ANSI/AWS D1.1-98
An American National Standard

Structural Welding Code—Steel

American Welding Society

Key Words — Allowable stress, cyclically loaded structures, structural details, statically loaded structures, steel welding, stud welding, tubular structures, welded joint details, welded steel structures

ANSI/AWS D1.1-98
An American National Standard

Approved by
American National Standards Institute
November 13, 1997

Structural Welding Code— Steel

16th Edition

Supersedes ANSI/AWS D1.1-96

Prepared by
AWS Committee on Structural Welding

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

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

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

Statement on Use of AWS Standards

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

International Standard Book Number: 0-87171-525-2

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

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

With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. However, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS Structural Welding Committee. It must be reviewed every five years and if not revised, it must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS Structural Welding Committee and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS Structural Welding Committee to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126.

Photocopy Rights

Personnel

AWS Committee on Structural Welding

D. L. McQuaid, Chairman	D & L Company
D. D. Rager, Vice Chairman	Reynolds Metal Company
D. K. Miller, Vice Chairman	The Lincoln Electric Company
A. W. Sindel, Vice Chairman	Sindel and Associates
H. H. Campbell III, Secretary	American Welding Society
**R. E. Albrecht*	Robertson, UDI
W. G. Alexander	Consultant
N. B. Altebrando	Hardesty and Hanover
F. G. Armao	Alcoa Technical Center
R. E. Avery	Nickel Development Institute
D. K. Baird	Argonne National Laboratory
E. M. Beck	Law Engineering, Incorporated
F. R. Beckmann	American Institute of Steel Construction
R. M. Bent	Welding Institute of Canada
E. L. Bickford	McDermott Incorporated
R. D. Block	Diamond Power Specialty Company
O. W. Blodgett	The Lincoln Electric Company
R. Bonneau	Canadian Welding Bureau
F. C. Breismeister	Bechtel Corporation
C. R. Briden	Cooper Lighting
B. M. Butler	Walt Disney World Company
**S. Camo*	Weidlinger Associates Incorporated
J. J. Cecilio	Naval Facilities Engineer Com.
H. A. Chambers	TRW Nelson Stud Welding Division
S. L. M. Cole	Cooper Lighting
L. E. Collins	Team Industries, Incorporated
R. B. Corbit	General Public Utilities Nuclear Corporation
E. G. Costello	Boeing Defense and Space Group
W. F. Crozier	California Department of Transportation
M. V. Davis	Consultant
D. A. DelSignore	Westinghouse Electric Corporation
R. A. Dennis	Chevron Research and Technology
P. B. Dickerson	Consultant
**J. D. Duncan*	Fluor Daniel
J. S. Fortenberry	Chevron Petroleum Tech. Company
G. L. Fox	Texas Department of Public Transportation
A. R. Fronduti	Rex Fronduti & Associates
**J. M. Gdaniec*	Atomic Energy of Canada, Limited
J. C. Gerardy	TradeARBED Incorporated
**G. A. Gix*	Consultant
M. A. Grieco	Massachusetts Highway Department
D. P. Gustafson	Concrete Reinforcing Steel Institute
R. Hamburger	EQE International Incorporated
M. J. Harker	Lockheed Idaho Technologies Company

*Advisor

AWS Committee on Structural Welding (Continued)

C. W. Hayes	The Lincoln Electric Company
C. R. Hess	High Steel Structures, Incorporated
F. L. Hicks	Tru-Weld Division, Tru-Fit Products Corporation
G. J. Hill	G. J. Hill and Associates, Incorporated
M. L. Hoitomt	Thomas and Betts-Meyer Ind.
E. R. Holby	IFR Engineering
C. W. Holmes	West Virginia Department of Transportation
W. Jaxa-Rozen	Bombardier Incorporated
M. J. Jordan	Bergen Southwest Steel
A. J. Julicher	A. J. Julicher and Associates
J. H. Kiefer	Conoco, Incorporated
L. A. Kloiber	LeJeune Steel Company
**Ing. D. Kosteas*	Technical University of Munich, Germany
R. M. Kotan	Omaha Public Power District
D. J. Kotecki	The Lincoln Electric Company
D. R. Lawrence II	Butler Manufacturing
D. L. Long	PDM Strocal, Incorporated
H. W. Ludewig	Caterpillar, Incorporated
**S. Mahin*	Earthquake Engineering Research Center
J. Malley	Degenkolb Engineers
P. W. Marshall	MHP Systems Engineering
D. M. Marudas	Morrison Knudsen Corporation
M. J. Mayes	Boss and Mayes Testing Engineers
J. W. McGrew	Babcock & Wilcox
R. D. Medlock	Texas Department of Transportation
J. K. Merrill	Law Engineering
J. K. Mieske	Phoenix Steel, Incorporated
W. A. Milek, Jr.	Consultant
R. C. Minor	Hapco Division of Kearney National, Incorporated
J. L. Munnerlyn	Consultant
J. E. Myers	SMI Owen Steel Company, Incorporated
J. C. Nordby	Consumers Power Company
T. Omura	Kawada Industries
J. A. Packer	University of Toronto, Canada
F. J. Palmer	American Institute for Hollow Structural Sections
C. C. Pease	C P Metallurgical
**T. Pekoz*	Cornell University
M. L. Peterson	Consultant
D. C. Phillips	ITW-Hobart Brothers Company
C. W. Pinkham	S. B. Barnes and Associates
J. W. Post	J. W. Post and Associates, Incorporated
D. Rees-Evans	Nucor-Yamato Steel
D. E. H. Reynolds	Canadian Welding Bureau
J. E. Roth	James E. Roth, Incoporated
W. W. Sanders, Jr.	Iowa State University
T. Schlafly	American Institute of Steel Construction
J. H. Schlect	Institute of the Ironworking Industry
D. R. Scott	Professional Service Industries
L. Seum	Bragg Crane & Rigging Company
D. Shapira	Morrison-Knudsen Corporation
J. G. Shaw	Mountain Enterprises, Inc.

*Advisor

AWS Committee on Structural Welding (Continued)

R. E. Shaw, Jr.	Steel Structures Technology Center, Incorporated
J. L. Skiles	Omaha Public Power District
D. L. Sprow	McDermott Inc., Retired
J. T. Staley	Minnesota Department of Transportation
R. W. Stieve	New York Department of Transportation
C. R. Stuart	Shell Offshore, Incorporated
P. J. Sullivan	Massachusetts Highway Department (Retired)
W. A. Svekric	Welding Consultants, Incorporated
G. R. Swank	State of Alaska
J. D. Theisen	Exxon Company, USA
W. Thornton	Cives Corporation
R. H. R. Tide	Wiss, Janney, Elstner Associates
C. Uang	University of California—San Diego
J. E. Uebele	Waukesha County Technical College
K. K. Verma	Federal Highway Administration
B. D. Wright	Consultant
B. Young	Westinghouse Savannah River Company

AWS Structural Welding Committee and Subcommittees

Main Committee

D. L. McQuaid, Chair
D. D. Rager, 1st V.C.
D. K. Miller, 2nd V.C.
A. W. Sindel, 3rd V.C.
H. H. Campbell III, Secretary
*W. G. Alexander**
E. M. Beck
F. R. Beckmann
R. D. Block
*O. W. Blodgett**
F. C. Breismeister
L. E. Collins
R. B. Corbit
W. F. Crozier
M. V. Davis
*J. D. Duncan**
G. L. Fox
A. R. Fronduti
*G. A. Gix**
M. A. Grieco
C. R. Hess
G. J. Hill
M. L. Hoitomt
C. W. Holmes
A. J. Julicher
R. M. Kotan
P. W. Marshall
W. A. Milek, Jr.
J. L. Munnerlyn
J. E. Myers
M. L. Peterson
J. W. Post
D. E. H. Reynolds
J. E. Roth
W. W. Sanders, Jr.
R. E. Shaw, Jr.
J. L. Skiles
D. L. Sprow
R. W. Stieve
P. J. Sullivan
J. D. Theisen
B. D. Wright

D1x—Executive Committee/General Requirements

D. L. McQuaid, Chair
D. D. Rager, 1st V.C.
D. K. Miller, 2nd V.C.
A. W. Sindel, 3rd V.C.
H. H. Campbell III, Secretary
R. D. Block
L. E. Collins
E. G. Costello
A. R. Fronduti
M. A. Grieco
C. R. Hess
M. L. Hoitomt
A. J. Julicher
J. E. Myers
R. E. Shaw, Jr.

D1a—Subcommittee 1 on Design

A. J. Julicher, Chair
T. J. Schlafly, V.C.
N. J. Altebrando
R. M. Bent
O. W. Blodgett
B. M. Butler
J. S. Fortenberry
M. J. Jordan
L. A. Kloiber
R. M. Kotan
P. W. Marshall
W. A. Milek, Jr.
T. Omura
J. A. Packer
F. J. Palmer
*W. W. Sanders, Jr.**
J. H. Schlect
J. G. Shaw
R. E. Shaw, Jr.
D. L. Sprow
R. H. R. Tide
W. Thornton

D1b—Subcommittee 2 on Qualification

D. D. Rager, Chair
R. A. Dennis, V.C.
E. L. Bickford
R. D. Block
R. Bonneau
F. C. Breismeister
J. J. Cecilio
R. B. Corbit
D. A. DelSignore
R. A. Dennis
*J. D. Duncan**
A. R. Fronduti
J. C. Gerardy
M. A. Grieco
M. L. Hoitomt
*E. R. Holby**
D. L. Long
H. W. Ludewig
J. Mieske
D. K. Miller
J. C. Nordby
*M. L. Peterson**
J. W. Post
J. E. Roth
D. Shapira
A. W. Sindel
D. L. Sprow
C. R. Stuart
*G. R. Swank**
J. E. Uebele
*B. E. Wright**

D1c—Subcommittee 3 on Fabrication

D. K. Miller, Chair
D. L. Long, V.C.
*W. G. Alexander**
F. R. Beckmann
L. E. Collins
G. L. Fox
*G. A. Gix**
M. A. Grieco
C. R. Hess
G. J. Hill
W. A. Milek, Jr.
J. L. Munnerlyn
J. E. Myers
J. W. Post
D. D. Rager
D. E. H. Reynolds
A. W. Sindel
J. L. Skiles
R. H. R. Tide
K. K. Verma

D1d—Subcommittee 4 on Inspection

M. L. Hoitomt, Chair
J. H. Kiefer, V.C.
*W. G. Alexander**
*E. M. Beck**
F. R. Beckmann
L. E. Collins
W. F. Crozier
G. L. Fox
C. W. Hayes
G. J. Hill
P. W. Marshall
D. M. Marudas
J. K. Merrill
*W. A. Milek, Jr.**
J. L. Munnerlyn
D. R. Scott
R. W. Stieve
P. J. Sullivan
W.A. Svekric
J. D. Theisen
K. K. Verma

D1e—Subcommittee 5 on Stud Welding

A. R. Fronduti, Chair
C. C. Pease, V.C.
H. Chambers
*G. A. Gix**
F. L. Hicks

*Advisor

D1f—Subcommitee 6 on Strengthening and Repair

R. E. Shaw, Jr., Chair
N. J. Altebrando, V.C.
R. M. Bent
J. J. Cecilio
C. R. Hess
G. J. Hill
*C. W. Holmes**
M. J. Mayes
J. W. Post
D. L. Sprow
R. W. Stieve
R. H. R. Tide

D1g—Subcommittee 7 on Aluminum Structures

E. G. Costello, Chair
F. G. Armao
R. Bonneau
R. C. Briden
S. L. M. Cole [Secretary]
M. V. Davis
P. B. Dickerson
*J. M. Gdaniec**
*D. Kosteas**
R. C. Minor
D. D. Rager
W. W. Sanders, Jr.
P. J. Sullivan

D1h—Subcommittee 8 on Sheet Steel

R. D. Block, Chair
J. E. Roth, V.C.
*R. E. Albrecht**
*O. W. Blodgett**
R. B. Corbit
*J. D. Duncan**
W. Jaxa-Rozen
R. D. Lawrence
*T. Pekoz**
J. L. Skiles
J. L. Uebele
B. D. Wright

D1i—Subcommittee 9 on Reinforcing Bars

J. E. Myers, Chair
W. F. Crozier
D. P. Gustafson
R. M. Kotan
M. J. Mayes
D. R. Scott

D1j—Subcommittee 10 on AASHTO/AWS Bridge Welding Committee

C. R. Hess, Co-Chair, AWS
M. A. Grieco, Co-Chair, AASHTO

AWS D1 Representatives

*W. G. Alexander**
*N. J. Altebrando**
F. R. Beckmann
*L. E. Collins**
*A. R. Fronduti**
C. R. Hess
*D. L. McQuaid**
J. K. Mieske
D. K. Miller
J. E. Myers

AASHTO Representatives

W. F. Crozier
C. W. Holmes
R. D. Medlock
J. T. Staley
*R. W. Stieve**
K. K. Verma

*Advisor

D1k—Subcommittee 11 on Stainless Steel Welding

A. W. Sindel, Chair
B. M. Butler, V.C.
*R. E. Avery**
D. Baird
R. D. Block
R. Bonneau
F. C. Breismeister
*H. Chambers**
R. B. Corbit
*E. G. Costello**
D. A. DelSignore
*J. D. Duncan**
*G. A. Gix**
M. J. Harker
G. J. Hill
M. L. Hoitomt
*E. R. Holby**
W. Jaxa-Rozen
R. M. Kotan
D. Kotecki
J. W. McGrew
J. Merrill
J. E. Roth
D. Shapira
J. D. Theisen
B. D. Wright
B. Young

D1l—Subcommittee 12 on Seismic Welding Issues

L. E. Collins, Chair
*N. J. Altebrando**
E. M. Beck
*R. M. Bent**
F. C. Breismeister
B. M. Butler
*S. Camo**
*E. G. Costello**
R. Hamburger
M. L. Hoitomt
R. M. Kotan
D. L. Long
*S. Mahin**
J. Malley
M. J. Mayes
*D. L. McQuaid**
*J. K. Merrill**
W. A. Milek
D. K. Miller
*D. C. Phillips**
J. W. Post
D. Rees-Evans
T. Schlafly
*R. E. Shaw, Jr.**
R. H. R. Tide
C. M. Uang
*K. K. Verma**

D1m—Standing Task Group on New Materials

D. K. Miller, Chair
T. Schlafly, V. C.
F. C. Breismeister
B. M. Butler
M. L. Hoitomt
R. D. Medlock
W. A. Milek
D. C. Phillips
J. W. Post
D. Rees-Evans
D. Shapira
A. W. Sindel

Foreword

(This Foreword is not a part of ANSI/AWS D1.1-98, *Structural Welding Code—Steel*, but is included for information purposes only.)

