) 443-5951; e-mail [info@aws.org](mailto:info@aws.org); or via the AWS web site <<http://www.aws.org>>.

This page is intentionally blank.

# Table of Contents

|                                                             | Page No. |
|-------------------------------------------------------------|----------|
| <i>Personnel</i> .....                                      | v        |
| <i>Foreword</i> .....                                       | ix       |
| <i>List of Tables</i> .....                                 | xviii    |
| <i>List of Figures</i> .....                                | xix      |
| <i>List of Forms</i> .....                                  | xxi      |
| <b>1. General Provisions</b> .....                          | 1        |
| 1.1 Application .....                                       | 1        |
| 1.2 Base Metal .....                                        | 1        |
| 1.3 Welding Processes .....                                 | 2        |
| 1.4 Fabricator Requirements .....                           | 3        |
| 1.5 Definitions .....                                       | 3        |
| 1.6 Welding Symbols .....                                   | 3        |
| 1.7 Safety Precautions .....                                | 3        |
| 1.8 Standard Units of Measurement .....                     | 3        |
| 1.9 Welding Procedure Specifications (WPSs) .....           | 3        |
| 1.10 Mechanical Testing .....                               | 4        |
| 1.11 Reference Documents .....                              | 4        |
| <b>2. Normative References</b> .....                        | 5        |
| <b>3. Terms and Definitions</b> .....                       | 8        |
| <b>4. Design of Welded Connections</b> .....                | 17       |
| <i>Part A—General Requirements</i> .....                    | 17       |
| 4.1 Drawings .....                                          | 17       |
| 4.2 Basic Unit Stresses .....                               | 18       |
| 4.3 Effective Weld Areas, Lengths, Throats, and Sizes ..... | 18       |
| <i>Part B—Structural Details</i> .....                      | 19       |
| 4.4 General .....                                           | 19       |
| 4.5 Welded Filler Plates .....                              | 19       |
| 4.6 PJP Groove Welds .....                                  | 19       |
| <i>Part C—Details of Welded Joints</i> .....                | 19       |
| 4.7 Joint Qualification .....                               | 19       |
| 4.8 Details of Fillet Welds .....                           | 19       |
| 4.9 Details of Plug and Slot Welds .....                    | 20       |
| 4.10 Lap Joints .....                                       | 20       |
| 4.11 Corner and T-Joints .....                              | 21       |
| 4.12 CJP Groove Welds .....                                 | 21       |
| 4.13 PJP Groove Welds .....                                 | 21       |
| 4.14 Prohibited Types of Joints and Welds .....             | 21       |
| 4.15 Combinations of Welds .....                            | 22       |
| 4.16 Welds in Combination with Rivets and Bolts .....       | 22       |
| 4.17 Connection Details .....                               | 22       |

|             |                                                                              |    |
|-------------|------------------------------------------------------------------------------|----|
| <b>5.</b>   | <b>Workmanship</b>                                                           | 63 |
| <u>5.1</u>  | General Requirements                                                         | 63 |
| <u>5.2</u>  | Preparation of Base Metal                                                    | 63 |
| <u>5.3</u>  | Assembly                                                                     | 67 |
| <u>5.4</u>  | Control of Distortion and Shrinkage                                          | 69 |
| <u>5.5</u>  | Dimensional Tolerances                                                       | 70 |
| <u>5.6</u>  | Weld Profiles                                                                | 73 |
| <u>5.7</u>  | Repairs                                                                      | 73 |
| <u>5.8</u>  | Peening                                                                      | 75 |
| <u>5.9</u>  | Caulking                                                                     | 75 |
| <u>5.10</u> | Arc Strikes                                                                  | 75 |
| <u>5.11</u> | Weld Cleaning                                                                | 75 |
| <u>5.12</u> | Weld Termination                                                             | 75 |
| <u>5.13</u> | Weld Backing                                                                 | 76 |
| <b>6.</b>   | <b>Technique</b>                                                             | 81 |
|             | <i>Part A—General Requirements</i>                                           | 81 |
| <u>6.1</u>  | Filler Metal Requirements                                                    | 81 |
| <u>6.2</u>  | Preheat and Interpass Temperature Requirements                               | 83 |
| <u>6.3</u>  | Heat Input Control for Grade <u>HPS</u> 690W [ <u>HPS</u> 100W] Steel        | 84 |
| <u>6.4</u>  | Stress Relief Heat Treatment                                                 | 84 |
|             | <i>Part B—Shielded Metal Arc Welding (SMAW)</i>                              | 84 |
| <u>6.5</u>  | Electrodes for SMAW                                                          | 84 |
| <u>6.6</u>  | Procedures for SMAW                                                          | 85 |
|             | <i>Part C—Submerged Arc Welding (SAW)</i>                                    | 86 |
| <u>6.7</u>  | General Requirements                                                         | 86 |
| <u>6.8</u>  | Electrodes and Fluxes for SAW                                                | 86 |
| <u>6.9</u>  | Procedures for SAW with a Single Electrode                                   | 87 |
| <u>6.10</u> | Procedures for SAW with <u>Parallel and</u> Multiple Electrodes              | 87 |
|             | <i>Part D—Gas Metal Arc Welding (GMAW) and Flux Cored Arc Welding (FCAW)</i> | 88 |
| <u>6.11</u> | <u>GMAW/FCAW</u> Electrodes                                                  | 88 |
| <u>6.12</u> | Shielding Gas                                                                | 88 |
| <u>6.13</u> | Procedures for GMAW and FCAW with a Single Electrode                         | 88 |
|             | <i>Part E—Electrogas Welding (EGW)</i>                                       | 89 |
| <u>6.14</u> | Qualification of Process, WPSs, and Joint Details                            | 89 |
| <u>6.15</u> | Condition of Electrodes and Guide Tubes                                      | 89 |
| <u>6.16</u> | Shielding Gas                                                                | 89 |
| <u>6.17</u> | Procedures for EGW                                                           | 89 |
|             | <i>Part F—Electroslag Welding (ESW)</i>                                      | 90 |
| <u>6.18</u> | Qualification of Process, WPSs, and Joint Details                            | 90 |
| <u>6.19</u> | Condition of Electrodes and Consumable Guides                                | 90 |
| <u>6.20</u> | Condition of Flux                                                            | 91 |
| <u>6.21</u> | Consumable Guide Electrical Insulators                                       | 91 |
| <u>6.22</u> | Procedures for ESW                                                           | 91 |
|             | <i>Part G—Plug and Slot Welds</i>                                            | 93 |
| <u>6.23</u> | Plug Welds                                                                   | 93 |
| <u>6.24</u> | Slot Welds                                                                   | 93 |
| <u>6.25</u> | Plug and Slot Welds                                                          | 93 |
|             | <i>Part H—Control of Production Welding Variables</i>                        | 93 |
| <u>6.26</u> | Tests                                                                        | 93 |
| <u>6.27</u> | Control of Variables                                                         | 93 |

|           |                                                                        |            |
|-----------|------------------------------------------------------------------------|------------|
| 6.28      | Calibration of Equipment                                               | 93         |
| 6.29      | Current Control                                                        | 94         |
| <b>7.</b> | <b>Qualification</b>                                                   | <b>100</b> |
| 7.0       | Scope                                                                  | 100        |
|           | <i>Part A—Welding Procedure Specification (WPS) Qualification</i>      | 100        |
| 7.1       | Approval                                                               | 100        |
| 7.2       | Qualification Responsibility                                           | 100        |
| 7.3       | Duration                                                               | 100        |
| 7.4       | Base Metal                                                             | 101        |
| 7.5       | Welding Consumables                                                    | 102        |
| 7.6       | Test Plate Thickness                                                   | 102        |
| 7.7       | General Requirements for WPS Qualification                             | 102        |
| 7.8       | Position of Test Welds                                                 | 103        |
| 7.9       | Options for WPS Qualification or Prequalification                      | 103        |
| 7.10      | Fillet Weld WPS Qualification                                          | 104        |
| 7.11      | Prequalified WPS                                                       | 104        |
| 7.12      | Heat Input Qualifications                                              | 104        |
| 7.13      | Electrode Gas Welding                                                  | 106        |
| 7.14      | Electroslag Welding                                                    | 106        |
| 7.15      | Type of Tests and Purpose                                              | 107        |
| 7.16      | Weld Specimens—Number, Type, and Preparation                           | 107        |
| 7.17      | Nondestructive Testing (NDT)                                           | 108        |
| 7.18      | Method of Testing Specimens                                            | 108        |
| 7.19      | Test Results Required                                                  | 108        |
| 7.20      | Retests                                                                | 109        |
|           | <i>Part B—Welder, Welding Operator, and Tack Welder Qualification</i>  | 110        |
| 7.21      | General Requirements                                                   | 110        |
| 7.22      | Production Welding Positions Qualified                                 | 111        |
| 7.23      | Qualification Tests Required                                           | 111        |
| 7.24      | Limitations of Variables                                               | 112        |
| 7.25      | Test Specimens: Number, Type, and Preparation                          | 113        |
| 7.26      | Method of Testing Specimens                                            | 113        |
| 7.27      | Test Results Required                                                  | 114        |
| 7.28      | Retests                                                                | 115        |
| <b>8.</b> | <b>Inspection</b>                                                      | <b>151</b> |
|           | <i>Part A—General Requirements</i>                                     | 151        |
| 8.1       | General                                                                | 152        |
| 8.2       | Inspection of Materials                                                | 152        |
| 8.3       | Inspection of WPS Qualification and Equipment                          | 152        |
| 8.4       | Inspection of Welder, Welding Operator, and Tack Welder Qualifications | 152        |
| 8.5       | Inspection of Work and Records                                         | 153        |
| 8.6       | Obligations of the Contractor                                          | 153        |
| 8.7       | Nondestructive Testing (NDT)                                           | 154        |
|           | <i>Part B—Radiographic Testing (RT) of Groove Welds in Butt Joints</i> | 156        |
| 8.8       | Extent of Testing                                                      | 156        |
| 8.9       | General                                                                | 156        |
| 8.10      | RT Procedure                                                           | 156        |
| 8.11      | Acceptability of Welds                                                 | 159        |
| 8.12      | Examination, Report, and Disposition of Radiographs                    | 159        |
|           | <i>Part C—Ultrasonic Testing (UT) of Groove Welds</i>                  | 160        |
| 8.13      | General                                                                | 160        |