The first edition of the *Code for Fusion Welding and Gas Cutting in Building Construction* was published by the American Welding Society in 1928. The first bridge welding specification was published separately in 1936. The two documents were consolidated in 1972 in the D1.1 document but were once again separated in 1988 when the joint ANSI/AASHTO/AWS D1.5, *Bridge Welding Code*, was published to address the specific requirements of State and Federal Transportation Departments. Coincident with this, the D1.1 code changed references of buildings and bridges to statically loaded and dynamically loaded structures, respectively, in order to make the document applicable to a broader range of structural configurations.

The 1994 edition of the code was extensively reorganized in the 1996 edition, which provided users with the 1994 reference numbers and their 1996 counterparts. However, that practice is discontinued. Underlined text indicates an editorial or technical change from the 1996 edition.

The following is a summary of the most significant technical revisions contained in D1.1-98:

Subsection 2.4.7.1—The requirements for terminating fillet welds have been changed.

Figure 3.4, Joint details B-U4a-S, BU4b-S, B-U8-S, TC-U8a-S—These new SAW details for joints in prequalified WPSs have been added.

Table 3.1 and 3.2—The following steels have been added to the base metal-filler metal and preheat/interpass temperature tables:

API 2W Grades 42, 50, 50T, 60

API 2Y Grades 42, 50, 50T, 60

ASTM A913 Grades 50, 60, 65

Table 4.10—Unlisted steels have been deleted as a welder qualification essential variable.

Subsection 5.3.2.4—Requirements for preparation of heating ovens for baking electrodes have been added.

Subsection 5.18.2.2—This subsection (numbered 5.18.2.3 in D1.1-96) has added the GMAW and FCAW-G processes for making tack welds in SAW joints.

Table 6.1 and subsection 6.11—ASTM A709 Grades 100 and 100W have been added as steels requiring at least a 48 hour delay prior to inspection.

Subsection 6.30.2.1—The graduation of display screens for ultrasonic testing equipment using digital amplitude readouts have been added.

Annex E—A WPS/PQR form for stud welding has been provided as a nonmandatory option.

Editorial changes include: renumbering and moving 6.14.1 from D1.1-96 as 6.1.1 of D1.1-98 (with subsequent renumbering of 6.1 and 6.14 subsections), revising formulae in 2.40.2.2, redrawing Figure 6.22 (IIIW block), and changing titles to 2.1.1, 2.4.7, 2.26, 2.28, 4.11.2, 5.3.2.4, 5.18.2.3, and 6.22.7.4.

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

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

Mandatory Annexes. These additions to the code are requirements that supplement the text.

Non-Mandatory Annexes. These annexes are not requirements but are provided as options that are permitted by the code. Though they are not mandatory, it is essential that all provisions of these appendixes be followed when the option to use them is exercised.

Index. As in previous codes, the entries in the Index are referred to by subsection 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, in the Society News Section of the AWS *Welding Journal*, any errata (major changes) that have been noted will be published in the July and November issues of the *Welding Journal*.

Suggestions. Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, Structural Welding Committee, American Welding Society, 550 N.W. LeJeune Road., Miami, Florida 33126.

Interpretations. Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services, American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126 (See Annex F).

Table of Contents

Page No.

Commentary

List of Tables

List of Figures

Figure **Page No.**

Commentary

1. General Requirements

1.1 Scope

This code contains the requirements for fabricating and erecting welded steel structures. When this code is stipulated in contract documents, conformance with all provisions of the code shall be required, except for those provisions that the Engineer or contract documents specifically modifies or exempts.

The following is a summary of the code sections:

1. General Requirements. This section contains basic information on the scope and limitations of the code.

2. Design of Welded Connections. This section contains requirements for the design of welded connections composed of tubular, or nontubular, product form members.

3. Prequalification. This section contains the requirements for exempting a WPS (Welding Procedure Specification) from the qualification requirements of this code.

4. Qualification. This section contains the qualification requirements for WPSs and welding personnel (welders, welding operators and tack welders) necessary to perform code work.

5. Fabrication. This section contains the requirements for the preparation, assembly and workmanship of welded steel structures.

6. Inspection. This section contains criteria for the qualifications and responsibilities of inspectors, acceptance criteria for production welds, and standard procedures for performing visual inspection and NDT (nondestructive testing)

7. Stud Welding. This section contains the requirement for the welding of studs to structural steel.

8. Strengthening and Repair of Existing Structures. This section contains basic information pertinent to the welded modification or repair of existing steel structures.

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

(1) Steels with a minimum specified yield strength greater than 100 ksi (690 MPa)

(2) Steels less than 1/8 in. (3.2 mm) thick. When base metals thinner than 1/8 in. thick are to be welded, the requirements of ANSI/AWS D1.3 should apply. When used in conjunction with ANSI/AWS D1.3, conformance with the applicable provisions of this code shall be required.

(3) Pressure vessels or pressure piping

(4) Base metals other than carbon or low-alloy steels

1.2 Approval

All references to the need for approval shall be interpreted to mean approval by the Building Commissioner or the Engineer. Hereinafter, the term *Engineer* will be used, and it is to be construed to mean the Building Commissioner or the Engineer.

1.3 Mandatory Provisions

Most provisions of the code are mandatory when the use of the code is specified. Certain provisions are optional and apply only when specified in contract documents for a specific project. Examples of common optional requirements and typical ways to specify them are given in Annex C.

1.4 Definitions

The welding terms used in this code shall be interpreted in accordance with the definitions given in the latest edition of ANSI/AWS A3.0, *Standard Welding*

Terms and Definitions, supplemented by Annex B of this code.

1.5 Welding Symbols

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

1.6 Safety Precautions

Safety precautions shall conform to the latest edition of ANSI Z49.1, *Safety in Welding, Cutting,* and *Allied Processes*, published by the American Welding Society (also see Annex J, Safe Practices).

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

1.7 Standard Units of Measurement

The values stated in U.S. customary units are to be regarded as the standard. The metric (SI) equivalents of U.S. customary units given in this code may be approximate.

2. Design of Welded Connections

2.0 Scope

This section covers the requirements for the design of welded connections. It is divided into four Parts, described as follows:

Part A—Common Requirements of Nontubular and Tubular Connections. This part covers the requirements applicable to all connections, regardless of the product form or the type of loading, and shall be used with the applicable requirements of Parts B, C, and D.

Part B—Specific Requirements for Nontubular Connections (Statically or Cyclically Loaded). This part covers the specific requirements for connections between non-tubular cross-sections, regardless of the type of loading, and shall be used with the applicable requirements of Parts A and C.

Part C—Specific Requirements for Cyclically Loaded Nontubular Connections. This part covers the specific requirements for connections between nontubular cross-sections subjected to cyclic loads of sufficient magnitude and frequency to cause the potential for fatigue failure, and shall be used with the applicable requirements of Parts A and B.

Part D—Specific Requirements for Tubular Connections. This part covers the specific requirements for connections between tubular cross-sections, regardless of the type of loading, and shall be used with the applicable requirements of Part A.

Part A
Common Requirements of Nontubular and Tubular Connections

2.1 Stresses

2.1.1 Allowable Base-Metal Stresses. The base-metal stresses shall not exceed those specified in the applicable design specifications.

2.1.2 Allowable Increase. Where the applicable design specifications permit the use of increased stresses in the base metal for any reason, a corresponding increase shall be applied to the allowable stresses given herein, but not to the stress ranges permitted for base metal or weld metal subject to cyclic loading.

2.1.3 Laminations and Lamellar Tearing. Where welded joints introduce through-thickness stresses, the anisotropy of the material and the possibility of base-metal separation should be recognized during both design and fabrication. See Commentary.

2.2 Drawings

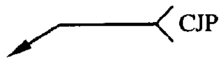
2.2.1 Drawing Information. Full and complete information regarding location, type, size, and extent of all welds shall be clearly shown on the drawings. The drawings shall clearly distinguish between shop and field welds.

2.2.2 Joint Welding Sequence. Drawings of those joints or groups of joints in which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted.

2.2.3 Weld Size and Length. Contract design drawings shall specify the effective weld length and, for partial penetration groove welds, the required weld size, as defined in this code. Shop or working drawings shall specify the groove depths (S) applicable for the weld size (E) required for the welding process and position of welding to be used.

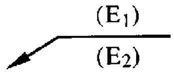
2.2.4 Groove Welds. Detail drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of material required to make them. Both width and thickness of steel backing shall be detailed.

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



complete joint penetration groove weld (CJP)

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



(E_1) (E_2) } partial joint penetration groove weld (PJP)

where

(E_1) = weld size, other side
(E_2) = weld size, arrow side

2.2.4.2 Prequalified Detail Dimensions. The joint details specified in 3.12 (PJP) and 3.13 (CJP) have repeatedly demonstrated their adequacy in providing the conditions and clearances necessary for depositing and fusing sound weld metal to base metal. However, the use of these details in prequalified WPSs shall not be interpreted as implying consideration of the effects of welding process on material beyond the fusion boundary nor suitability for a given application.

2.2.4.3 Special Details. When special groove details are required, they shall be completely detailed in the contract plans.

2.2.5 Special Inspection Requirements. Any special inspection requirements shall be noted on the drawings or in the specifications.

2.3 Groove Welds

2.3.1 Effective Weld Length. The maximum effective weld length for any groove weld, square or skewed, shall be the width of the part joined, perpendicular to the direction of tensile or compressive stress. For groove welds transmitting shear, the effective length is the length specified.

2.3.2 Effective Area. The effective area shall be the effective weld length multiplied by the weld size.

2.3.3 Partial Joint Penetration Groove Welds

2.3.3.1 Minimum Weld Size. Partial joint penetration groove weld sizes shall be equal to or greater than the size specified in 3.12.2 unless the WPS is qualified per section 4.

2.3.3.2 Effective Weld Size (Flare Groove). The effective weld size for flare groove welds when filled flush to the surface of a round bar, a 90° bend in a formed section, or a rectangular tube shall be as shown in Table 2.1, except as permitted by 4.10.5.

Table 2.1
Effective Weld Sizes of Flare Groove Welds (see 2.3.3.2)

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
5/16 R	1/2 R*

NOTE: R = radius of outside surface

* Use 3/8 R for GMAW (except short circuiting transfer) process when R is 1/2 in. (13 mm) or greater.

2.3.4 Complete Joint Penetration Groove Welds

2.3.4.1 Weld Size. The weld size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase in the effective area for design calculations is permitted for weld reinforcement. Groove weld sizes for welds in T-, K-, and Y-connections in tubular members are shown in Table 3.6.

2.4 Fillet Welds

2.4.1 Effective Throat

2.4.1.1 Calculation. The effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld (see Annex I). *Note: See Annex II for formula governing the calculation of effective throats for fillet welds in skewed T-joints. A tabulation of measured legs (W) and acceptable root openings (R) related to effective throats (E) has been provided for dihedral angles between 60° and 135°.*

2.4.1.2 Shear Stress. Stress on the effective throat of fillet welds is considered as shear stress regardless of the direction of the application.

2.4.1.3 Reinforcing Fillet Welds. The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld minus 1/8 in. (3 mm) for any groove detail requiring such deduction (see Figure 3.3 and Annex I).

2.4.2 Length

2.4.2.1 Effective Length (Straight). The effective length of a straight fillet weld shall be the overall length of the full-size fillet, including boxing. No reduction in effective length shall be assumed in design calculations to allow for the start or stop crater of the weld.

2.4.2.2 Effective Length (Curved). 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 calculated from this length is greater than the area calculated from 2.5.1, then this latter area shall be used as the effective area of the fillet weld.

2.4.2.3 Minimum Length. The minimum effective length of a fillet weld shall be at least four times the nominal size, or the effective size of the weld shall be considered not to exceed 25% of its effective length.

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

2.4.4 Minimum Leg Size. See 5.14 for the minimum leg sizes required for fillet welds.

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

(1) the thickness of the base metal, for metal less than 1/4 in. (6.4 mm) thick (see Figure 2.1, Detail A)

(2) 1/16 in. (1.6 mm) less than the thickness of base metal, for metal 1/4 in. (6.4 mm) or more in thickness (see Figure 2.1, 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 less than 1/16 in. (1.6 mm), provided the weld size is clearly verifiable.

2.4.6 Intermittent Fillet Welds (Minimum Length). The minimum length of an intermittent fillet weld shall be 1-1/2 in. (38 mm).

2.4.7 Fillet Weld Terminations

2.4.7.1 Drawings. The length and disposition of welds, including end returns or boxing, shall be indicated on the design and detail drawings. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may be boxed except as limited by 2.4.7.2 through 2.4.7.5.

2.4.7.2 Lap Joints. In lap joints between parts subject to calculated tensile stress in which one part extends beyond the edge or side of the part to which it is connected, fillet welds shall terminate not less than the size of the weld from the start of the extension. (See Commentary.)

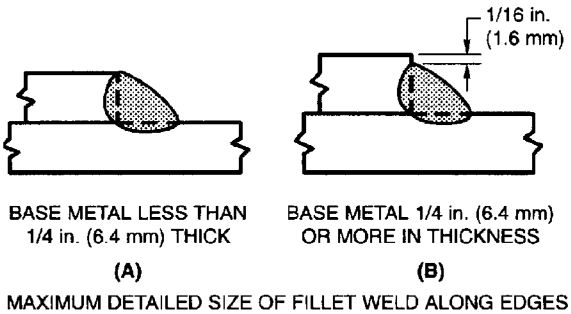


Figure 2.1—Details for Prequalified Fillet Welds (see 2.4.5)

2.4.7.3 Maximum End Return Length. Flexible connections rely on the flexibility of the outstanding legs. If the outstanding legs are attached with end returned welds, the length of the end return shall not exceed four times the nominal weld size. Examples of flexible connections include framing angles, top angles of seated beam connections and simple end plate connections.

2.4.7.4 Stiffener Welds. Except where the ends of stiffeners are welded to the flange, fillet welds joining transverse stiffeners to girder webs shall start or terminate not less than four times, nor more than six times, the thickness of the web from the web toe of the web-to-flange welds.

2.4.7.5 Opposite Sides of Common Plane. Fillet welds which occur on opposite sides of a common plane shall be interrupted at the corner common to both welds. (See Figure 2.12.)

2.4.8 Lap Joints. 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.

2.4.8.1 Double-Fillet Welds. Transverse fillet welds in lap joints transferring stress between axially loaded parts shall be double-fillet welded (see Figure 2.5) except where deflection of the joint is sufficiently restrained to prevent it from opening under load.

2.4.8.2 Minimum Overlap. The minimum overlap of parts in stress-carrying lap joints shall be five times the thickness of the thinner part, but not less than 1 inch.

2.4.8.3 Fillet Welds in Holes or Slots. Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to the requirements of 2.5. 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 2.4.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

2.5 Plug and Slot Welds

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

2.5.2 Minimum Spacing (Plug Welds). The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

2.5.3 Minimum Spacing (Slot Welds). The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction on any line shall be two times the length of the slot.