|            |                                                                                                                 |     |
|------------|-----------------------------------------------------------------------------------------------------------------|-----|
| 8.14       | Extent of Testing                                                                                               | 160 |
| 8.15       | UT Equipment                                                                                                    | 160 |
| 8.16       | Reference Standards                                                                                             | 161 |
| 8.17       | Equipment Qualification                                                                                         | 161 |
| 8.18       | Calibration for Testing                                                                                         | 162 |
| 8.19       | Testing Procedures                                                                                              | 163 |
| 8.20       | Preparation and Disposition of Reports                                                                          | 164 |
| 8.21       | Calibration of the UT Unit with IIW or Other Approved Reference Blocks                                          | 164 |
| 8.22       | Equipment Qualification Procedures                                                                              | 165 |
| 8.23       | Discontinuity Size Evaluation Procedures                                                                        | 167 |
| 8.24       | Scanning Patterns                                                                                               | 168 |
| 8.25       | Examples of dB Accuracy Certification                                                                           | 168 |
|            | <i>Part D—Weld Acceptance Criteria</i>                                                                          | 168 |
| 8.26       | Quality of Welds                                                                                                | 168 |
| <b>9.</b>  | <b>Stud Welding</b>                                                                                             | 190 |
| 9.1        | Scope                                                                                                           | 190 |
| 9.2        | General Requirements                                                                                            | 190 |
| 9.3        | Mechanical Requirements                                                                                         | 191 |
| 9.4        | Workmanship                                                                                                     | 191 |
| 9.5        | Technique                                                                                                       | 192 |
| 9.6        | Stud Application Qualification Requirements                                                                     | 192 |
| 9.7        | Production Control                                                                                              | 193 |
| 9.8        | Inspection Requirements                                                                                         | 195 |
| <b>10.</b> | <b>Tubular Structures</b> (No Applications within this code)                                                    | 199 |
| <b>11.</b> | <b>Strengthening and Repairing Existing Structures</b> (No Applications within this code)                       | 200 |
| <b>12.</b> | <b>AASHTO/AWS Fracture Control Plan (FCP) for Nonredundant Members</b>                                          | 201 |
| 12.1       | General Provisions                                                                                              | 201 |
| 12.2       | Definitions                                                                                                     | 201 |
| 12.3       | Contract Documents                                                                                              | 201 |
| 12.4       | Base Metal Requirements                                                                                         | 202 |
| 12.5       | Welding Processes                                                                                               | 202 |
| 12.6       | Consumable Requirements                                                                                         | 202 |
| 12.4.7     | Welding Procedure Specification (WPS)                                                                           | 205 |
| 12.8       | Certification and Qualification                                                                                 | 206 |
| 12.9       | As-Received Inspection of Base Metal                                                                            | 206 |
| 12.10      | Thermal Cutting                                                                                                 | 206 |
| 12.11      | Repair of Base Metal                                                                                            | 206 |
| 12.12      | Straightening, Curving, and Cambering                                                                           | 207 |
| 12.13      | Tack Welds and Temporary Welds                                                                                  | 207 |
| 12.14      | Preheat and Interpass Temperature Control                                                                       | 207 |
| 12.15      | Postweld Thermal Treatments                                                                                     | 207 |
| 12.16      | Weld Inspection                                                                                                 | 208 |
| 12.17      | Repair Welding                                                                                                  | 209 |
|            | <i>Annexes</i>                                                                                                  | 215 |
|            | Annex A (Normative)—Effective Throat                                                                            | 217 |
|            | Annex B (Normative)—Effective Throats of Fillet Welds in Skewed T-Joints                                        | 219 |
|            | Annex C (Normative)—Flatness of Girder Webs—Bridges                                                             | 221 |
|            | Annex D (Normative)—Manufacturer’s Stud Base Qualification Requirements                                         | 226 |
|            | Annex E (Normative)—Part A—Qualification and Calibration of the UT Unit with<br>Other Approved Reference Blocks | 230 |
|            | Part B—UT Equipment Qualification Procedures                                                                    | 231 |

|                                                                                                                                                                                                       |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Annex F (Normative)—Guidelines on Alternative Methods for Determining Preheat . . . . .                                                                                                               | 239 |
| Annex G (Normative)—Welding Requirements for Conventional, Nonfracture Critical M 270M/M 270<br>(A709/A709M) HPS 485W [HPS 70W] Components with Reduced Preheat<br>and Interpass Temperature. . . . . | 251 |
| Annex H (Normative)—ESW Consumable Requirements. . . . .                                                                                                                                              | 253 |
| Annex I (Normative)—Guidelines for the Acceptance of Alternative ESW Processes . . . . .                                                                                                              | 255 |
| Annex J (Normative)—Advanced Ultrasonic Examination . . . . .                                                                                                                                         | 257 |
| Annex <u>K</u> (Normative)—Weld Quality Requirements for Tension Joints . . . . .                                                                                                                     | 273 |
| Annex L (Informative)—Description of Common Weld and Base Metal Discontinuities . . . . .                                                                                                             | 275 |
| Annex M (Informative)—Short Circuiting Transfer . . . . .                                                                                                                                             | 287 |
| Annex N (Informative)—Suggested Sample Welding Forms . . . . .                                                                                                                                        | 291 |
| Annex O (Informative)—Guide for Use of Electroslag Welding—Narrow Gap (ESW-NG) . . . . .                                                                                                              | 305 |
| Annex P (Informative)—Requesting an Official Interpretation of a Joint AASHTO/AWS Standard . . . . .                                                                                                  | 319 |
| <i>Commentary on Bridge Welding Code</i> . . . . .                                                                                                                                                    | 321 |
| Foreword. . . . .                                                                                                                                                                                     | 323 |
| Index . . . . .                                                                                                                                                                                       | 467 |
| List of AWS Documents on Structural Welding . . . . .                                                                                                                                                 | 485 |