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

2.5.5 Prequalified Dimensions. For plug and slot weld dimensions that are prequalified, see 3.10.

2.5.6 Prohibition in Q&T Steel. Plug and slot welds are not permitted in quenched and tempered steels.

2.5.7 Limitation. Plug or slot weld size design shall be based on shear in the plane of the faying surfaces.

2.6 Joint Configuration

2.6.1 General Requirements for Joint Details. In general, details should minimize constraint against ductile behavior, avoid undue concentration of welding, and afford ample access for depositing the weld metal.

2.6.2 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 calculated with reference to the axis of the group in order to determine the allowable capacity of the combination. However, such methods of adding individual capacities of welds does not apply to fillet welds reinforcing groove welds (see Annex I).

2.6.3 Welds with Rivets or Bolts. Rivets or bolts used in bearing type connections shall not be considered as sharing the load in combination with welds. Welds, if used, shall be provided to carry the entire load in the connection. However, connections that are welded to one member and riveted or bolted to the other member are permitted. High-strength bolts properly installed as a slip-critical-type connection prior to welding may be considered as sharing the stress with the welds.

2.7 Beam End Connections

Welded beam end connections shall be designed in accordance with the assumptions about the degree of restraint involved in the designated type of construction.

2.8 Eccentricity

In the design of welded joints, the total stresses, including those due to eccentricity, if any, in alignment of the corrected parts and the disposition, size and type of welded joints shall not exceed those provided in this code. For statically loaded structures, the disposition of fillet welds to balance the forces about the neutral axis or axes for end connections of single-angle, double-angle, and similar type members is not required; such weld arrangements at the heel and toe of angle members may be distributed to conform to the length of the various available edges. Similarly, Ts or beams framing into chords of trusses, or similar joints, may be connected with unbalanced fillet welds.

Part B
Specific Requirements for Nontubular Connections (Statically or Cyclically Loaded)

2.9 General

The specific requirements of Part B commonly apply to all connections of nontubular members subject to static or cyclic loading. Part B shall be used with the applicable requirements of Parts A or C.

2.10 Allowable Stresses

The allowable stresses in welds shall not exceed those given in Table 2.3, or as permitted by 2.14.4 and 2.14.5, except as modified by 2.1.2.

2.11 Skewed T-Joints

2.11.1 General. Prequalified skewed T-joint details are shown in Figure 3.11. The details for the obtuse and acute side may be used together or independently depending on service conditions and design with proper consideration for concerns such as eccentricity and rotation. The Engineer shall specify the weld locations and must make clear on the drawings the weld dimensions required. In detailing skewed T-joints, a sketch of the desired joint, weld configuration, and desired weld dimensions shall be clearly shown on the drawing.

2.11.2 Prequalified Minimum Weld Size. See 3.9.3.2 for prequalified minimum weld sizes.

2.11.3 Effective Throat. The effective throat of skewed T-joint welds is dependent on the magnitude of the root opening. See 5.22.1.

2.11.3.1 Z Loss Reduction. The acute side of prequalified skewed T-joints with dihedral angles less than 60° and greater than 30° may be used as shown in Figure 3.11, Detail D. The method of sizing the weld, effective throat "E" or leg "W" shall be specified on the drawing or specification. The "Z" loss dimension specified in Table 2.2 shall apply.

Table 2.2
Z Loss Dimension (Nontubular) (see 2.11.3.1)

	Position of Welding V or OH			Position of Welding H or F		
Dihedral Angles Ψ	Process	Z (in.)	Z (mm)	Process	Z (in.)	Z (mm)
60° > Ψ ≥ 45°	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
45° > Ψ ≥ 30°	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6

2.12 Partial Length Groove Weld Prohibition

Intermittent or partial length groove welds are not permitted except that members built-up of elements connected by fillet welds, at points of localized load application, may have groove welds of limited length to participate in the transfer of the localized load. The groove weld shall extend at uniform size for at least the length required to transfer the load. Beyond this length, the groove shall be transitioned in depth to zero over a distance, not less than four times its depth. The groove shall be filled flush before the application of the fillet weld. (See Commentary, Figure C2.24)

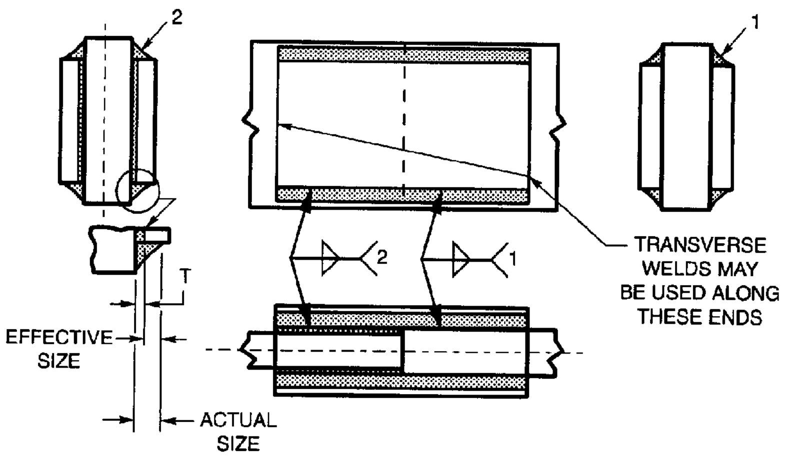
2.13 Filler Plates

Filler plates may be used in the following:

(1) Splicing parts of different thicknesses

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

2.13.1 Filler Plates Less Than 1/4 in. Filler plates less than 1/4 in. (6.4 mm) thick shall not be used to transfer stress, but shall be kept flush with the welded edges of the stress-carrying part. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler plate (see Figure 2.2).



NOTE: THE EFFECTIVE AREA OF WELD 2 SHALL EQUAL THAT OF WELD 1, BUT ITS SIZE SHALL BE ITS EFFECTIVE SIZE PLUS THE THICKNESS OF THE FILLER PLATE T.

Figure 2.2—Filler Plates Less Than 1/4 in. (6.4 mm) Thick (see 2.13.1)

2.13.2 Filler Plates 1/4 in. or Larger. Any filler plate 1/4 in. (6.4 mm) or more in thickness shall extend beyond the edges of the splice plate or connection material. It shall be welded to the part on which it is fitted, and the joint shall be of sufficient strength to transmit the splice plate or connection material stress applied at the surface of the filler plate as an eccentric load. The welds joining the splice plate or connection material to the filler plate shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid over stressing the filler plate along the toe of the weld (see Figure 2.3).

2.14 Fillet Welds

2.14.1 Longitudinal Fillet Welds. If longitudinal fillet welds are used alone in end connections of flat bar tension members, the length of each fillet weld shall be no less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 8 in. (200 mm) unless end transverse welds or intermediate plug or slot welds are used.

2.14.2 Intermittent Fillet Welds. Intermittent fillet welds may be used to carry calculated stress.

2.14.3 Corner and T-Joint Reinforcement. If fillet welds are used to reinforce groove welds in corner and T-joints, the fillet weld size shall not be less than 25% of the thickness of the thinner part joined, but need not be greater than 3/8 in. (9.5 mm).

2.14.4 In-Plane Center of Gravity Loading. The allowable stress in a linear weld group loaded in-plane through the center of gravity is the following:

$$F_v = 0.30F_{EXX} (1.0 + 0.50 \sin^{1.5} \Theta)$$

where:

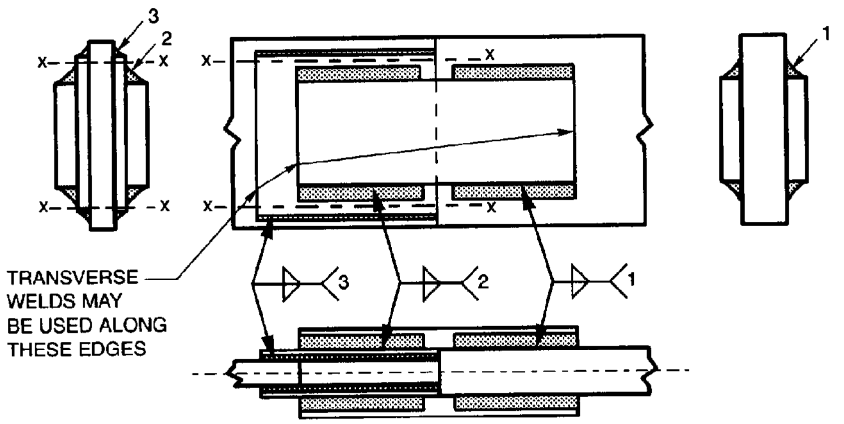
F_v = allowable unit stress, ksi
F_{EXX} = electrode classification number, i.e., minimum specified strength, ksi
Θ = angle of loading measured from the weld longitudinal axis, degrees

2.14.5 Instantaneous Center of Rotation. The allowable stresses in weld elements within a weld group that are loaded in-plane and analyzed using an instantaneous center of rotation method to maintain deformation compatibility and the nonlinear load-deformation behavior of variable angle loaded welds is the following:

$$F_{vx} = \Sigma F_{vix}$$
$$F_{vy} = \Sigma F_{viy}$$
$$F_{vi} = 0.30 F_{EXX} (1.0 + 0.50 \sin^{1.5}\Theta) f(p)$$
$$f(p) = [p(1.9 - 0.9p)]^{0.3}$$
$$M = \Sigma [F_{viy} (x) - F_{vix} (y)]$$

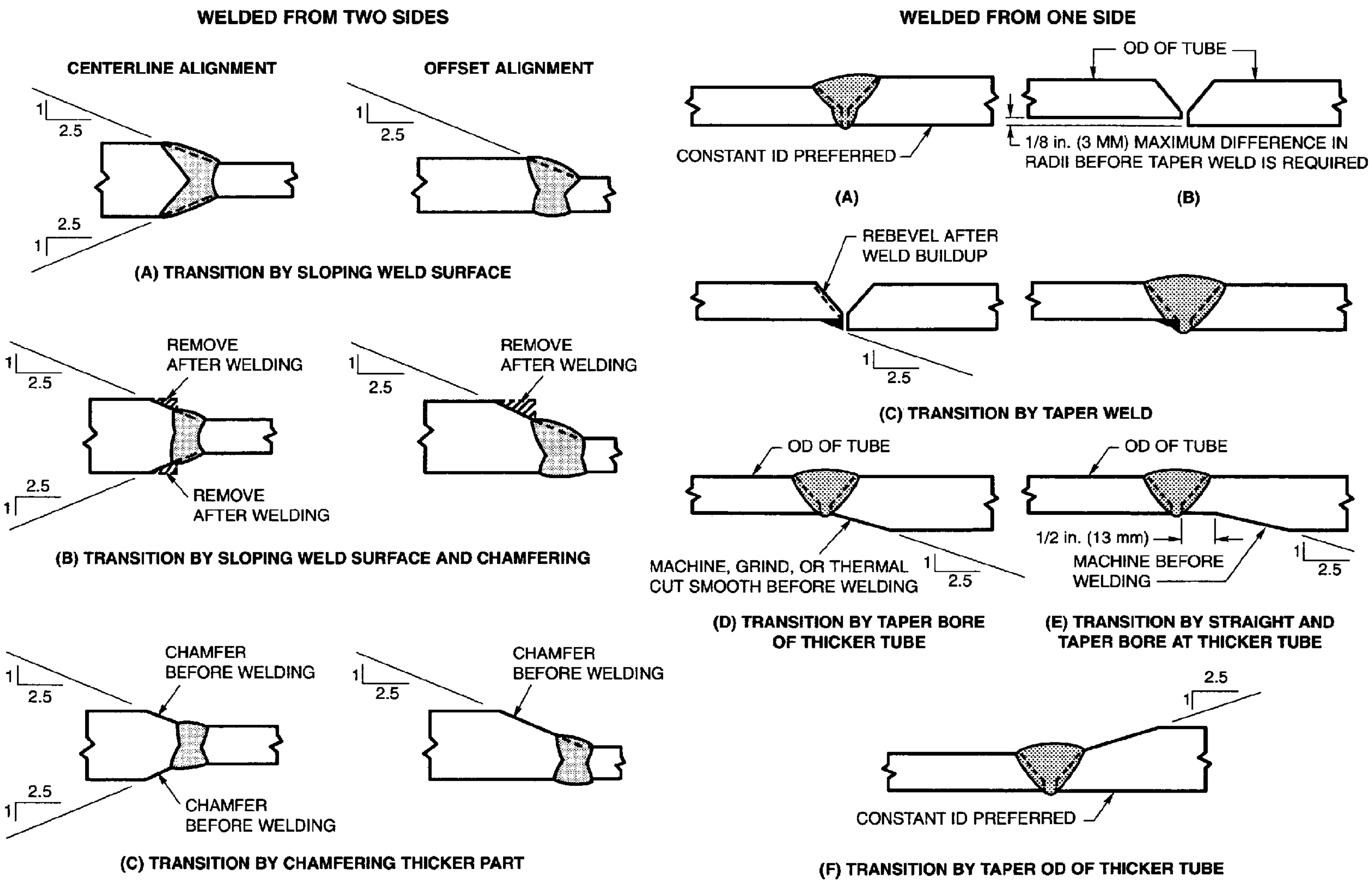
where:

F_{vix} = x component of stress F_{vi}
F_{viy} = y component of stress F_{vi}
M = moment of external forces about the instantaneous center of rotation
$p = \Delta_i/\Delta_m$ ratio of element "i" deformation to deformation in element at maximum stress



Notes:
1. The effective area of weld 2 shall equal that of weld 1. The length of weld 2 shall be sufficient to avoid overstressing the filler plates in shear along planes x-x.
2. The effective area of weld 3 shall 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 plates.

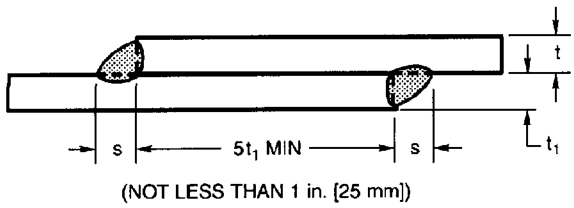
Figure 2.3—Filler Plates 1/4 in. (6.4 mm) or Thicker (see 2.13.2)



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

Note 3: In (B), (D), and (E) groove may be any permitted or qualified type and detail. Transition slopes shown are maximum permitted.

Figure 2.4—Transition of Thickness of Butt Joints in Parts of Unequal Thickness (Tubular) (see 2.41)



Notes:
1. s = as required
2. $t > t_1$

Figure 2.5—Double-Fillet Welded Lap Joint (see 2.4.8.1)

$\Delta_m = 0.209\ (\Theta + 2)^{-0.32}$ W, deformation of weld element at maximum stress, in.

$\Delta_u = 1.087\ (\Theta + 6)^{-0.65}$ W, < 0.17W, deformation of weld element at ultimate stress (fracture), usually in element furthest from instantaneous center of rotation, in.