# List of Tables

| Table | Page No.                                                                                                                                             |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.1   | Minimum Fillet Weld Size . . . . . 24                                                                                                                |
| 4.2   | Minimum Effective Weld Size for PJP Groove Welds. . . . . 24                                                                                         |
| 5.1   | Limits on Acceptability and Repair of Cut Edge Discontinuities of Material. . . . . 77                                                               |
| 5.2   | Camber Tolerance for Typical Girder . . . . . 77                                                                                                     |
| 5.3   | Camber Tolerance for Girders without a Designed Concrete Haunch. . . . . 77                                                                          |
| 6.1   | Matching Filler Metals for WPSs . . . . . 95                                                                                                         |
| 6.2   | Filler Metal Requirements for Exposed Bare Application of M 270M/M 270 (A709/A709M)<br>Gr. 345W [50W] and Gr. HPS 345W [HPS 50W] Steels . . . . . 97 |
| 6.3   | Minimum Preheat and Interpass Temperature, °C [°F] . . . . . 97                                                                                      |
| 6.4   | Minimum Holding Time . . . . . 98                                                                                                                    |
| 6.5   | Alternate Stress-Relief Heat Treatment . . . . . 98                                                                                                  |
| 6.6   | Allowable Atmospheric Exposure of Low-Hydrogen SMAW Electrodes. . . . . 98                                                                           |
| 6.7   | Required Voltage for ESW. . . . . 98                                                                                                                 |
| 7.1   | Base Metal Options for WPS Qualification Test Plates [AASHTO M 270M/M 270<br>(ASTM A709/A709M) Grades . . . . . 116                                  |
| 7.2   | AASHTO and ASTM Equivalent Base Metal Grades. . . . . 116                                                                                            |
| 7.3   | Test Requirements for WPSs Qualified in Conformance with 5.12 . . . . . 117                                                                          |
| 7.4   | WPS Qualification Requirements for Consumables . . . . . 118                                                                                         |
| 7.5   | WPS Qualification or Prequalification Options. . . . . 118                                                                                           |
| 7.6   | PQR Essential Variable Changes for WPSs Qualified per 5.12.4 . . . . . 119                                                                           |
| 7.7   | Additional PQR Essential Variable Changes Requiring WPS Requalification for EGW . . . . . 122                                                        |
| 7.8   | PQR Essential Variable Changes Requiring WPS Requalification for ESW. . . . . 123                                                                    |
| 7.9   | Required Number of Test Specimens—WPS Qualification . . . . . 123                                                                                    |
| 7.10  | Welder Qualification—Type and Position Limitations . . . . . 123                                                                                     |
| 7.11  | Number and Type of Specimens and Range of Thickness Qualified—Welder and Welding<br>Operator Qualification . . . . . 124                             |
| 7.12  | Amperage Limits for Heat Input Welding Procedure Qualification . . . . . 125                                                                         |
| 8.1   | NDT Methods and Frequency . . . . . 171                                                                                                              |
| 8.2   | Hole-Type IQI Requirements. . . . . 172                                                                                                              |
| 8.2A  | Wire IQI Requirements . . . . . 172                                                                                                                  |
| 8.3   | Testing Angle . . . . . 173                                                                                                                          |
| 8.4   | UT Acceptance-Rejection Criteria-Tensile Stress . . . . . 175                                                                                        |
| 8.5   | UT Acceptance-Rejection Criteria-Compressive Stress . . . . . 176                                                                                    |
| 9.1   | Mechanical Property Requirements for Studs . . . . . 196                                                                                             |
| 9.2   | Minimum Fillet Weld Size for Small Diameter Studs . . . . . 196                                                                                      |
| 12.1  | CVN Test Values of Weld Metal with Matching Strength . . . . . 212                                                                                   |
| 12.2  | Limits on Acceptability and Repair of Cut Edge Discontinuities of Material. . . . . 212                                                              |
| 12.3  | Tack Weld Requirements . . . . . 212                                                                                                                 |
| 12.4  | M 270M (A709M) Gr. 250, 345, 345S Minimum Preheat and Interpass Temperatures, °C. . . . . 213                                                        |
| 12.5  | M 270 (A709) Gr. 36, 50, 50S Minimum Preheat and Interpass Temperatures, °F. . . . . 213                                                             |
| 12.6  | M 270M (A709M) Gr. 345W, HPS 485W Minimum Preheat and Interpass Temperatures, °C . . . . . 213                                                       |
| 12.7  | M 270 (A709) Gr. 50W, HPS 50W, HPS 70W Minimum Preheat and Interpass Temperatures, °F . . . . 214                                                    |
| 12.8  | M 270M/M 270 (A709/A709M) Grade HPS 690W [HPS 100W]<br>Minimum and Maximum Preheat/Interpass Temperature, °C [°F] (see 12.14). . . . . 214           |
| B.1   | Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints, R = 0 . . . . . 219                                                                     |

|            |                                                                                                                                              |     |
|------------|----------------------------------------------------------------------------------------------------------------------------------------------|-----|
| <u>E.1</u> | Minimum Preheat and Interpass Temperatures for Three Levels of Restraint. . . . .                                                            | 243 |
| <u>G.1</u> | Minimum Preheat and Interpass Temperature for M 270M/M 270 (A709/A709M) HPS 485W<br>[HPS 70W], °C [°F]. . . . .                              | 252 |
| <u>G.2</u> | Filler Metals for Use with the Reduced Preheat of Table H.1, Diffusible Hydrogen Levels<br>4 mL/100 g Maximum . . . . .                      | 252 |
| <u>H.1</u> | Required Filler Metal Chemical Composition for ESW . . . . .                                                                                 | 254 |
| <u>H.2</u> | Maximum Alloy Limits for ESW Consumable Guide. . . . .                                                                                       | 254 |
| <u>J.1</u> | Discontinuity Classification. . . . .                                                                                                        | 267 |
| <u>J.2</u> | Essential Variables for PAUT (see J7.1 and J7.3) . . . . .                                                                                   | 267 |
| <u>J.3</u> | PAUT Acceptance Criteria (see J10.2). . . . .                                                                                                | 267 |
| <u>J.4</u> | Linearity Verification Report Form (see J14) . . . . .                                                                                       | 268 |
| <u>K.1</u> | Discontinuity Classification. . . . .                                                                                                        | 000 |
| <u>K.2</u> | Essential Variables for PAUT. . . . .                                                                                                        | 000 |
| <u>K.4</u> | Linearity Verification Report Form . . . . .                                                                                                 | 000 |
| <u>L.1</u> | Common Types of Discontinuities. . . . .                                                                                                     | 280 |
| <u>M.1</u> | Typical Current Ranges for Short Circuiting Transfer Gas Metal Arc Welding of Steel (GMAW-S) . . . . .                                       | 288 |
| <u>O.1</u> | Example ESW-NG Consumable Guide Configurations . . . . .                                                                                     | 314 |
| <u>O.2</u> | Example Operating Conditions for ESW-NG of ASTM M 270M/M 270 (A709/A709M)<br>Grades 250 [36], 345 [50], 345S [50S], and 345W [50W] . . . . . | 314 |

## List of Figures

| Figure |                                                                                                  | Page No. |
|--------|--------------------------------------------------------------------------------------------------|----------|
| 4.1    | Filler Plates Less Than 6 mm [1/4 in] Thick . . . . .                                            | 25       |
| 4.2    | Filler Plates 6 mm [1/4 in] or Thicker . . . . .                                                 | 25       |
| 4.3    | Details for Fillet Welds . . . . .                                                               | 26       |
| 4.4    | Details of Welded Joints for CJP Groove Welds . . . . .                                          | 28       |
| 4.5    | Details of Welded Joints for PJP Groove Welds . . . . .                                          | 48       |
| 4.6    | Fillet Welds on Opposite Sides of a Common Plane of Contact . . . . .                            | 60       |
| 4.7    | Transition of Thickness at Butt Joints of Parts Having Unequal Thickness . . . . .               | 61       |
| 4.8    | Transition of Width at Butt Joints of Parts Having Unequal Width. . . . .                        | 62       |
| 5.1    | Discontinuities in Cut Plate . . . . .                                                           | 78       |
| 5.2    | Workmanship Tolerances in Assembly of Groove Welded Joints . . . . .                             | 78       |
| 5.3    | Flange Offset for Box Girders . . . . .                                                          | 79       |
| 5.4    | Acceptable and Unacceptable Weld Profiles . . . . .                                              | 80       |
| 6.1    | Weld Bead in Which Depth and Width Exceed the Width of the Weld Face. . . . .                    | 99       |
| 7.1    | WPS Qualification or Pretest—Test Plate A . . . . .                                              | 126      |
| 7.2    | WPS Verification—Test Plate B . . . . .                                                          | 127      |
| 7.3    | Weld Soundness Test Plate for Details Not Conforming to Figure 2.4 or 2.5—Test Plate C . . . . . | 128      |
| 7.4    | Positions of Fillet Welds . . . . .                                                              | 129      |
| 7.5    | Positions of Groove Welds. . . . .                                                               | 130      |
| 7.6    | Position of Test Plates for Groove Welds. . . . .                                                | 131      |
| 7.7    | Position of Test Plates for Fillet Welds . . . . .                                               | 132      |
| 7.8    | Fillet Weld Soundness Test (Macroetch) for WPS Qualification—Test Plate D. . . . .               | 133      |
| 7.9    | Standard Round All-Weld-Metal Tension Specimen . . . . .                                         | 134      |
| 7.10   | Reduced Section Tension Specimen . . . . .                                                       | 134      |
| 7.11   | Side-Bend Specimen . . . . .                                                                     | 135      |
| 7.12   | Face- and Root-Bend Specimen. . . . .                                                            | 135      |
| 7.13   | CVN Test Specimen—Type A . . . . .                                                               | 136      |
| 7.14   | Guided Bend Test Jig . . . . .                                                                   | 137      |