W = leg size of the fillet weld, in.

Δ_i = deformation of weld elements at intermediate stress levels, linearly proportioned to the critical deformation based on distance from the instantaneous center of rotation, in. = $r_i \Delta_u / r_{crit}$

r_{crit} = distance from instantaneous center of rotation to weld element with minimum Δ_u/r_i ratio, in.

2.15 Built-Up Members

If two or more plates or rolled shapes are used to build up a member, sufficient welding (of the fillet, plug, or slot type) shall be provided to make the parts act in unison but not less than that which may be required to transfer calculated stress between the parts joined.

2.16 Maximum Spacing of Intermittent Welds

The maximum longitudinal spacing of intermittent welds connecting two or more rolled shapes or plates in contact with one another shall not exceed 24 in. (610 mm).

2.17 Compression Members

In built-up compression members, the longitudinal spacing of intermittent welds connecting a plate component to other components shall not exceed 12 in. (305 mm) nor the plate thickness times $4000/\sqrt{F_y}$ for F_y in psi; [$332/\sqrt{F_y}$ for F_y in MPA] (F_y = specified minimum yield strength of the type steel being used.) The unsupported width of web, cover plate, or diaphragm plates, between adjacent lines of welds, shall not exceed the plate thickness times $8000/\sqrt{F_y}$ (for F_y in psi), [$664/\sqrt{F_y}$ for F_y in MPa.]

When the unsupported width exceeds this limit, but a portion of its width no greater than 800 times the thickness would satisfy the stress requirements, the member will be considered acceptable.

2.18 Tension Members

In built-up tension members, the longitudinal spacing of intermittent welds connecting a plate component to other components, or connecting two plate components to each other, shall not exceed 12 in. (305 mm) or 24 times the thickness of the thinner plate.

2.19 End Returns

Side or end fillet welds terminating at ends or sides of header angles, brackets, beam seats and similar connections shall be returned continuously around the corners for a distance at least twice the nominal size of the weld except as provided in 2.4.7.

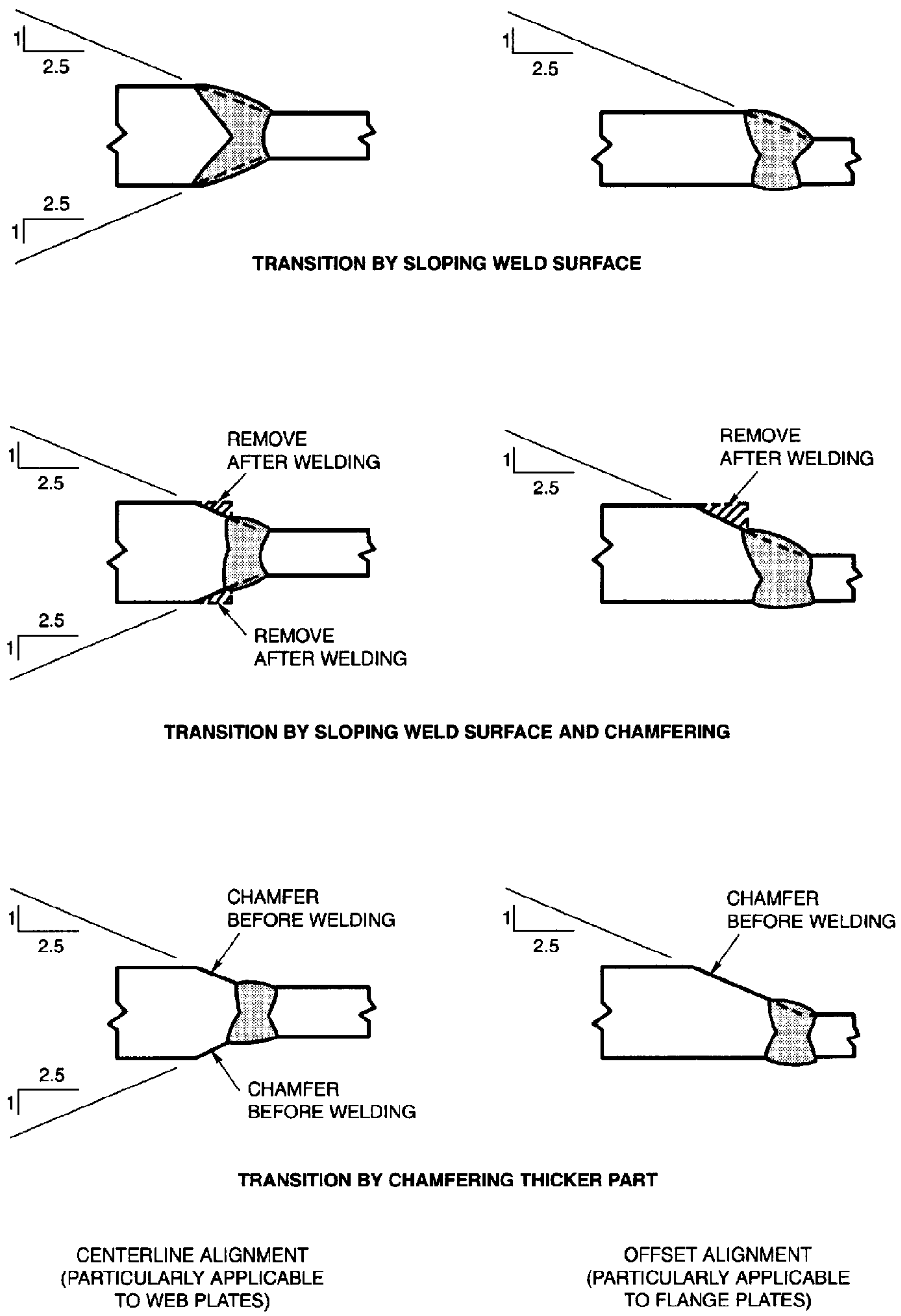
2.20 Transitions of Thicknesses and Widths

Tension butt joints between axially aligned members of different thicknesses or widths, or both, and subject to tensile stress greater than one-third the allowable design tensile stress shall be made in such a manner that the slope in the transition does not exceed 1 in 2-1/2 (see Figure 2.6 for thickness and Figure 2.7 for width). The transition shall be accomplished by chamfering the thicker part, tapering the wider part, sloping the weld metal, or by any combination of these.

Part C
Specific Requirements for Cyclically Loaded Nontubular Connections

2.21 General

Part C applies only to nontubular members and connections subject to cyclic load of frequency and magnitude sufficient to initiate cracking and progressive failure (fatigue). The provisions of Part C shall be applied to minimize the possibility of such a failure mechanism. The Engineer shall provide either complete details, including weld sizes, or shall specify the planned cycle life and the maximum range of moments, shears and reactions for the connections.



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

Figure 2.6—Transition of Butt Joints in Parts of Unequal Thickness (Nontubular) (see 2.20 and 2.29.1)

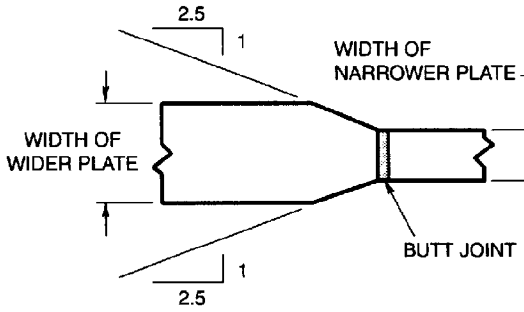


Figure 2.7—Transition of Widths (Statically Loaded Nontubular) (see 2.20)

2.21.1 Symmetrical Sections. 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.

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

2.21.3 Continuous Welds. 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.

2.22 Allowable Stresses

Except as modified by 2.23 and 2.24, allowable unit stresses in welds shall not exceed those listed in Table 2.3, or as determined by 2.14.4 or 2.14.5, as applicable.

2.23 Combined Stresses

In the case of axial stress combined with bending, the allowable stress, or stress range, as applicable, of each kind shall be governed by the requirements of 2.22 and 2.24 and the maximum combined stresses calculated therefrom shall be limited in accordance with the requirements of the applicable general specifications.

2.24 Cyclic Load Stress Range

The allowable stress range (fatigue) for structures subject to cyclic loading shall be provided in Table 2.4 and Figures 2.8, 2.9, and 2.10 for the applicable condition and cycle life.

2.25 Corner and T-Joints

2.25.1 Fillet Weld Reinforcement. Groove welds in corner and T-joints shall be reinforced by fillet welds with leg sizes not less than 25% of the thickness of the thinner part joined, but need not exceed 3/8 in. (9.5 mm).

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

2.26 Connections or Splices—Tension and Compression Members

Connections or splices of tension or compression members made by groove welds shall have complete joint penetration (CJP) welds. Connections or splices made with fillet or plug welds, except as noted in 2.31, 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 permitted by the applicable general specification.

2.26.1 RT or UT Requirements. When required by Table 2.4, weld soundness, for CJP groove welds subject to tension and reversal of stress, shall be established by radiographic or ultrasonic testing in conformance with section 6.

2.27 Prohibited Joints and Welds

2.27.1 Partial Joint Penetration Groove Welds. Partial joint penetration groove welds subject to tension normal to their longitudinal axis shall not be used where design criteria indicate cyclic loading could produce fatigue failure.

2.27.2 One-Sided Groove Welds. Groove welds, made from one side only, are prohibited, if the welds are made:

(1) without any backing, or

(2) with backing, other than steel, that has not been qualified in accordance with section 4.

These prohibitions for groove welds made from one side only shall not apply to the following:

Table 2.3
Allowable Stresses in Nontubular Connection Welds
(see 2.10 and 2.22)

Type of Weld	Stress in Weld[1]	Allowable Connection Stress[5]	Required Filler Metal Strength Level[2]
Complete joint penetration groove welds	Tension normal to the effective area	Same as base metal	Matching filler metal shall be used.
	Compression normal to the effective area	Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [69 MPa]) less than matching filler metal may be used.
	Tension or compression parallel to the axis of the weld	Same as base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Shear on the effective areas	0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	
Partial joint penetration groove welds	Compression normal to effective area (Joint not designed to bear)	0.50 × nominal tensile strength of filler metal, except stress on base metal shall not exceed 0.60 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Compression normal to effective area (Joint designed to bear)	Same as base metal	
	Tension or compression parallel to the axis of the weld[3]	Same as base metal	
	Shear parallel to axis of weld	0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	
	Tension normal to effective area	0.30 × nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed 0.60 × yield strength of base metal	
Fillet weld	Shear on effective area	0.30 × nominal tensile strength of filler metal[4]	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Tension or compression parallel to axis of weld[3]	Same as base metal	
Plug and slot welds	Shear parallel to faying surfaces (on effective area)	0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.

Notes:
1. For definition of effective area, see 2.3.2 for groove welds, 2.4.3 for fillet welds, and 2.5.1 for plug and slot welds.
2. For matching filler metal to base metal strength for code approved steels, see Table 3.1 and Annex M.
3. Fillet weld and partial joint penetration groove welds joining the component elements of built-up members, such as flange-to-web connections, may be designed without regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
4. Alternatively, see 2.14.4 and 2.14.5.
5. For cyclically loaded connections, see 2.10, 2.22, 2.23, and 2.24. For statically loaded connections, see 2.10.

Table 2.4
Fatigue Stress Provisions—Tension or Reversal Stresses* (Nontubulars) (see 2.24)

General Condition	Situation	Stress Category (see Figure 2.8)	Example (see Figure 2.8)
Plain material	Base metal with rolled or cleaned surfaces. Oxygen-cut edges with ANSI smoothness of 1000 or less.	A	1, 2
Built-up members	Base metal and weld metal in members without attachments, built up of plates or shapes connected by continuous complete or partial joint penetration groove welds or by continuous fillet welds parallel to the direction of applied stress.	B	3, 4, 5, 7
	Calculated flextural stress at toe of transverse stiffener welds on girder webs or flanges.	C	6
	Base metal at end of partial length welded cover plates having square or tapered ends, with or without welds across the ends.	E	7
Groove welds	Base metal and weld metal at complete joint penetration groove welded splices of rolled and welded sections having similar profiles when welds are ground[1] and weld soundness established by nondestructive testing.[2]	B	8, 9
	Base metal and weld metal in or adjacent to complete joint penetration groove welded splices at transitions in width or thickness, with welds ground[1] to provide slopes no steeper than 1 to 2-1/2[3] for yield strength less than 90 ksi (620 MPa) and a radius[8] of R ≥ 2 ft (0.6 m) for yield strength ≥ 90 ksi, and weld soundness established by nondestructive testing.[2]	B	10, 11a, 11b

General Condition	Situation	Longitudinal loading	Transverse loading[4]: Materials having equal or unequal thickness sloped,[6] welds ground,[1] web connections excluded.	Transverse loading[4]: Materials having equal thickness, not ground; web connections excluded.	Transverse loading[4]: Materials having unequal thickness, not sloped or ground, including web connections.	Example (see Figure 2.8)
Groove welded connections	Base metal at details of any length attached by groove welds subjected to transverse or longitudinal loading, or both, when weld soundness transverse to the direction of stress is established by nondestructive testing[2] and the detail embodies a transition radius, R, with the weld termination ground[1] when					
	(a) R ≥ 24 in. (610 mm)	B	B	C	E	13
	(b) 24 in. > R ≥ 6 in. (150 mm)	C	C	C	E	13
	(c) 6 in. > R ≥ 2 in. (50 mm)	D	D	D	E	13
	(d) 2 in. > R ≥ 0[7]	E	E	E	E	12,13