|      |                                                                                                                                                        |     |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 7.15 | Alternate Wraparound Guided Bend Test Jig . . . . .                                                                                                    | 138 |
| 7.16 | Alternate Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen . . . . .                                                          | 139 |
| 7.17 | Test Plate for Unlimited Thickness—Welder Qualification . . . . .                                                                                      | 140 |
| 7.18 | Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification . . . . .                                                         | 141 |
| 7.19 | Test Plate for Limited Thickness—All Positions—Welder Qualification . . . . .                                                                          | 142 |
| 7.20 | Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification . . . . .                                                           | 142 |
| 7.21 | Fillet-Weld-Break and Macroetch Test Plate—Welder Qualification—Option 1 . . . . .                                                                     | 143 |
| 7.22 | Fillet Weld Root-Bend Test Plate—Welder Qualification—Option 2 . . . . .                                                                               | 144 |
| 7.23 | Plug Weld Macroetch Test Plate—Welder Qualification . . . . .                                                                                          | 145 |
| 7.24 | Test Plate for Unlimited Thickness—Welding Operator Qualification . . . . .                                                                            | 146 |
| 7.25 | Butt Joint for Welding Operator Qualification—ESW and EGW . . . . .                                                                                    | 147 |
| 7.26 | Fillet-Weld-Break and Macroetch Test Plate—Welding Operator Qualification—Option 1 . . . . .                                                           | 148 |
| 7.27 | Fillet Weld Root Bend Test Plate—Welding Operator Qualification—Option 2 . . . . .                                                                     | 149 |
| 7.28 | Fillet-Weld-Break Specimen—Tack Welder Qualification . . . . .                                                                                         | 150 |
| 7.29 | Method of Rupturing Specimen—Tack Welder Qualification . . . . .                                                                                       | 150 |
| 8.1A | Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 250 mm [10 in] and Greater in Length . . . . . | 177 |
| 8.1B | Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less than 250 mm [10 in] in Length . . . . .   | 177 |
| 8.1C | Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 250 mm [10 in] and Greater in Length . . . . .                    | 178 |
| 8.1D | Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less than 250 mm [10 in] in Length . . . . .                      | 178 |
| 8.1E | Hole-Type IQI Design . . . . .                                                                                                                         | 179 |
| 8.1F | Wire-Type IQI . . . . .                                                                                                                                | 180 |
| 8.2  | RT Edge Block Placement . . . . .                                                                                                                      | 181 |
| 8.3  | Transducer Crystal . . . . .                                                                                                                           | 182 |
| 8.4  | Qualification Procedure of Search Unit Using IIW Reference Block . . . . .                                                                             | 182 |
| 8.5A | International Institute of Welding (IIW) UT Reference Blocks . . . . .                                                                                 | 183 |
| 8.5B | Other Approved UT Reference Blocks . . . . .                                                                                                           | 184 |
| 8.6  | Transducer Positions (Typical) . . . . .                                                                                                               | 186 |
| 8.7  | Plan View of UT Scanning Patterns . . . . .                                                                                                            | 187 |
| 8.8  | Weld Quality Requirements for Discontinuities Occurring in Tension Welds (Limitations of Porosity and Fusion Discontinuities) . . . . .                | 188 |
| 8.9  | Weld Requirements for Discontinuities Occurring in Compression Welds (Limitations of Porosity or Fusion Type Discontinuities) . . . . .                | 189 |
| 9.1  | Dimension and Tolerances of Standard-Type Shear Connectors . . . . .                                                                                   | 197 |
| 9.2  | Typical Tension Test Fixture . . . . .                                                                                                                 | 197 |
| 9.3  | Torque Testing Arrangement and Table of Testing Torques . . . . .                                                                                      | 198 |
| D.1A | Bend Testing Device . . . . .                                                                                                                          | 228 |
| D.1B | Suggested Type of Device for Qualification Testing of Small Studs . . . . .                                                                            | 229 |
| E.1  | Example of the Use of Form F-1 UT Unit Certification . . . . .                                                                                         | 232 |
| E.2  | Example of Form F-2 . . . . .                                                                                                                          | 233 |
| E.3  | Example of the Use of Form F-2 . . . . .                                                                                                               | 234 |
| E.4  | Example of Form F-3 . . . . .                                                                                                                          | 235 |
| E.5  | Example of the Use of Form F-3 . . . . .                                                                                                               | 236 |
| E.6  | Form F-4—Report of UT of Welds . . . . .                                                                                                               | 237 |
| F.1  | Zone Classification of Steels . . . . .                                                                                                                | 245 |
| F.2  | Critical Cooling Rate for 350 HV and 400 HV . . . . .                                                                                                  | 245 |
| F.3  | Charts to Determine Cooling Rates for Single-Pass Submerged Arc Fillet Welds . . . . .                                                                 | 246 |
| F.4  | Relation Between Fillet Weld Size and Energy Input . . . . .                                                                                           | 249 |
| J.1  | Phased Array Imaging Views . . . . .                                                                                                                   | 269 |
| J.2  | Example Standard Reflector Locations in Weld Mockup . . . . .                                                                                          | 269 |
| J.3  | Example Phased Array Calibration Standard (PACS) Type Block . . . . .                                                                                  | 270 |

|                   |                                                                         |     |
|-------------------|-------------------------------------------------------------------------|-----|
| <u>J.4</u>        | Sensitivity Levels . . . . .                                            | 270 |
| <u>J.5</u>        | Example of Time Based Linearity Verification . . . . .                  | 271 |
| <u>L.1</u>        | Weld in Butt Joint . . . . .                                            | 281 |
| <u>L.2</u>        | Weld in Corner Joint . . . . .                                          | 282 |
| <u>L.3</u>        | Weld in T-Joint . . . . .                                               | 283 |
| <u>L.4</u>        | Weld in Lap Joint . . . . .                                             | 284 |
| <u>L.5</u>        | Single-Pass Fillet Weld in T-Joint . . . . .                            | 284 |
| <u>L.6</u>        | Single-V-Groove Weld in Butt Joint . . . . .                            | 285 |
| <u>M.1</u>        | Oscillograms and Sketches of Short Circuiting Transfer . . . . .        | 289 |
| <u>O.1</u>        | ESW Single and Multiple Guide Configurations . . . . .                  | 315 |
| <u>O.2</u>        | ESW Welded and Single Piece Sumps . . . . .                             | 315 |
| <u>O.3</u>        | ESW Sump and Run-Off Tab Illustration . . . . .                         | 316 |
| <u>O.4</u>        | Allowable Operating Ranges for ESW-NG . . . . .                         | 317 |
| <b>Commentary</b> |                                                                         |     |
| <u>C-4.1</u>      | Details of Alternative Groove Preparations for Corner Joints . . . . .  | 344 |
| <u>C-5.1</u>      | Examples of Unacceptable Reentrant Corners . . . . .                    | 368 |
| <u>C-5.2</u>      | Examples of Good Practice for Cutting Copes . . . . .                   | 368 |
| <u>C-5.3</u>      | Permissible Offset in Abutting Members . . . . .                        | 368 |
| <u>C-5.4</u>      | Typical Method to Determine Variations in Girder Web Flatness . . . . . | 369 |
| <u>C-5.5</u>      | Correction of Misaligned Members . . . . .                              | 369 |
| <u>C-5.6</u>      | Illustration of Camber Tolerances for Steel Beams . . . . .             | 370 |
| <u>C-5.7</u>      | Measurement of Flange Warpage and Tilt . . . . .                        | 371 |
| <u>C-5.8</u>      | Tolerances Bearing Points . . . . .                                     | 372 |

## List of Forms

| <b>Figure</b> |                                                                                                     | <b>Page No.</b> |
|---------------|-----------------------------------------------------------------------------------------------------|-----------------|
| <u>N.1</u>    | Certificate of Conformance to Requirements for Welding Electrodes . . . . .                         | 292             |
| <u>N.2</u>    | Sample Welding Procedure Specification . . . . .                                                    | 293             |
| <u>N.3</u>    | Procedure Qualification Record (PQR) for Qualification, Pretest, and Verification Results . . . . . | 294             |
| <u>N.4</u>    | Procedure Qualification Record (PQR) Worksheet . . . . .                                            | 295             |
| <u>N.5</u>    | Welder and Welding Operator Qualification Record . . . . .                                          | 296             |
| <u>N.6</u>    | Report of Radiographic Examination of Welds . . . . .                                               | 297             |
| <u>N.7</u>    | Report of Magnetic Particle Examination of Welds . . . . .                                          | 298             |
| <u>N.8</u>    | ESW-NG Procedure Qualification Record . . . . .                                                     | 299             |
| <u>N.9</u>    | ESW-NG Welding Procedure Specification . . . . .                                                    | 303             |

This page is intentionally blank.

# Bridge Welding Code

## 1. General Provisions

### 1.1 Application

**1.1.1** This code covers welding fabrication requirements applicable to welded highway bridges. The code is applicable to both shop and field fabrication of steel bridges and bridge components. The code is to be used in conjunction with the AASHTO *Standard Specification for Highway Bridges* or the AASHTO *LRFD Bridge Design Specifications*.

The code is not intended to be used for the following:

- (1) Steels with a minimum specified yield strength greater than 690 MPa [100 ksi]
- (2) Pressure vessels or pressure piping
- (3) Base metals other than carbon or low-alloy steels
- (4) Structures composed of structural tubing

Fabrication of structures or components not specifically addressed by this code shall be performed in conformance with the special provisions of the contract or in conformance with the written directives of the Engineer who may choose to reference an alternate applicable welding standard.

**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 described 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 may be based on the 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.** Base metals to be welded under this code shall meet the requirements of the latest edition of AASHTO M 270M/M 270 (ASTM A709/A709M) for the following grades:

- (1) 250 [36],
- (2) 345 [50] (Type 1, 2, or 3),

(3) 345S [50S],

(4) 345W [50W],

(5) HPS 345W [HPS 50W],

(6) HPS 485W [HPS 70W], or

(7) HPS 690W [HPS 100W]

**1.2.3 Thickness Limitations.** The provisions of this code do not apply to welding base metals less than 3 mm [1/8 in] thick. Where base metals thinner than 3 mm [1/8 in] are to be welded, the requirements of AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*, should apply. When used in conjunction with AWS D1.3/D1.3M, the applicable provisions of this code shall be observed.

## 1.3 Welding Processes

**1.3.1** This code addresses SMAW, SAW, FCAW, GMAW, ESW, EGW, and SW. Other welding processes may be used if approved by the Engineer. These processes shall be qualified by the applicable tests described in 7.12.4 and any other tests required by the Engineer. In conjunction with the tests, the WPSs and limitations of essential variables applicable to the specific welding process shall be established by the Contractor developing the WPS. The ranges 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 to an essential variable outside the established range shall require requalification.

**1.3.2** Shielded metal arc welding (SMAW) WPSs (Welding Procedure Specifications) that conform to the provisions of Clauses 4, 5, and 6, are operated within the limitation of variables recommended by the manufacturer, and that produce weld metal with a minimum specified yield strength less than 620 MPa [90 ksi], shall be deemed prequalified and exempt from the tests described in Clause 7. WPSs for SAW, FCAW, GMAW, ESW, and EGW shall be qualified as described in 7.12, as applicable.

**1.3.3** Electrode gas (EGW) welding may be used for groove welds in butt joints in compression, provided the WPSs conform to the applicable provisions of Clauses 4, 5, and 6, and are qualified in accordance with the requirements of 7.13. EGW shall be subject to nondestructive testing, as specified in Clause 8.

**1.3.4** Electroslag (ESW) may be used for Zone I and II non-fracture-critical bridge members and member components, including components subject to tensile stresses or reversal of stress, provided the WPSs conform to the applicable provisions of Clauses 4, 5, and 6, and are qualified in accordance with the requirements of 7.14. ESW shall be subject to nondestructive testing, as specified in Clause 8. Only the “narrow-gap improved” ESW process (ESW-NG) shall be permitted, unless another process is approved in accordance with Annex I. Application of ESW shall be limited to members or member components made from M 270M/M 270 (A 709/A 709M) Grades 250 [36], 345 [50], 345S [50S], and 345W [50W] steels.

**1.3.5** Stud welding may be used, provided the WPSs conform to the applicable provisions of Clause 9.

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

**1.3.7 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 Clause 7, subject to the following restrictions:

(1) SMAW, SAW, FCAW, and GMAW WPSs shall be considered prequalified and exempt from the qualification tests described in Clause 7, provided that welding is performed in conformance with all other provisions of the code.

(2) All welding performed in conformance with this subclause 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 Fabricator Requirements

Fabricators shall be certified under the AISC Quality Certification Program, Simple Steel Bridges, Intermediate Steel Bridges, or Complex Steel Bridges as required by the Engineer, or an equivalent program acceptable to the Engineer.

## 1.5 Definitions

The welding terms used in this code shall be interpreted in conformance with the definitions given in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, supplemented by [Clause 3](#) of this code.

## 1.6 Welding Symbols

Welding symbols shall be those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Non-destructive Examination*. Special conditions shall be fully explained by notes or details.

## 1.7 Safety Precautions

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

American Welding Society:

- (1) ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

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

## 1.8 Standard Units of Measurement

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

## 1.9 Welding Procedure Specifications (WPSs)

All production welding shall be performed in conformance 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 conformance with 1.3.2. 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. Recommended forms for WPSs and PQRs are provided in Annex N. WPSs for SMAW that meet the requirements of 7.11 shall be considered prequalified and exempt from qualification testing.

## 1.10 Mechanical Testing

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

## 1.11 Reference Documents

See [Clause 2](#) for a description of the documents referenced in AASHTO/AWS D1.5M/D1.5:2020

## **2. Normative References**

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Association of State Highway and Transportation Officials (AASHTO) documents:<sup>1</sup>

AASHTO Guide Specifications for Highway Bridge Fabrication with HPS 70W (HPS 485W) Steel

AASHTO Standard Specification for Highway Bridges

AASHTO LRFD Bridge Design Specifications

AASHTO M270M/M270, *Standard Specification for Structural Steel Bridges*

AASHTO T244, *Standard Method of Test for Mechanical Testing of Steel Products*

American Welding Society (AWS) documents:<sup>2</sup>

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

AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying.*

AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

A4.4M, *Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings*

AWS A5.01M/A5.01:2013 (ISO 14344:2010 MOD) *Welding Consumables – Procurement of Filler Metals and Fluxes*

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

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

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

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

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

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

AWS A5.25/A5.25M, *Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding*

AWS A5.26/A5.26M, *Specifications for Carbon and Low-Alloy Steel Electrodes for Electroslag Welding*

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

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

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

<sup>1</sup> AASHTO documents are published by the American Association of State Highway and Transportation Officials, 444 N. Capitol Street NW, Suite 249, Washington DC 20001.

<sup>2</sup> AWS documents are published by the American Welding Society, 8669 NW 36<sup>th</sup> Street, #130, Miami, FL 33166.

AWS C4.1-G, *Oxygen Cutting Surface Roughness Gauge*

AWS C5.4, *Recommended Practices for Stud Welding*

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

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

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

AWS *Welding Handbook*, Volume 1, 8th Edition, Chapter 11

American National Standards Institute (ANSI) document:<sup>3</sup>

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

American Society of Mechanical Engineers (ASME) documents:<sup>4</sup>

ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*

ASME *Boiler and Pressure Vessel Code*, Section V, Article 2

American Society for Nondestructive Testing (ASNT) document:<sup>5</sup>

ASNT *Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing*

ASTM International (ASTM) documents:<sup>6</sup>

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

ASTM A108, *Standard Specification for Steel Bar, Carbon, and Alloy, Cold-Finished*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A435/A435M, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

ASTM A709/A709M, *Standard Specification for Structural Steel Bridges*

ASTM A770/A770M, *Standard Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications*

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

ASTM E94, *Standard Guide for Radiographic Examination*

ASTM E140, *Standard Hardness Conversion Tables for Metals*

ASTM E164, *Standard Practice for Contact Ultrasonic Testing of Weldments*

ASTM E165, *Standard Practice for Liquid Penetrant Examination for General Industry*

ASTM E317, *Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments*

ASTM E384, *Standard Test Method for Knoop and Vickers Hardness of Materials*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E747, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*

<sup>3</sup> This ANSI document is published by the American Welding Society, 8669 NW 36<sup>th</sup> Street, #130, Miami, FL 33166.

<sup>4</sup> ASME documents are published by the American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

<sup>5</sup> This ASNT document is published by the American Society for Nondestructive Testing, P.O. Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518.

<sup>6</sup> ASTM International documents are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiography*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

ASTM E1254, *Standard Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films*

ASTM E2033, *Standard Practice for Computed Radiology (Photostimulable Luminescence Method)*

ASTM E2339, *Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)*

ASTM E2445, *Standard Practice for Qualification and Long-Term Stability of Computed Radiology Systems*

ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

ASTM E2699, *Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Digital Radiographic (DR) Test Methods*

ASTM E2737, *Standard Practice for Digital Detector Array Performance Evaluation and Long-Term Stability*

CSA Group (CSA) document:<sup>7</sup>

Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*

International Institute of Welding (IIW) document:<sup>8</sup>

The International Institute of Welding (IIW) Ultrasonic Reference Block

Other documents:

Fracture and Fatigue Control in Structures—Applications of Fracture Mechanics, Barsom and Rolfe, Prentice-Hall Inc. SSC-383, “Optimum Weld-Metal Strength for High Strength Ship Structures”, Dexter and Ferrell, Ship Structure Committee, 1995.<sup>9</sup>

<sup>7</sup> This CSA document is published by the CSA Group, 178 Rexdale Boulevard, Toronto, ON, CANADA M9W 1R3.

<sup>8</sup> This IIW document is published by the International Institute of Welding, BP 51362 – Villepinte, 95 942 Roissy Ch de Gaulle Cedex, FRANCE.

<sup>9</sup> This SSC document is published by the Ship Structure Committee, <[www.shipstructure.org](http://www.shipstructure.org)>.

### **3. Terms and Definitions**

The welding terms used in this code shall be interpreted in conformance with the definitions given in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.

The terms and definitions in this glossary are divided into two categories: (1) terms, defined by the AWS Structural Welding Committee, that apply only to ultrasonic testing, designated by (UT) following the term, and (2) other terms, preceded by asterisks, that are defined as they relate to this code.

For the purposes of this document, the following terms and definitions apply:

#### **A**

**\*active flux (SAW).** 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 may significantly change weld metal chemical composition and mechanical properties.

**\*alloy flux (SAW).** A flux which contains alloy ingredients intended to modify the weld metal chemical composition. Changes in arc voltage may significantly change weld metal chemical composition.