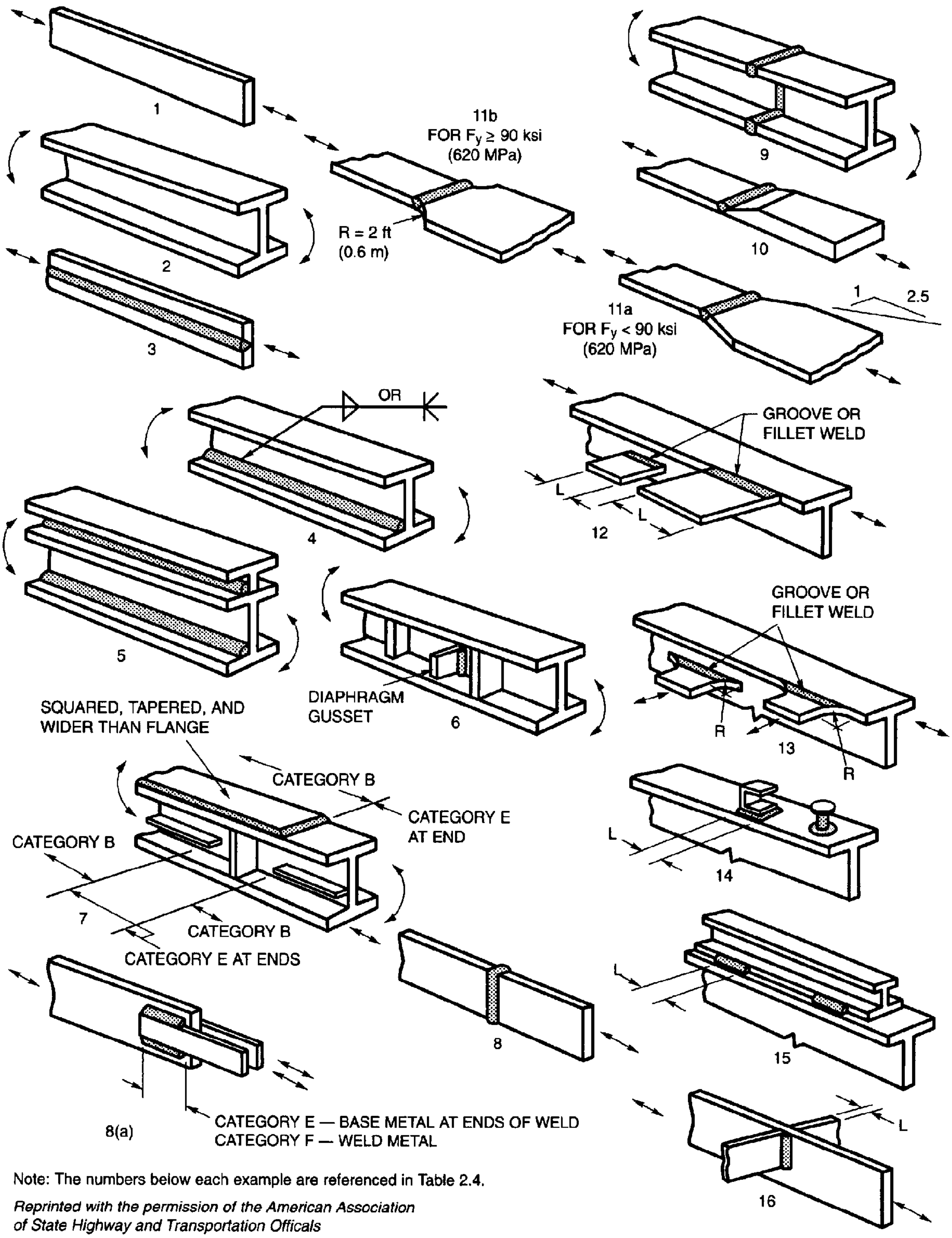
*Except as noted for fillet and stud welds.

Table 2.4 (Continued)

General Condition	Situation	Stress Category (see Figure 2.8)	Example (see Figure 2.8)
Groove welds	Base metal and weld metal in, or adjacent to, complete joint penetration groove welded splices either not requiring transition or when required with transitions having slopes no greater than 1 to 2-1/2[3] for yield strength less than 90 ksi (620 MPa) and a radius[8] of R ≥ 2 ft (0.6 m) for yield strength ≥ 90 ksi, and when in either case reinforcement is not removed and weld soundness is established by nondestructive testing.[2]	C	8, 9, 10, 11a, 11b
Groove or fillet welded connections	Base metal at details attached by groove or fillet welds subject to longitudinal loading where the details embody a transition radius, R, less than 2 in.[7], and when the detail length, L, parallel to the line of stress is		
	(a) < 2 in. (50 mm)	C	12, 14, 15, 16
	(b) 2 in. ≤ L < 4 in. (100 mm)	D	12
	(c) L ≥ 4 in.	E	12
Fillet welded connections	Base metal at details attached by fillet welds parallel to the direction of stress regardless of length when the detail embodies a transition radius, R, 2 in. or greater and with the weld termination ground.[1]		
	(a) When R ≥ 24 in. (610 mm)	B[5]	13
	(b) When 24 in. > R ≥ 6 in. (150 mm)	C[5]	13
	(c) When 6 in. > R ≥ 2 in. (50 mm)	D[5]	13
Fillet welds	Shear stress on throat of fillet welds.	F	8a
	Base metal at intermittent welds attaching transverse stiffeners and stud-type shear connectors.	C	7, 14
	Base metal at intermittent welds attaching longitudinal stiffeners.	E	—
Stud welds	Shear stress on nominal shear area of Type B shear connectors.	F	14
Plug and slot welds	Base metal adjacent to or connected by plug or slot welds.	E	—

Notes:
1. Finished according to 5.24.4.1 and 5.24.4.2.
2. Either RT or UT to meet quality requirements of 6.12.2 or 6.13.2 for welds subject to tensile stress.
3. Sloped as required by 2.29.1.
4. Applicable only to complete joint penetration groove welds.
5. Shear stress on throat of weld (loading through the weld in any direction) is governed by Category F.
6. Slopes similar to those required by Note 3 are mandatory for categories listed. If slopes are not obtainable, Category E must be used.
7. Radii less than 2 in. (50 mm) need not be ground.
8. Radii used as required by 2.29.3.

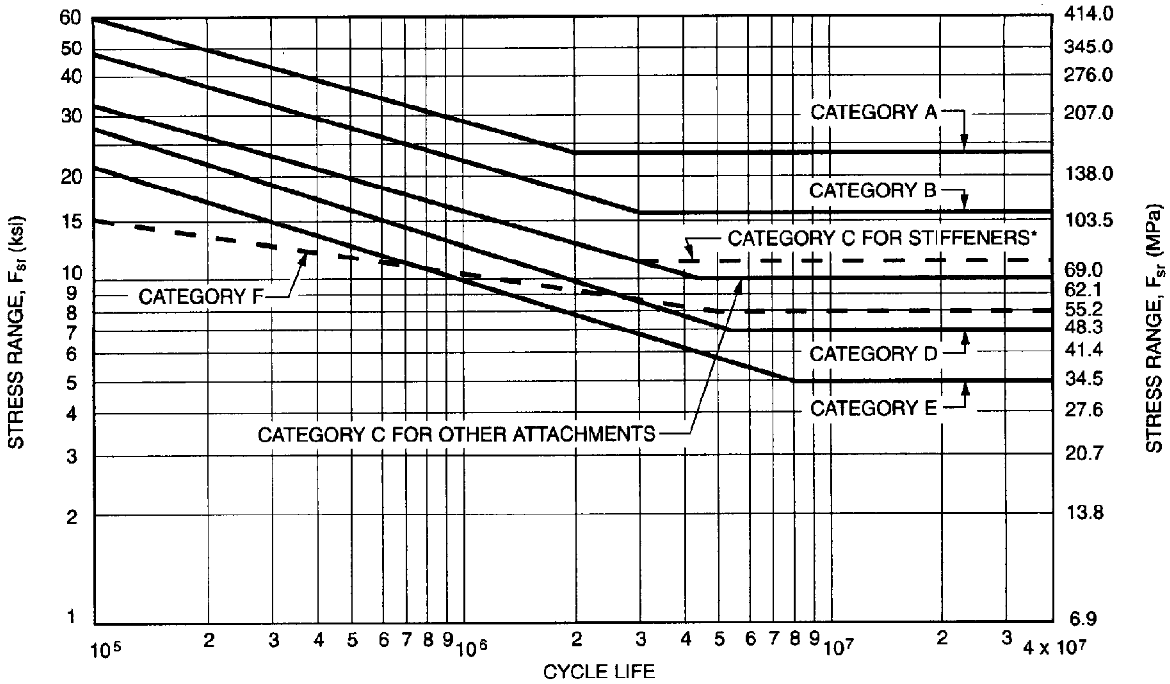
*Except as notified for fillet and stud welds.



Note: The numbers below each example are referenced in Table 2.4.

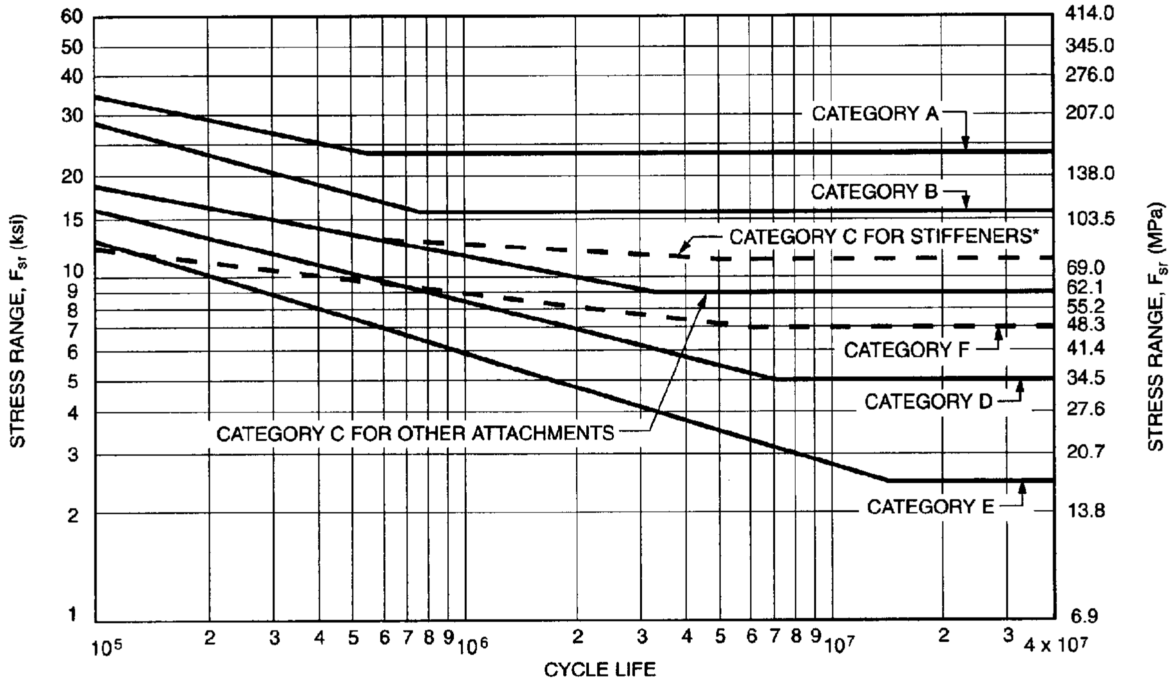
Reprinted with the permission of the American Association of State Highway and Transportation Officals

Figure 2.8—Examples of Various Fatigue Categories (see 2.24)



*TRANSVERSE STIFFENER WELDS ON GIRDER WEBS OR FLANGES

Figure 2.9—Design Stress Range Curves for Categories A to F—Redundant Structures (Nontubular) (see 2.24)



*TRANSVERSE STIFFENER WELDS ON GIRDER WEBS OR FLANGES

Figure 2.10—Design Stress Range Curves for Categories A to F—Nonredundant Structures (Nontubular) (see 2.24)

(a) Secondary or nonstress-carrying members and shoes or other nonstressed appurtenances, and

(b) Corner joints parallel to the direction of calculated stress, between components for built-up members designed primarily for axial stress

2.27.3 Intermittent Groove Welds. Intermittent groove welds are prohibited.

2.27.4 Intermittent Fillet Welds. Intermittent fillet welds, except as provided in 2.30.1, are prohibited.

2.27.5 Horizontal Position Limitation. Bevel-groove and J-grooves in butt joints for other than the horizontal position are prohibited.

2.27.6 Plug and Slot Welds. Plug and slot welds on primary tension members are prohibited.

2.27.7 Fillet Welds < 3/16 in. Fillet weld sizes less than 3/16 in. shall be prohibited.

2.28 Fillet Weld Terminations

For details and structural elements such as brackets, beam seats, framing angles, and simple end plates, the outstanding legs of which are subject to cyclic (fatigue) stresses that would tend to cause progressive failure initiating from a point of maximum stress at the weld termination, fillet welds shall be returned around the side or end for a distance not less than two times the weld size or the width of the part, whichever is less.

2.29 Transition of Thicknesses and Widths

2.29.1 Tension Butt-Joint Thickness. 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 in 2-1/2 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 2.6).

2.29.2 Shear or Compression Butt-Joint Thickness. In butt joints between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished as specified in 2.29.1 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 in 2-1/2 from the surface of the thinner part or shall be sloped to the surface of the thicker part if this requires a lesser slope with the following exception: Truss member joints and beam and girder flange joints shall be made with smooth transitions of the type specified in 2.29.1.

2.29.3 Tension Butt-Joint Width. Butt joints between parts having unequal width and subject to tensile stress shall have a smooth transition between offset edges at a slope of no more than 1 in 2-1/2 with the edge of either part or shall be transitioned with a 2.0 ft (610 mm) minimum radius tangent to the narrower part of the center of the butt joints (see Figure 2.11). A radius transition is required for steels having a yield strength greater than or equal to 90 ksi (620 MPa).

2.30 Stiffeners

2.30.1 Intermittent Fillet Welds. Intermittent fillet welds used to connect stiffeners to beams and girders shall comply with the following requirements:

(1) Minimum length of each weld shall be 1-1/2 in. (38 mm).

(2) A weld shall be made on each side of the joint. The length of each weld shall be at least 25% of the joint length.

(3) Maximum end-to-end clear spacing of welds shall be twelve times the thickness of the thinner part but not more than 6 in. (150 mm).

(4) Each end of stiffeners, connected to a web, shall be welded on both sides of the joint.

2.30.2 Arrangement. Stiffeners, if used, shall preferably be arranged in pairs on opposite sides of the web. Stiffeners may be welded to tension or compression flanges. The fatigue stress or stress ranges at the points of attachment to the tension flange or tension portions of the web shall comply with the fatigue requirements of the general specification. Transverse fillet welds may be used for welding stiffeners to flanges.

2.30.3 Single-Sided Welds. If stiffeners are used on only one side of the web, they shall be welded to the compression flange.

2.31 Connections or Splices in Compression Members with Milled Joints

If members subject to compression only are spliced and full-milled bearing is provided, the splice material and its welding shall be arranged, unless otherwise stipulated by the applicable general specifications, to hold all parts in alignment and shall be proportioned to carry 50% of the calculated stress in the member. Where such members are in full-milled bearing on base plates, there shall be sufficient welding to hold all parts securely in place.

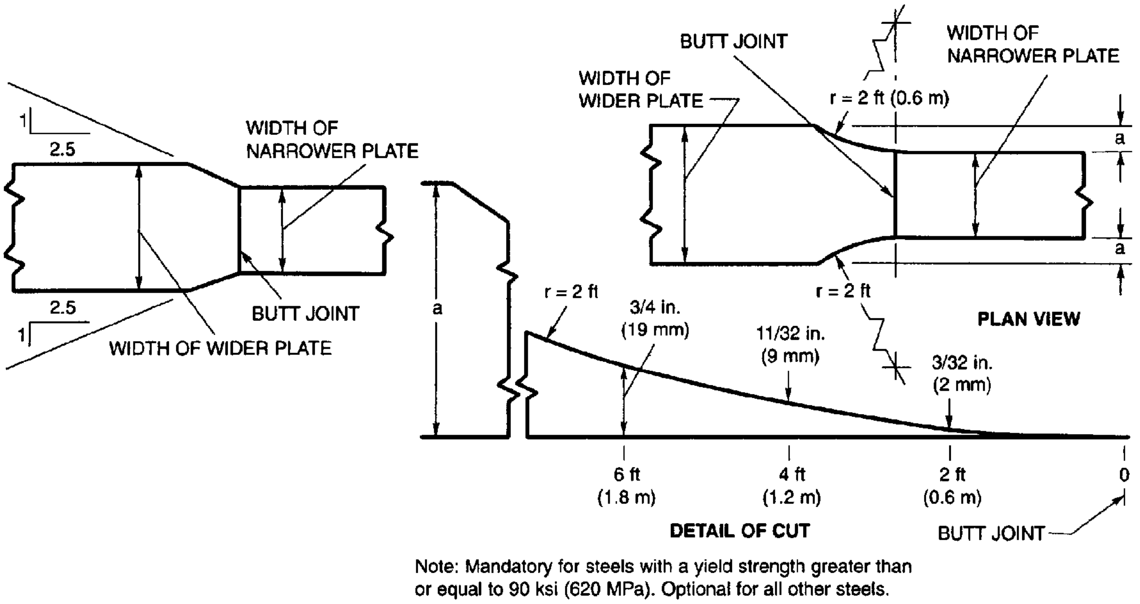


Figure 2.11—Transition of Width (Cyclically Loaded Nontubular) (see 2.29.3)

2.32 Lap Joints

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

2.32.2 Hole or Slot Spacing. 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.

2.33 Built-Up Sections

Girders (built-up I sections) shall preferably be made with one plate in each flange, i.e., without cover plates. The unsupported projection of a flange shall be no more than permitted by the applicable general specification. The thickness and width of a flange may be varied by butt joint welding parts of different thickness or width with transitions conforming to the requirements of 2.29.

2.34 Cover Plates

2.34.1 Thickness and Width. Cover plates shall preferably be limited to one on any flange. The maximum thickness of cover plates on a flange (total thickness of all cover plates if more than one is used) shall not be greater than 1-1/2 times the thickness of the flange to which the cover plate is attached. The thickness and width of a cover plate may be varied by butt joint welding parts of different thickness or width with transitions conforming to the requirements of 2.29. Such plates shall be assembled and welds ground smooth before being attached to the flange. The width of a cover plate, with recognition of dimensional tolerances allowed by ASTM A6, shall allow suitable space for a fillet weld along each edge of the joint between the flange and the plate cover.

2.34.2 Partial Length. Any partial length cover plate shall extend beyond the theoretical end by the terminal distance, or it shall extend to a section where the stress or stress range in the beam flange is equal to the allowable fatigue stress permitted by 2.24, whichever is greater. The theoretical end of the cover plate is the section at which the stress in the flange without that cover plate equals the allowable stress exclusive of fatigue considerations. The terminal distance beyond the theoretical end shall be at least sufficient to allow terminal development in one of the following manners:

(1) Preferably, terminal development shall be made with the end of the cover plate cut square, with no reduction of width in the terminal development length, and with a continuous fillet weld across the end and along both edges of the cover plate or flange to connect the cover plate to the flange. For this condition, the terminal development length, measured from the actual end of the cover plate, shall be 1-1/2 times the width of the cover plate at its theoretical end. See also 2.28 and Figure 2.12.

(2) Alternatively, terminal development may be made with no weld across the end of the cover plate provided that all of the following conditions are met:

(a) The terminal development length, measured from the actual end of the cover plate, is twice the width.

(b) The width of the cover plate is symmetrically tapered to a width no greater than 1/3 the width at the theoretical end, but no less than 3 in. (75 mm).

(c) There is a continuous fillet weld along both edges of the plate in the tapered terminal development length to connect it to the flange.

2.34.3 Terminal Fillet Welds. Fillet welds connecting a cover plate to the flange in the region between terminal developments shall be continuous welds of sufficient size to transmit the incremental longitudinal shear between the cover plate and the flange. Fillet welds in each terminal development shall be of sufficient size to develop the cover plate's portion of the stress in the beam or girder at the inner end of the terminal development length and in no case shall the welds be smaller than the minimum size permitted by 5.14.

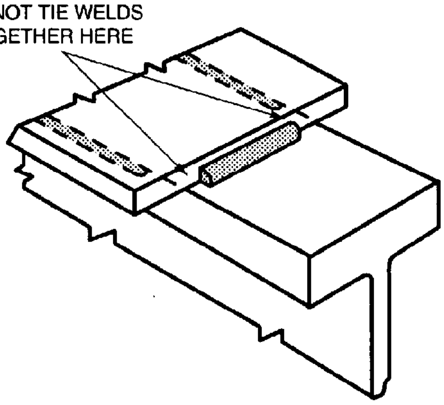


Figure 2.12—Fillet Welds on Opposite Sides of a Common Plane of Contact (see 2.4.7.5)

Part D
Specific Requirements for Tubular Connections

2.35 General

The specific requirements of Part D apply only to tubular connections, and shall be used with the applicable requirements of Part A. All provisions of Part D apply to static applications and cyclic applications, with the exception of the fatigue provisions of 2.36.6, which are unique to cyclic applications.

2.35.1 Eccentricity. Moments caused by significant deviation from concentric connections shall be provided for in analysis and design. See Figure 2.14(H) for an illustration of an eccentric connection.

2.36 Allowable Stresses

2.36.1 Base-Metal Stresses. These provisions may be used in conjunction with any applicable design specifications in either allowable stress design (ASD) or load and resistance factor design (LRFD) formats. Unless the applicable design specification provides otherwise, tubular connection design shall be as described in 2.36.5, 2.36.6 and 2.40. The base-metal stresses shall be those specified in the applicable design specifications, with the following limitations:

2.36.2 Circular Section Limitations. Limitations on diameter/thickness for circular sections, and largest flat width/thickness ratio for box sections, beyond which local buckling or other local failure modes must be considered, shall be in accordance with the governing design code. Limits of applicability for the criteria given in 2.40 shall be observed as follows:

(1) circular tubes: $D/t < 3300/F_y$

(2) box section gap connections: $D/t \le 210/\sqrt{F_y}$ but not more than 35

(3) box section overlap connections: $D/t \le 190/\sqrt{F_y}$

2.36.3 Welds Stresses. The allowable stresses in welds shall not exceed those given in Table 2.5, or as permitted by 2.14.4 and 2.14.5, except as modified by 2.36.5, 2.36.6, and 2.40.

2.36.4 Fiber Stresses. Fiber stresses due to bending shall not exceed the values prescribed for tension and compression, unless the members are compact sections (able to develop full plastic moment) and any transverse weld is proportioned to develop fully the strength of sections joined.

Table 2.5
Allowable Stresses in Tubular Connection Welds (see 2.36.3)

Type of Weld	Tubular Application	Kind of Stress	Allowable Stress Design (ASD): Allowable Stress	Load and Resistance Factor Design (LRFD): Resistance Factor Φ	LRFD: Nominal Strength	Required Filler Metal Strength Level[1]
Complete Joint Penetration Groove Weld	Longitudinal butt joints (longitudinal seams)	Tension or compression parallel to axis of the weld[2]	Same as for base metal[3]	0.9	0.6 F_y	Filler metal with strength equal to or less than matching filler metal may be used.
		Beam or torsional shear	base metal 0.40 F_y filler metal 0.3 F_{EXX}	0.9 0.8	0.6 F_y 0.6 F_{EXX}	
	Circumferential butt joints (girth seams)	Compression normal to the effective area[2]	Same as for base metal	0.9	F_y	Matching filler metal shall be used.
		Shear on effective area		Base metal 0.9 Weld metal 0.8	0.6 F_y 0.6 F_{EXX}	
		Tension normal to the effective area		0.9	F_y	
	Weld joints in structural T-, Y-, or K-connections in structures designed for critical loading such as fatigue, which would normally call for complete joint penetration welds.	Tension, compression or shear on base metal adjoining weld conforming to detail of Figures 3.6, 3.8–3.10 (tubular weld made from outside only without backing).	Same as for base metal or as limited by connection geometry (see 2.40 provisions for ASD)	Same as for base metal or as limited by connection geometry (see 2.40 provisions for LRFD)		Matching filler metal shall be used.
		Tension, compression, or shear on effective area of groove welds, made from both sides or with backing.				
Fillet Weld	Longitudinal joints of built-up tubular members	Tension or compression parallel to axis of the weld.	Same as for base metal	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Shear on effective area.	0.30 F_{EXX}[5]	0.75	0.6 F_{EXX}	
	Joints in structural T-, Y-, or K-connections in circular lap joints and joints of attachments to tubes.	Shear on effective throat regardless of direction of loading. (See 2.39 and 2.40.1.3)	0.30 F_{EXX} or as limited by connection geometry (see 2.40)	0.75 or as limited by connection geometry (see 2.40 for provision for LRFD)	0.6 F_{EXX}	Filler metal with a strength level equal to or less than matching filler metal may be used.[4]

(continued)

Table 2.5 (Continued)

Type of Weld	Tubular Application	Kind of Stress		Allowable Stress Design (ASD): Allowable Stress	Load and Resistance Factor Design (LRFD): Resistance Factor Φ	Load and Resistance Factor Design (LRFD): Nominal Strength	Required Filler Metal Strength Level[1]
Plug and Slot Welds	Shear parallel to faying surfaces (on effective area)			base metal 0.40 F_y filler metal 0.3 F_{EXX}	Not Applicable		Filler metal with a strength level equal to or less than matching filler metal may be used.
Partial Joint Penetration Groove Weld	Longitudinal seam of tubular members	Tension or compression parallel to axis of the weld[2]		Same as for base metal[3]	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Circumferential and longitudinal joints that transfer loads	Compression normal to the effective area	Joint not designed to bear	0.50 F_{EXX}, except that stress on adjoining base metal shall not exceed 0.60 F_y.	0.9	F_y	Filler metal with a strength level equal to or less than matching filler metal may be used.
			Joint designed to bear	Same as for base metal			
		Shear on effective area		0.30 F_{EXX}, except that stress on adjoining base metal shall not exceed 0.50 F_y for tension, or 0.40 F_y for shear.	0.75	0.6 F_{EXX}	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Tension on effective area			base metal 0.9 filler metal 0.8	F_y 0.6 F_{EXX}	
	Structural T-, Y-, or K-connection in ordinary structures	Load transfer across the weld as stress on the effective throat (see 2.39 and 2.40.1.3)		0.30 F_{EXX} or as limited by connection geometry (see 2.40), except that stress on an adjoining base metal shall not exceed 0.50 F_y for tension and compression, nor 0.40 F_y for shear.	base metal 0.9 filler metal 0.8	F_y 0.6 F_{EXX}	Matching filler metal shall be used.
					or as limited by connection geometry (see 2.40 provisions for LRFD)		

Notes:
1. For matching filler metal see Table 3.1.
. . Beam or torsional shear up to 0.30 minimum specified tensile strength of filler metal is permitted, except that shear on adjoining base metal shall not exceed 0.40 F_y (LRFD; see shear).
3. Groove and fillet welds parallel to the longitudinal axis of tension or compression members, except in connection areas, are not considered as transferring stress and hence may take the same stress as that in the base metal, regardless of electrode (filler metal) classification. Where the provisions of .40.1 are applied, seams in the main member within the connection area shall be complete joint penetration groove welds with matching filler metal, as defined in Table 3.1.
4. See .40.1.3.
5. Alternatively, see .14.4 and .14.5.

2.36.5 Load and Resistance Factor Design. Resistance factors, Φ, given elsewhere in this section, may be used in context of load and resistance factor design (LRFD) calculations in the following format:

$$\Phi \times (P_u \text{ or } M_u) = \Sigma(LF \times Load)$$

where P_u or M_u is the ultimate load or moment as given herein; and LF is the load factor as defined in the governing LRFD design code, e.g., *AISC Load and Resistance Factor Design Specification for Structural Steel in Buildings.*

2.36.6 Fatigue

2.36.6.1 Stress Range and Member Type. In the design of members and connections subject to repeated variations in live load stress, consideration shall be given to the number of stress cycles, the expected range of stress, and type and location of member or detail.

2.36.6.2 Fatigue Stress Categories. The type and location of material shall be categorized as shown in Table 2.6.

2.36.6.3 Basic Allowable Stress Limitation. Where the applicable design specification has a fatigue requirement, the maximum stress shall not exceed the basic allowable stress provided elsewhere, and the range of stress at a given number of cycles shall not exceed the values given in Figure 2.13.

2.36.6.4 Cumulative Damage. Where the fatigue environment involves stress ranges of varying magnitude and varying numbers of applications, the cumulative fatigue damage ratio, D, summed over all the various loads, shall not exceed unity, where

$$D = \Sigma \frac{n}{N}$$

where

n = number of cycles applied at a given stress range
N = number of cycles for which the given stress range would be allowed in Figure 2.13

2.36.6.5 Critical Members. For critical members whose sole failure mode would be catastrophic, D (see 2.36.6.4) shall be limited to a fractional value of 1/3.

2.36.6.6 Fatigue Behavior Improvement. For the purpose of enhanced fatigue behavior, and where specified in contract documents, the following profile improvements may be undertaken for welds in tubular T-, Y-, or K-connections:

(1) A capping layer may be applied so that the as-welded surface merges smoothly with the adjoining base metal, and approximates the profile shown in Figure 3.10. Notches in the profile shall not be deeper than 0.04 in. or 1 mm, relative to a disc having a diameter equal to or greater than the branch member thickness.

(2) The weld surface may be ground to the profile shown in Figure 3.10. Final grinding marks shall be transverse to the weld axis.

(3) The toe of the weld may be peened with a blunt instrument, so as to produce local plastic deformation which smooths the transition between weld and base metal, while inducing a compressive residual stress. Such peening shall always be done after visual inspection, and be followed by magnetic–particle inspection as described below. Consideration should be given to the possibility of locally degraded notch toughness due to peening.

In order to qualify fatigue categories X1 and K1, representative welds (all welds for nonredundant structures or where peening has been applied) shall receive magnetic-particle inspection for surface and near-surface discontinuities. Any indications which cannot be resolved by light grinding shall be repaired in accordance with 5.26.1.4.

2.36.6.7 Size and Profile Effects. Applicability of welds to the fatigue categories listed below is limited to the following weld size or base-metal thicknesses:

C1	2 in. (50 mm) thinner member at transition
C2	1 in. (25 mm) attachment
D	1 in. (25 mm) attachment
E	1 in. (25 mm) attachment
ET	1.5 in. (38 mm) branch
F	0.7 in. (18 mm) weld size
FT	1 in. (25 mm) weld size

For applications exceeding these limits, consideration should be given to reducing the allowable stresses or improving the weld profile (see Commentary). For T-, Y-, and K-connections, two levels of fatigue performance are provided for in Table 2.7. The designer shall designate when Level I is to apply; in the absence of such designation, and for applications where fatigue is not a consideration, Level II shall be the minimum acceptable standard.