**\*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 allowed by various indication ratings associated with weld size, as indicated in Tables [8.4](#) and [8.5](#).

**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 [1 in] of sound path distance after the first 25 mm [1 in].)

**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 [1 in] of sound path distance after the first 25 mm [1 in].)

**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 **mechanized welding**.

#### **B**

**backgouging.** The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and CJP 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 ESW and EGW, 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.

**blooming pixel.** A pixel whose charge spreads to adjacent pixels.

**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.

**CJP (complete joint penetration).** A joint root condition in a groove weld in which weld metal extends through the joint thickness.

**\*CJP (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 fusion.** Fusion over the entire fusion faces and between all adjoining weld beads.

**computed radiography (CR).** A digital replacement of conventional X-ray film that uses a flexible phosphor imaging plate to capture digital images.

**\*consumable guide ESW or EGW.** 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.

**crater.** A depression in the weld face at the termination of a weld bead.

**CVN.** Charpy V-notch.

## 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.

**\*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.

**EGW (electrogas welding).** 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.

**ESW (electroslag welding).** 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.

The narrow-gap improved electroslag welding process is a version of consumable guide ESW that meets the toughness requirements of AASHTO Temperature Zone 1 and 2 bridges. Compared to conventional electroslag welding, the ESW-NG process is characterized by: (a) improved CVN toughness of the weld metal and heat-affected zone (HAZ), (b) higher fatigue resistance, and (c) increased productivity.

## 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.

**FCAW (flux cored arc welding).** 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.

**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.

**finish.** *verb.* The use of mechanical methods (e.g., grinding, machining) to prepare a surface to meet a quality standard requirement.

**\*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.

**\*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**.

**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 pocket.** A cavity caused by entrapped gas.

**GMAW (gas metal arc welding).** 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.

**\*GMAW-S (gas metal arc welding short circuit arc).** A gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits.

**\*gouging (thermal).** The forming of a bevel or groove by material removal. See also **backgouging**, **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

**HAZ (heat-affected zone).** 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 7.4 and 7.7(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 7.5 and 7.6(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.

**\*hybrid joint.** A welded joint of material with two different minimum specified yield strengths.

**hydrogen diffusion postheat.** A thermal treatment applied to an assembly after welding for the purpose of releasing diffusible hydrogen.

## I

**indication (UT).** The signal displayed on the test equipment 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.

**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.

**\*IQI (image quality indicator).** 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.

## 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.

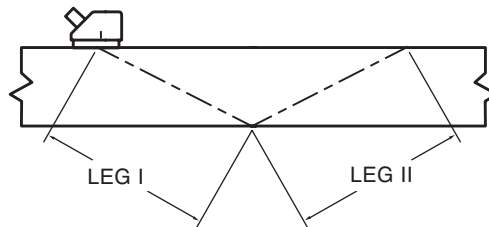
**\*joint welding procedure.** The materials and detailed methods and practices employed in the welding of a particular joint.

## 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, verb.** To shape, plane, mill, grind, cut, rout, abrade or otherwise achieve a desired contour or finish by machine-operated tools.

**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**, **mechanized welding**, and **semiautomatic welding**.

**\*mechanized 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**.

**MT.** Magnetic particle testing.

## N

**neutral flux (SAW).** 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**.

**nondestructive testing (NDT).** The process of determining acceptability of a material or a component in accordance with established criteria without impairing its future usefulness.

## O

**\*overhead welding position.** The position in which welding is performed from the underside of the joint [see Figures 7.4, 7.5, 7.6(D), and 7.7(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 **SAW**.

**pass.** See preferred term **weld pass**.

**peening.** The mechanical working of metals using impact blows.

**\*pipng porosity (ESW and EGW).** Elongated gas pores whose major dimension lie in a direction approximately parallel to the weld axis which is vertical during welding.

**\*pipng 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.

**PJP (partial joint penetration).** Joint penetration that is intentionally less than complete.

**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 shall not 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 shall 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.

**PT.** Liquid penetrant testing.

## 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 UT equipment to give separate indications from closely spaced reflectors.

**root face.** That portion of the groove face within the joint root (see AWS A3.0, Figure B5).

**root of joint.** See **joint root**.

**root of weld.** See **weld root**.

**root opening.** The separation at the joint root between the workpieces.

**RT.** Radiographic testing.

## S

**SAW (submerged arc welding).** 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.

**scanning level (UT).** The dB setting used during scanning, as described in Tables [8.4](#) and [8.5](#).

**\*semiautomatic welding.** Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

**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 shall not be construed as conforming to this definition.

**SMAW (shielded metal arc welding).** 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.

**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.

**spatter.** The metal particles expelled during fusion welding that do not form a part of the weld.

**storage phosphor imaging plate (SPIP).** Phosphor imaging plates release stored energy within a phosphor by stimulation with visible light, to produce a luminescent signal.

**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 [1/8 in] of the body of the stud adjacent to the tip.

## 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.

**UT.** Ultrasonic testing.

## V

**\*vertical welding position.** The position of welding in which the axis of the weld is approximately vertical [see Figures 7.4, 7.5, 7.6(C), and 7.7(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 nonmetals 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 specific, 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 Clause 7 Part B.

**welder performance qualification.** The demonstration of a welder's ability to produce welds meeting specified 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, 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.

## 4. Design of Welded Connections

### *Part A* *General Requirements*

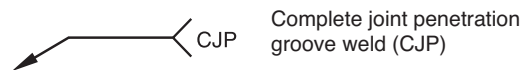
#### 4.1 Drawings

**4.1.1** 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 (CJP) groove welds.

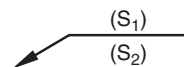
**4.1.2** Those joints or groups of joints for which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted on shop and working drawings.

**4.1.3** Contract design drawings shall specify the effective weld length and, for partial joint penetration (PJP) groove welds, the required weld size, as defined in 4.3. Shop or working drawings shall specify the groove angles ( $\alpha$  and  $\beta$ ) and depths ( $D$ ) applicable for the weld size ( $S$ ) required for the welding processes and position of welding to be used.

**4.1.3.1** It is recommended that contract design drawings show CJP or PJP groove weld requirements. The welding symbol without dimensions designates a CJP weld, as follows:



The welding symbol with the effective groove weld size ( $S$ ) above or below the reference line designates a PJP weld as follows:



Where

( $S_1$ ) = effective groove weld size, other side

( $S_2$ ) = effective groove weld size, arrow side

**4.1.3.2** Special groove details shall be specified where required.

**4.1.4** 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.

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

**4.1.6 Use of Undermatched Filler Metals.** Undermatching filler metal may be used:

- (1) For all fillet and PJP groove welds, when consistent with design requirements.
- (2) For all CJP groove welds where the stress in the weld is tension or compression parallel to the weld axis, providing shear on the effective weld area meets AASHTO design requirements for all applications.

For CJP groove welds in compression, undermatching up to 70 MPa [10 ksi] may be used. Weld sizes shall be based on the strength of filler metal that is required to be used, or the strength of filler metal that may be used. Weld sizes and weld

metal strength levels shall be in conformance with AASHTO Design Specifications. Design drawings shall show the weld size and, where required or allowed, the undermatching filler metal strength classification shall be shown. Shop drawings shall show the weld size and filler metal strength classification when undermatching filler metal is to be used.

## 4.2 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*.

## 4.3 Effective Weld Areas, Lengths, Throats, and Sizes

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

**4.3.1.1** 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.

**4.3.1.2** The effective weld size of a CJP groove weld shall be the thickness of the thinner part joined. No increase is allowed for weld reinforcement.

**4.3.1.3** The effective weld size of a PJP groove weld shall be the depth of bevel less 3 mm [1/8 in] for grooves having a groove angle less than 60° but not less than 45° at the root of the groove, when made by SMAW or SAW, when made in the vertical or overhead welding positions by GMAW or FCAW.

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

(1) having a groove angle of 60° 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° at the root of the groove when made in flat or horizontal positions by GMAW or FCAW.

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

**4.3.1.5** The minimum effective weld size of a PJP groove weld shall be as described in Table 4.2.

**4.3.2 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.

**4.3.2.1** 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.

**4.3.2.2** 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 4.3.3, then this latter area shall be used as the effective area of the fillet weld.

**4.3.2.3** The minimum length of a fillet weld shall be at least four times the nominal size, or the effective size of the weld shall be considered not to exceed 25% of its effective length. Whenever practicable, the minimum length for fillet welds shall be 40 mm [1-1/2 in].

**4.3.2.4** The effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld (see Annex A). *NOTE: See Annex B 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° fillet weld has been provided for dihedral angles between 60° and 135° in Annex B, Table B.1.*

**4.3.3 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.

**4.3.4** The effective weld size of a combination PJP 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 [1/8 in], for any groove detail requiring such deduction (see Annex A).

## ***Part B***

### ***Structural Details***

#### **4.4 General**

Welded connections shall be designed and detailed to satisfy the strength, stiffness, flexibility, and fatigue requirements of the AASHTO and/or other applicable design specifications.