2.37 Identification

Members in tubular structures shall be identified as shown in Figure 2.14.

2.38 Symbols

Symbols used in section 2, Part D, are as shown in Annex XII.

Table 2.6
Stress Categories for Type and Location of Material for Circular Sections (see 2.36.6.2)

Stress Category	Situation	Kinds of Stress[1]
A	Plain unwelded pipe.	TCBR
B	Pipe with longitudinal seam.	TCBR
B	Butt splices, complete joint penetration groove welds, ground flush and inspected by RT or UT (Class R).	TCBR
B	Members with continuously welded longitudinal stiffeners.	TCBR
C_1	Butt splices, complete joint penetration groove welds, as welded.	TCBR
C_2	Members with transverse (ring) stiffeners.	TCBR
D	Members with miscellaneous attachments such as clips, brackets, etc.	TCBR
D	Cruciform and T-joints with complete joint penetration welds (except at tubular connections).	TCBR
DT	Connections designed a simple T-, Y-, or K-connections with complete joint penetration groove welds conforming to Figures 3.8–3.10 (including overlapping connections in which the main member at each intersection meets punching shear requirements). See Note 2	TCBR in branch member. (Note: Main member must be checked separately per category K_1 or K_2.)
E	Balanced cruciform and T-joints with partial joint penetration groove welds or fillet welds (except at tubular connections).	TCBR in member; weld must also be checked per category F.
E	Members where doubler wrap, cover plates, longitudinal stiffeners, gusset plates, etc., terminate (except at tubular connections).	TCBR in member; weld must also be checked per category F.
ET	Simple T-, Y-, and K-connections with partial joint penetration groove welds or fillet welds; also, complex tubular connections in which the punching shear capacity of the main member cannot carry the entire load and load transfer is accomplished by overlap (negative eccentricity), gusset plates, ring stiffeners, etc. See Note 2	TCBR in branch member. (Note: Main member in simple T-, Y-, or K-connections must be checked separately per category K_1 or K_2; weld must also be checked per category FT and 2.40.1.)
F	End weld of cover plate or doubler wrap; welds on gusset plates, stiffeners, etc.	Shear in weld.
F	Cruciform and T-joints, loaded in tension or bending, having fillet or partial joint penetration groove welds (except at tubular connections).	Shear in weld (regardless of direction of loading). See 2.39
FT	Simple T-, Y-, or K-connections loaded in tension or bending, having fillet or partial joint penetration groove welds.	Shear in weld (regardless of direction of loading).

(continued)

Table 2.6 (Continued)

Stress Category	Situation	Kinds of Stress[1]
X_2	Intersecting members at simple T-, Y-, and K-connections; any connection whose adequacy is determined by testing an accurately scaled model or by theoretical analysis (e.g., finite element).	Greatest total range of hot spot stress or strain on the outside surface of intersecting members at the toe of the weld joining them—measured after shakedown in model or prototype connection or calculated with best available theory.
X_1	As for X_2, profile improved per 2.36.6.6 and 2.36.6.7.	As for X_2
X_1	Unreinforced cone-cylinder intersection.	Hot-spot stress at angle change; calculate per Note 4.
K_2	Simple T-, Y-, and K-connections in which the gamma ratio R/t_c of main member does not exceed 24. (See Note 3)	Punching shear for main members; calculate per Note 5.
K_1	As for K_2, profile improved per 2.36.6.6 and 2.36.6.7.	

Notes:
1. T = tension, C = compression, B = bending, R = reversal—i.e., total range of nominal axial and bending stress.
2. Empirical curves (Figure 2.13) based on "typical" connection geometries; if actual stress concentration factors or hot spot strains are known, use of curve X_1 or X_2 is preferred.
3. Empirical curves (Figure 2.13) based on tests with gamma (R/t_c) of 18 to 24; curves on safe side for very heavy chord members (low R/t_c); for chord members (R/t_c greater than 24) reduce allowable stress in proportion to

$$\frac{\text{Allowable fatigue stress}}{\text{Stress from curve K}} = \left(\frac{24}{R/t_c}\right)^{0.7}$$

Where actual stress concentration factors or hot-spot strains are known, use of curve X_1 or X_2 is preferred.

4. Stress concentration factor – SCF = $\dfrac{1}{\text{Cos}\ \bar{\Psi}} + 1.17 \tan \bar{\Psi}\sqrt{\gamma_b}$

where
$\bar{\Psi}$ = angle change at transition
γ_b = radius to thickness ratio of tube at transition

5. Cyclic range of punching shear is given by

$$V_p = \tau \sin\theta\left[\alpha f_a + \sqrt{(0.67 f_{by})^2 + (1.5 f_{bz})^2}\right]$$

where
τ and θ are previously defined, and
f_a = cyclic range of nominal branch member stress for axial load.
f_{by} = cyclic range of in-plane bending stress.
f_{bz} = cyclic range of out-of-plane bending stress.
α is as defined in Table 2.9.

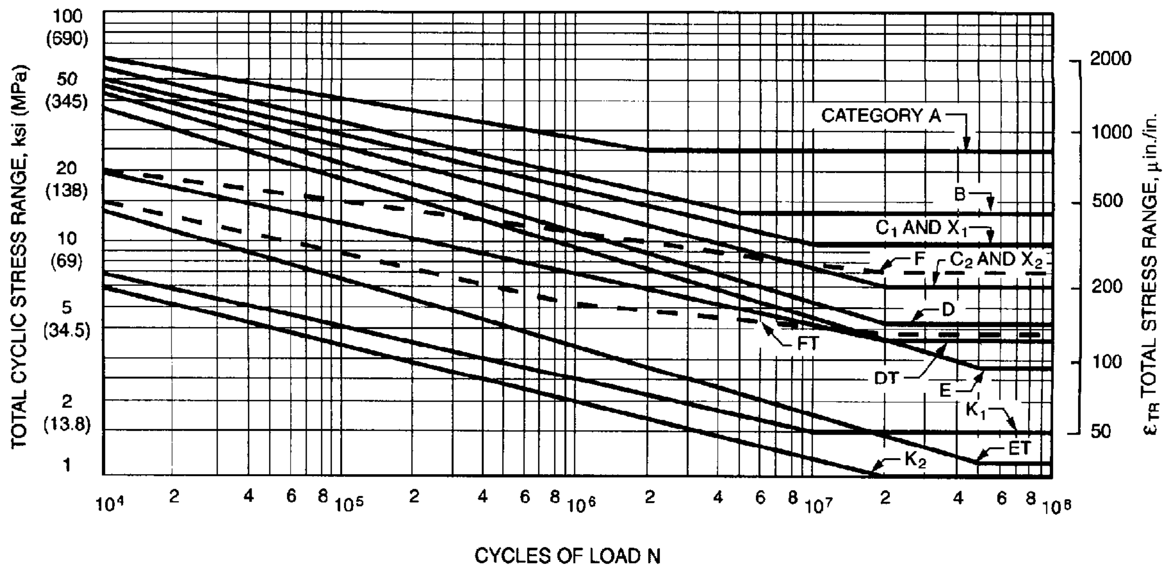


Figure 2.13—Allowable Fatigue Stress and Strain Ranges for Stress Categories (see Table 2.6), Redundant Tubular Structures for Atmospheric Service (see 2.36.6.3)

Table 2.7
Fatigue Category Limitations on Weld Size or Thickness and Weld Profile (Tubular Connections) (see 2.36.6.7)

Weld Profile	Level I Limiting Branch Member Thickness for Categories X_1, K_1, DT in. (mm)	Level II Limiting Branch Member Thickness for Categories X_2, K_2 in. (mm)
Standard flat weld profile Figure 3.8	0.375 (9.5)	0.625 (15.9)
Profile with toe fillet Figure 3.9	0.625 (15.9)	1.50 (38.1) qualified for unlimited thickness for static compression loading
Concave profile, as welded, Figure 3.10 with disk test per 2.36.6.6(1)	1.00 (25.4)	unlimited
Concave smooth profile Figure 3.10 fully ground per 2.36.6.6(2)	unlimited	—

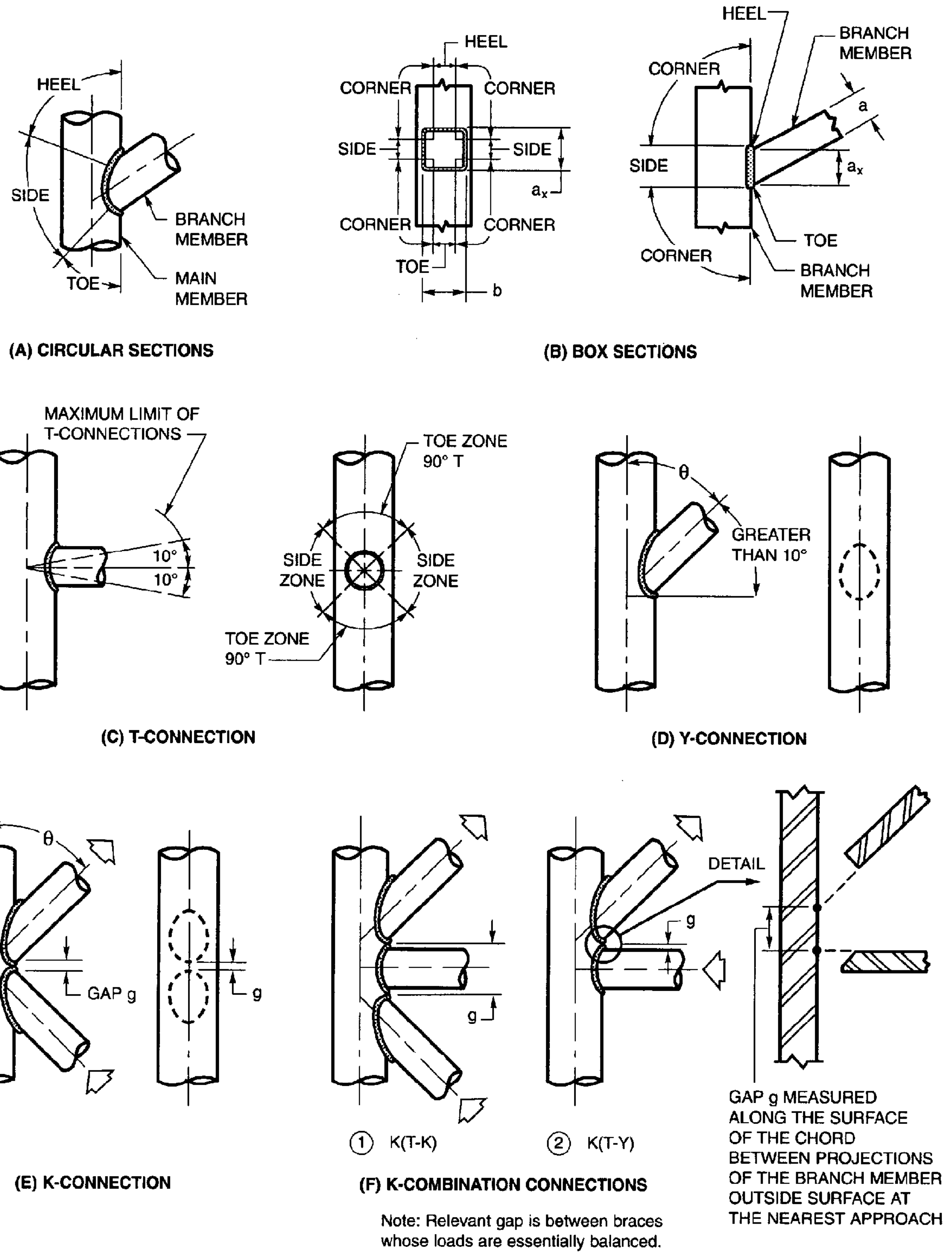
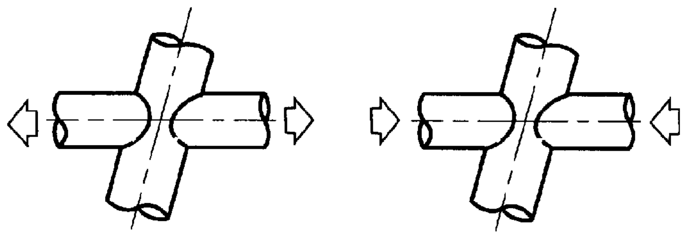
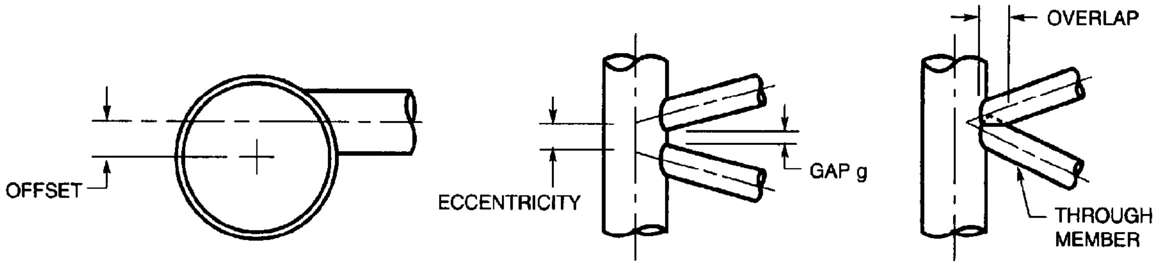


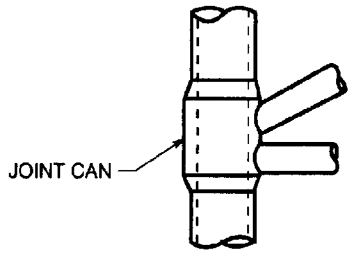
Figure 2.14—Parts of a Tubular Connection (see 2.37)