#### **4.5 Welded Filler Plates**

**4.5.1** Welded filler plates (see Figures 4.1 and 4.2) are designated Category E fatigue details and shall be avoided when joining tension and reversal of stress members. When the design allows 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, shall accommodate offsets to allow simple framing

**4.5.2** A filler plate less than 6 mm [1/4 in] 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 4.1).

**4.5.3** Any filler plate 6 mm [1/4 in] 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 4.2).

#### **4.6 PJP Groove Welds**

Joints containing PJP groove welds, made from one side only, shall be restrained to prevent rotation.

## ***Part C***

### ***Details of Welded Joints***

#### **4.7 Joint Qualification**

Details of welded joints that may be used in a prequalified WPS are described in 4.8 through 4.13.

**4.7.1** Joint details may depart from the details described in 4.12 and 4.13 only if the Contractor submits the proposed WPSs to the Engineer for approval, and at the Contractor's expense, demonstrates their adequacy in conformance with the requirements of 7.7.5 and 7.12.4 of this code and their conformance with the applicable provisions of Clauses 5, 6, and 7.

#### **4.8 Details of Fillet Welds**

**4.8.1** The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 4.1, or as calculated using procedures established to prevent cracking in conformance with 6.2.1.2. In both cases, the minimum size shall apply if it is sufficient to satisfy design requirements.

**4.8.2** The maximum fillet weld size detailed along edges of material shall be the following:

**4.8.2.1** The thickness of the base metal, for metal less than 6 mm [1/4 in] thick (see Figure 4.3, Detail A).

**4.8.2.2** 2 mm [1/16 in] less than the thickness of base metal, for metal 6 mm [1/4 in] or more in thickness (see Figure 4.3, 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 [1/16 in], provided the weld size shall be clearly verifiable.

**4.8.3** 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, subject to the provisions of 4.3.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

**4.8.4** Fillet welds may be used in skewed T-joints having a dihedral angle ( $\psi$ ) of not less than 60° nor more than 135° (see Figure 4.3, Details C and D). Detail D shall be used when  $R_n$  would exceed 5 mm [3/16 in] using Detail C.

**4.8.5** When the design allows intermittent fillet welds, the minimum length of an intermittent fillet weld shall be as described in 4.3.2.3.

**4.8.6** Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to the requirements of 4.9.

**4.8.7** Fillet welds supporting 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.

**4.8.8** 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 4.6).

## 4.9 Details of Plug and Slot Welds

**4.9.1** The details of plug and slot welds made by the SMAW, GMAW, or FCAW processes are described in 4.9.2 through 4.9.7 and 5.3.1.1.

**4.9.1.1** Plug and slot welds may be used without performing the WPS qualification described in 7.7.5, provided the technique provisions of 6.23, 6.24, and 6.25, as applicable, are met.

**4.9.2** 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 [5/16 in]. The maximum diameter shall equal the minimum diameter plus 3 mm [1/8 in] or 2-1/4 times the thickness of the member, whichever is greater.

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

**4.9.4** 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 [5/16 in]. The maximum width shall equal the minimum width plus 3 mm [1/8 in] or 2-1/4 times the thickness of the member, whichever is greater.

**4.9.5** 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 that extend to the edge of the part.

**4.9.6** 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.

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

## 4.10 Lap Joints

**4.10.1** 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.

**4.10.2** 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 4.6). 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.

**4.10.3** 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.

**4.10.4** Lap joints are Category E details and should be avoided, when possible, in members subject to tension or reversal of stresses.

## **4.11 Corner and T-Joints**

**4.11.1** Corner and T-joints subject to bending perpendicular to the joint shall have their welds arranged to avoid concentration of tensile stress at the root of any weld.

**4.11.2** Corner and T-joints parallel to the direction of computed stress between components of built-up members designed for axial stress need not be CJP groove welds. Fillet welds or a combination of PJP welds and reinforcing fillet welds may be used.

**4.11.3** Groove welds in corner and T-joints shall be reinforced with fillet welds with a leg size equal to or greater than  $T/4$ , but which need not exceed 10 mm [ $3/8$  in].  $T$  shall be defined as the thickness of the thinner part being joined.

## **4.12 CJP Groove Welds**

**4.12.1 Dimensional Tolerances.** Dimensions of groove welds specified on design or detailed drawings may vary as shown in Figure 4.4.

**4.12.2 Corner Joints.** For corner joints using beveled 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.

## **4.13 PJP Groove Welds** (see Figure 4.5)

**4.13.1 Definition.** Except as provided in Figure 4.4, groove welds without steel backing, welded from one side, and groove welds welded from both sides but without backgouging, are considered PJP groove welds unless qualified as CJP by 7.7.5.

**4.13.1.1** All PJP groove welds made by GMAW-S shall be qualified by the WPS qualification tests described in 7.12.4.

**4.13.2 Minimum Effective Weld Size.** The minimum effective weld size of PJP square-, single- or double-V-, bevel-, J-, and U-groove welds shall be as shown in Table 4.2.

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

**4.13.3 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.

## **4.14 Prohibited Types of Joints and Welds**

The joints and welds described in the following paragraphs shall be prohibited:

- (1) All PJP groove welds in butt joints except those conforming to 4.17.3
- (2) CJP 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 conformance with 7.7.5 and 7.12.4
- (3) Intermittent groove welds
- (4) Intermittent fillet welds, except as approved by the Engineer
- (5) Flat position bevel-groove and J-groove welds in butt joints where V-groove and U-groove welds are practicable
- (6) Plug and slot welds in members subject to tension and reversal of stress

## **4.15 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 A). However, such methods of adding individual capacities of welds do not apply to fillet welds reinforcing CJP groove welds.

## **4.16 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.

## **4.17 Connection Details**

### **4.17.1 Eccentricity of Connections**

**4.17.1.1** Eccentricity between intersecting parts and members shall be avoided insofar as practical.

**4.17.1.2** 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.

**4.17.1.3** 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.

**4.17.1.4** 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 allowed by this code.

**4.17.2 Connections or Splices—Tension and Compression Members.** Connections or splices of tension or compression members made by groove welds shall have CJP groove welds. Connections or splices made with fillet welds, except as noted in 4.17.3, shall be designed for an average of the calculated stress and the strength of the member, but not less than 75% 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 allowed by the applicable AASHTO specification.

**4.17.3 Connections or Splices in Compression Members with Finished-to-Bear Joints.** If members subject only to compression are spliced and a finished-to-bear fit is provided, the welding shall be arranged to hold all parts in alignment, and welds and contact areas shall be proportioned to each carry 50% of the computed stress in the member. Where such members are finished to achieve direct bearing on base plates, contact tolerances shall satisfy the second paragraph of 5.5.9 and there shall be sufficient welding to hold all parts securely in place.

**4.17.4 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.

**4.17.5 Transition of Thicknesses or Widths at Butt Joints**

**4.17.5.1** 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 4.7).

**4.17.5.2** In butt joints between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished as described in 4.17.5.1 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 described in 4.17.5.1.

**4.17.5.3** Butt joints between parts having unequal width and subject to tensile stress shall have a smooth transition between offset edges at a slope transition of no more than 1 transverse to 2.5 longitudinal with the edge of either part or shall be transitioned with a 600 mm [24 in] minimum radius tangent to the narrower part at the center of the butt joint (see Figure 4.8). The stress range for the transitional detail shall be as allowed by AASHTO design specifications.

**4.17.6 Girders and Beams**

**4.17.6.1** Connections or splices in beams or girders when made by groove welds shall have CJP groove 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 no 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 allowed by the AASHTO specification.

**4.17.6.2** 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.

**4.17.6.3 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.

**Table 4.1**  
**Minimum Fillet Weld Size<sup>a, b</sup> (see 4.8.1)**

| Base Metal Thickness of Thicker Part Joined (T) | Minimum Size of Fillet Weld |                                 |
|-------------------------------------------------|-----------------------------|---------------------------------|
| T ≤ 20 mm [3/4 in]                              | 6 mm [1/4 in]               | Single-pass welds shall be used |
| T > 20 mm [3/4 in]                              | 8 mm [5/16 in]              |                                 |

<sup>a</sup> Smaller fillet welds may be approved by the Engineer based on applied stress and the use of appropriate preheat.

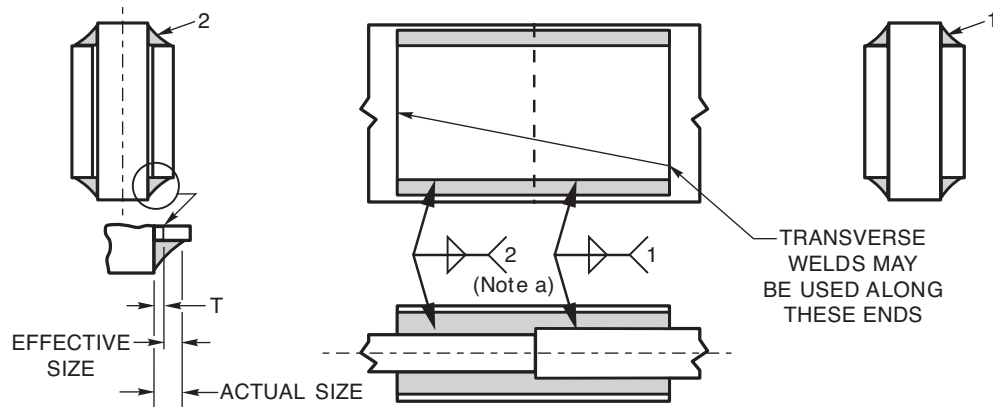
<sup>b</sup> Except that the weld size need not exceed the thickness of the thinner part joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.

**Table 4.2**  
**Minimum Effective Weld Size for PJP Groove Welds<sup>a, b</sup> (see 4.13.2)**

| Base Metal Thickness of Thicker Part Joined (T) | Minimum Effective Weld Size |
|-------------------------------------------------|-----------------------------|
| T ≤ 20 mm [3/4 in]                              | 6 mm [1/4 in]               |
| T > 20 mm [3/4 in]                              | 8 mm [5/16 in]              |

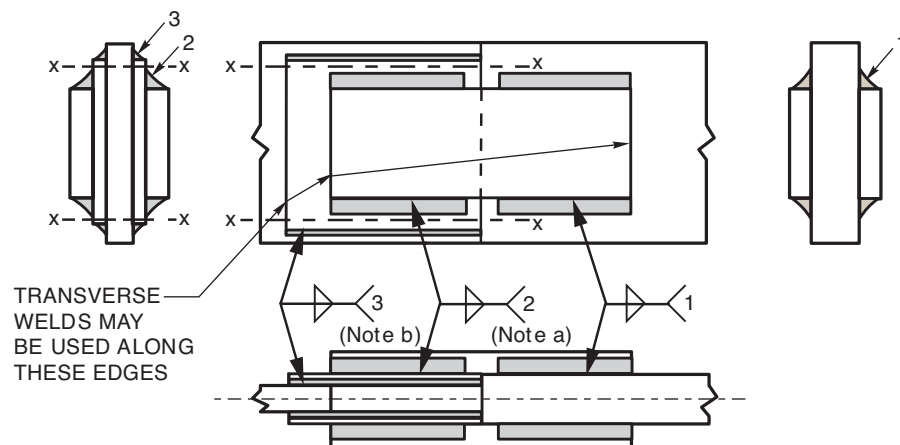
<sup>a</sup> Smaller welds may be approved by the Engineer based on applied stress and the use of appropriate preheat.

<sup>b</sup> Except that the weld size need not exceed the thickness of the thinner part.



<sup>a</sup> 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.

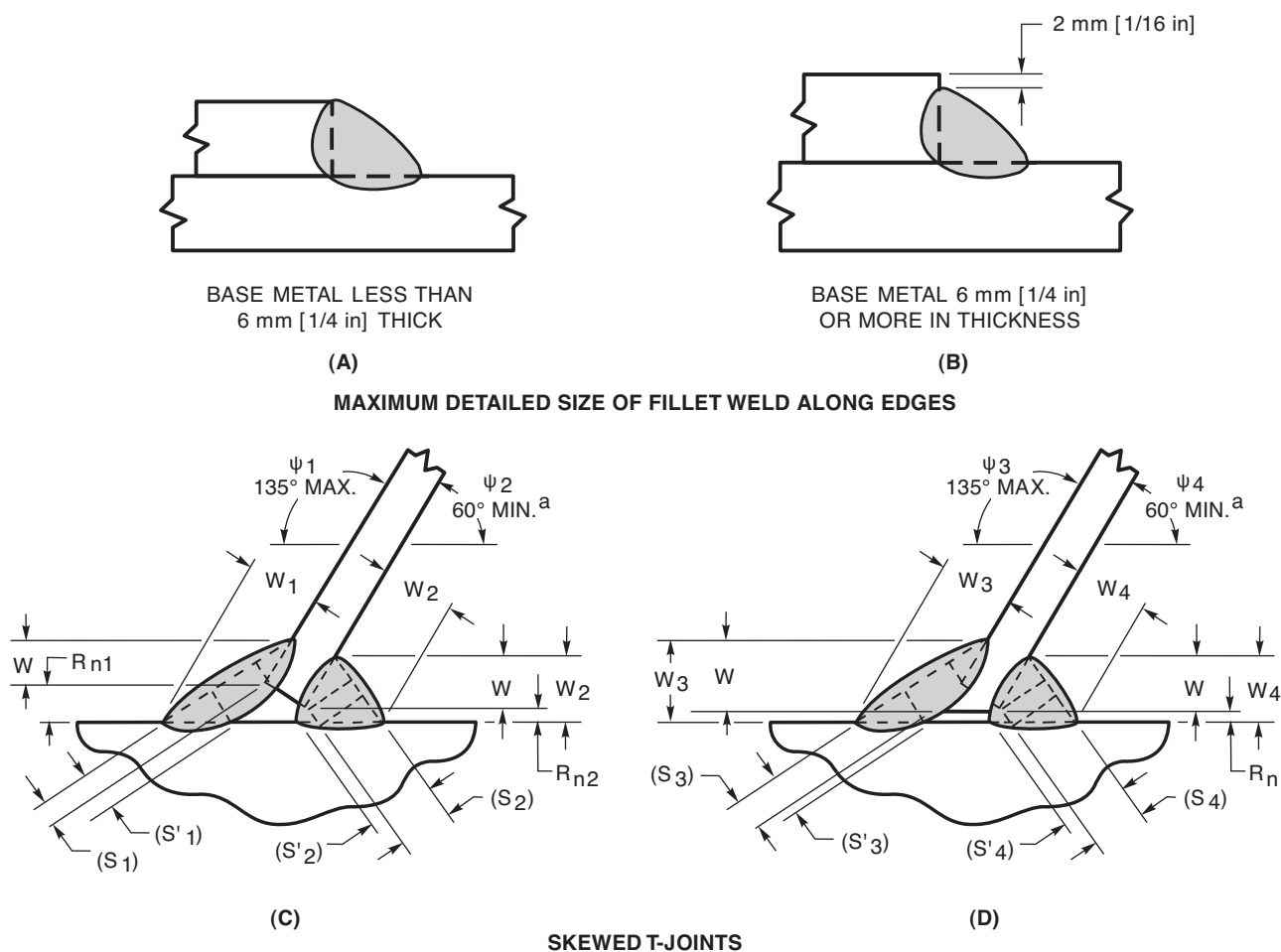
**Figure 4.1—Filler Plates Less Than 6 mm [1/4 in] Thick (see 4.5.1)**



<sup>a</sup> 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.

<sup>b</sup> 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 4.2—Filler Plates 6 mm [1/4 in] or Thicker (see 4.5.3)**



<sup>a</sup> Angles smaller than 60° are allowed; however, in such cases, the weld is considered to be a PJP groove weld.

Note:  $(\underline{S})(n)$ ,  $(\underline{S}')(n)$  = effective throats dependent on magnitude of root opening ( $R_n$ ) (see 5.3.1). Subscript (n) represents 1, 2, 3, or 4.

**Figure 4.3—Details for Fillet Welds (see 4.8)**

### Legend for Figures 4.4 and 4.5

#### 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

#### Welding processes

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

#### Symbols for base-metal thickness and penetration

- L — limited thickness—CJP
- U — unlimited thickness—CJP
- P — PJP

#### Welding positions

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

#### 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

#### Dimensions

- R — Root Opening
- $\alpha$ ,  $\beta$  — Groove Angles
- f — Root Face
- r — J- or U-groove Radius
- D, D<sub>1</sub>, D<sub>2</sub> — PJP Groove Weld Depth of Groove
- S, S<sub>1</sub>, S<sub>2</sub> — PJP Groove Weld Sizes corresponding to S, S<sub>1</sub>, S<sub>2</sub>, respectively

#### Symbols for welding processes if not SMAW

- S — SAW
- G — GMAW
- F — FCAW

#### 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.

### Notes for Figures 4.4 and 4.5

<sup>a</sup> Groove preparations detailed for SMAW joints may be used for GMAW or FCAW.

<sup>b</sup> Joint shall be welded from one side only.

<sup>c</sup> Backgouge root to sound metal before welding second side.

<sup>d</sup> Minimum weld size (S) as shown in Table 4.2; S as specified on drawings.

<sup>e</sup> Evidence of CJP shall be required (see 6.7.4).

<sup>f</sup> 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.

<sup>g</sup> Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note d. Also the weld size (S), less any reduction, applies individually to each groove.

<sup>h</sup> 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.

<sup>i</sup> For corner and T-joints, the member orientation may be changed provided the groove angle is maintained as specified.

<sup>j</sup> The member orientation may be changed provided that the groove dimensions is maintained as specified.

<sup>k</sup> 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.

<sup>l</sup> These joint details shall not be used where V-groove or U-groove details are practicable (see 4.14).