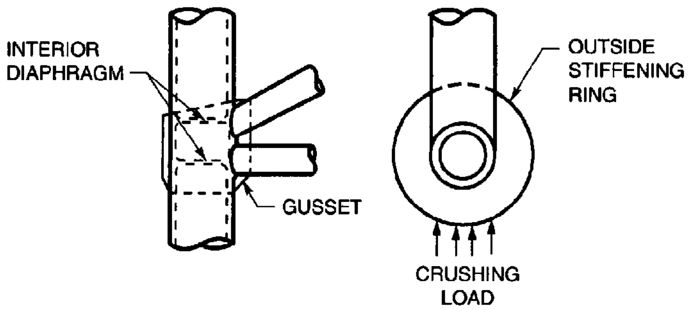
(G) CROSS CONNECTIONS



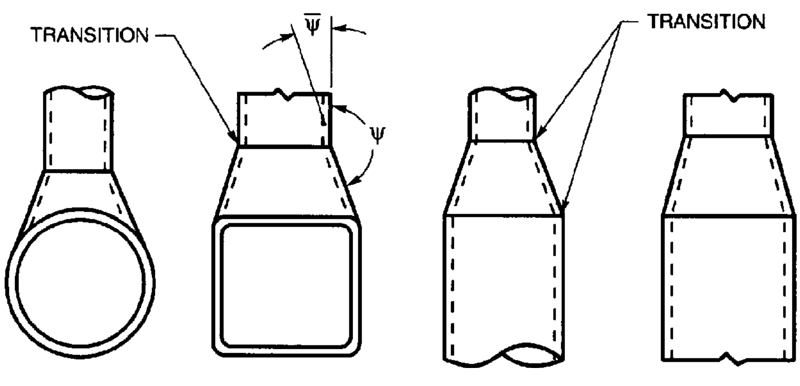
(H) DEVIATIONS FROM CONCENTRIC CONNECTIONS



(I) SIMPLE TUBULAR CONNECTION

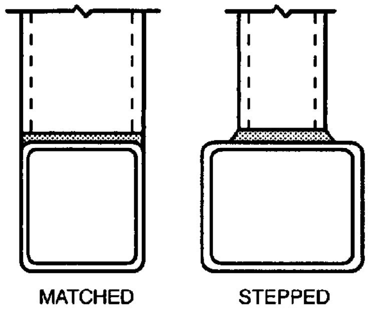


(J) EXAMPLES OF COMPLEX REINFORCED CONNECTIONS

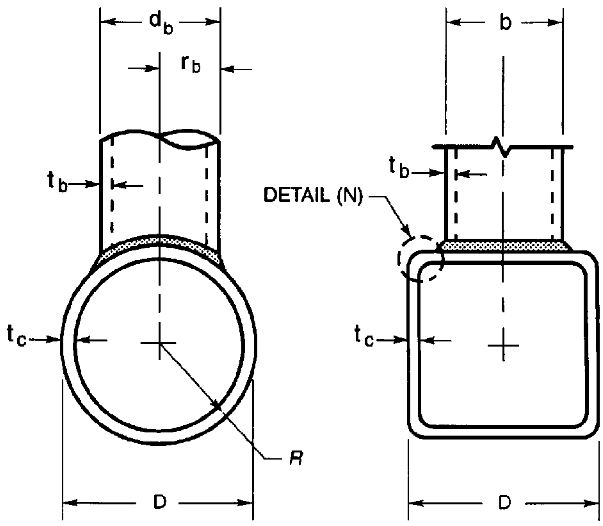


(K) FLARED CONNECTIONS AND TRANSITIONS

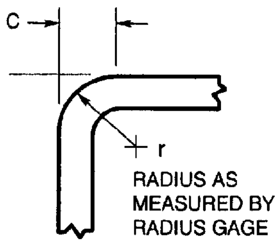
Figure 2.14 (Continued)—Parts of a Tubular Connection (see 2.37)



(L) CONNECTION TYPES FOR BOX SECTIONS



(M) GEOMETRIC PARAMETERS



(N) CORNER DIMENSION OR RADIUS MEASUREMENT

PARAMETER	CIRCULAR SECTIONS	BOX SECTIONS
β	r_b/R OR d_b/D	b/D
η	—	a_x/D
γ	R/t_c	$D/2t_c$
τ	t_b/t_c	t_b/t_c
θ	ANGLE BETWEEN MEMBER CENTERLINES	
ψ	LOCAL DIHEDRAL ANGLE AT A GIVEN POINT ON WELDED JOINT	
c	CORNER DIMENSION AS MEASURED TO THE POINT OF TANGENCY OR CONTACT WITH A 90 DEGREE SQUARE PLACED ON THE CORNER	

Figure 2.14 (Continued)—Parts of a Tubular Connection (see 2.37)

2.39 Weld Design

2.39.1 Fillet Welds

2.39.1.1 Effective Area. The effective area shall be in accordance with 2.4.3 and the following: the effective length of fillet welds in structural T-, Y-, and K-connections shall be calculated in accordance with 2.39.4 or 2.39.5, using the radius or face dimensions of the branch member as measured to the centerline of the weld.

2.39.1.2 Beta Limitation for Prequalified Details. Details for prequalified fillet welds in tubular T-, Y-, and K-connections are described in Figure 3.2. These details are limited to $\beta \leq 1/3$ for circular connections, and $\beta \leq 0.8$ for box sections. They are also subject to the limitations of 3.9.2. For a box section with large corner radii, a smaller limit on β may be required to keep the branch member and the weld on the flat face.

2.39.1.3 Lap Joints. Lap joints of telescoping tubes (as opposed to an interference slip-on joint as used in tapered poles) in which the load is transferred via the weld may be single fillet welded in accordance with Figure 2.15.

2.39.2 Groove Welds. The effective area shall be in accordance with 2.3.2 and the following: the effective length of groove welds in structural T-, Y-, and K-connections shall be calculated in accordance with 2.39.4 or 2.39.5, using the mean radius r_m or face dimensions of the branch member.

2.39.2.1 Prequalified Partial Joint Penetration Groove Weld Details. Prequalified partial joint penetration groove welds in tubular T-, Y-, or K-connections shall conform to Figure 3.5. The Engineer shall use the figure in conjunction with Table 2.8 to calculate the minimum weld size in order to determine the maximum weld stress except where such calculations are waived by 2.40.1.3(2).

The Z loss dimension shall be deducted from the distance from the work point to the theoretical weld face to find the minimum weld size.

2.39.2.2 Prequalified Complete Joint Penetration Groove Weld Details Welded from One Side without Backing in T-, Y-, and K-Connections. See 3.13.4 for the detail options. If fatigue behavior improvement is required, the details selected shall be based on the profile requirements of 2.36.6.6 and Table 2.7.

2.39.3 Stresses in Welds. When weld allowable stress calculations are required for circular sections, the nominal stress in the weld joining branch to chord in a simple T-, Y-, or K-connection shall be computed as:

$$f_{weld} = \frac{t_b}{t_w}\left[\frac{f_a}{K_a}\left(\frac{r_m}{r_w}\right) + \left(\frac{f_b}{K_b}\right)\frac{r_m^2}{r_w^2}\right]$$

where:

t_b = thickness of branch member

t_w = effective throat of the weld

f_a and f_b = nominal axial and bending stresses in the branch

For r_m and r_w, see Figure 2.16.

In ultimate strength or LRFD format, the following expression for branch axial load capacity P shall apply for both circular and box sections:

$$P_u = Q_w \cdot L_{eff}$$

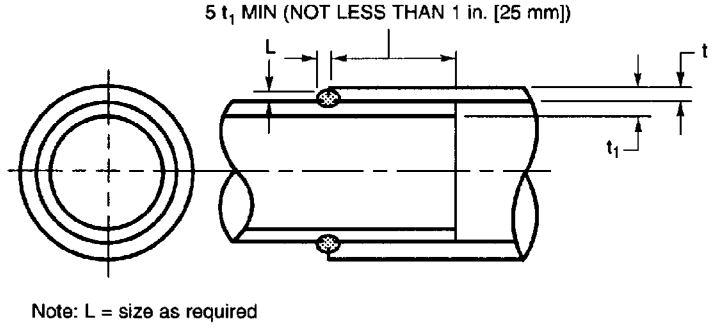


Figure 2.15—Fillet Welded Lap Joint (Tubular) (see 2.39.1.3)

Table 2.8
Z Loss Dimensions for Calculating Prequalified PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes (see 2.39.2.1)

	Position of Welding: V or OH			Position of Welding: H or F		
Groove Angle ϕ	Process	Z (in.)	Z (mm)	Process	Z (in.)	Z (mm)
$\phi \geq 60°$	SMAW	0	0	SMAW	0	0
	FCAW-S	0	0	FCAW-S	0	0
	FCAW-G	0	0	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	0	0	GMAW-S	0	0
$60° > \phi \geq 45°$	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	1/8	3	GMAW-S	1/8	3
$45° > \phi \geq 30°$	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6
	GMAW-S	3/8	10	GMAW-S	1/4	6

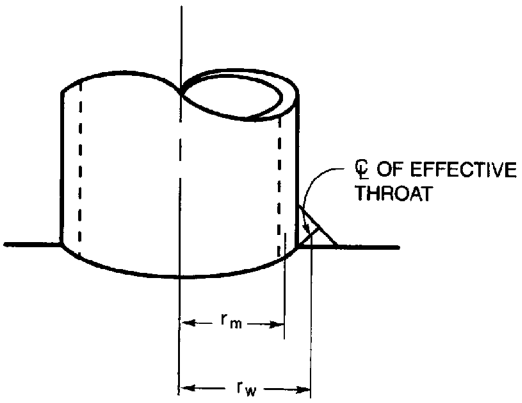


Figure 2.16—Tubular T-, Y-, and K-Connection Fillet Weld Footprint Radius (see 2.39.3)

where Q_w = weld line load capacity (kips/inch) and L_{eff} = weld effective length.

For fillet welds,

$$Q_w = 0.6\, t_w\, F_{EXX}$$

with $\Phi = 0.8$

where F_{EXX} = classified minimum tensile strength of weld deposit.

K_a and K_b are effective length and section factors given in 2.39.4 and 2.39.5.

2.39.4 Circular Connection Lengths. Length of welds and the intersection length in T-, Y-, and K-connections shall be determined as $2\pi r K_a$ where r is the effective radius of the intersection (see 2.39.2, 2.39.1.1 and 2.40.1.3(4)).

$$K_a = x + y + 3\sqrt{(x^2 + y^2)}$$

$$x = 1/(2\pi \sin\theta)$$

$$y = \frac{1}{3\pi}\left(\frac{3-\beta^2}{2-\beta^2}\right)$$

where:

θ = the acute angle between the two member axes

β = diameter ratio, branch/main, as previously defined

Note: The following may be used as conservative approximations:

$$K_a = \frac{1 + 1/\sin\theta}{2} \text{ for axial load}$$

$$K_b = \frac{3 + 1/\sin\theta}{4\sin\theta} \text{ for in-plane bending}$$

$$K_b = \frac{1 + 3/\sin\theta}{4} \text{ for out-of-plane bending}$$

2.39.5 Box Connection Lengths

2.39.5.1 K- and N-Connections. The effective length of branch welds in structural, planar, gap K- and N-connections between box sections, subjected to predominantly static axial load, shall be taken as:

$2a_x + 2b$, for $\theta \leq 50°$

$2a_x + b$, for $\theta \geq 60°$

Thus for $\theta \geq 50°$ the heel, toe and sides of the branch can be considered fully effective. For $\theta \geq 60°$, the heel is considered ineffective due to uneven distribution of load. For $50° < \theta < 60°$, interpolate.

2.39.5.2 T-, Y- and X-Connections. The effective length of branch welds in structural, planar, T-, Y-, and X-connections between box sections, subjected to predominantly static axial load, shall be taken as:

$2a_x + b$, for $\theta \leq 50°$

$2a_x$, for $\theta \geq 60°$

For $50° < \theta < 60°$, interpolate.

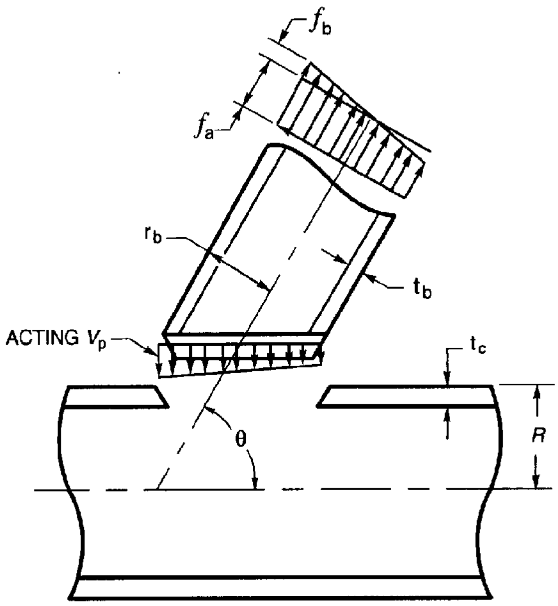


Figure 2.17—Punching Shear Stress (see 2.40.1.1)

2.40 Limitations of the Strength of Welded Connections

2.40.1 Circular T-, Y-, and K-Connections (See 2.42.1.1)

2.40.1.1 Local Failure. Where a T-, Y-, or K-connection is made by simply welding the branch member(s) individually to the main member, local stresses at potential failure surface through the main member wall may limit the usable strength of the welded joint. The shear stress at which such failure occurs depends not only upon the strength of the main member steel, but also on the geometry of the connection. Such connections shall be proportioned on the basis of either (1) punching shear, or (2) ultimate load calculations as given below. The punching shear is an allowable stress design (ASD) criterion and includes the safety factor. The ultimate load format may be used in load and resistance factor design (LRFD), with the resistance factor Φ to be included by the designer, see 2.36.5.

(1) Punching Shear Format. The acting punching shear stress on the potential failure surface (see Figure 2.17) shall not exceed the allowable punching shear stress.

The acting punching shear stress is given by

$$\text{acting } V_p = \tau f_n \sin\theta$$

The allowable punching shear stress is given by

$$\text{allow } V_p = Q_q \cdot Q_f \cdot F_{yo}/(0.6\,\gamma)$$

The allowable V_p shall also be limited by the allowable shear stress specified in the applicable design specification (e.g., 0.4 F_{yo}).

Terms used in the foregoing equations are defined as follows:

τ, θ, γ, β and other parameters of connection geometry are defined in Figure 2.14(M).

f_n is the nominal axial (f_a) or bending (f_b) stress in the branch member (punching shear for each kept separate)

F_{yo} = The specified minimum yield strength of the main member chord, but not more than 2/3 the tensile strength.

Q_q, Q_f are geometry modifier and stress interaction terms, respectively, given in Table 2.9.

For bending about two axes (e.g., y and z), the effective resultant bending stress in circular and square box sections may be taken as

$$f_b = \sqrt{f_{by}^2 + f_{bz}^2}$$

For combined axial and bending stresses, the following inequality shall be satisfied:

$$\left[\frac{\text{Acting } V_p}{\text{allow } V_p}\right]^{1.75}_{\text{axial}} + \left[\frac{\text{acting } V_p}{\text{allow } V_p}\right]_{\text{bending}} \leq 1.0$$

Table 2.9
Terms for Strength of Connections (Circular Sections) (see 2.40.1.1)

Branch member Geometry and load modifier Q_q	$Q_q = \left(\frac{1.7}{\alpha} + \frac{0.18}{\beta}\right) Q_\beta^{0.7(\alpha-1)}$	For axial loads (see Note 6)
	$Q_q = \left(\frac{2.1}{\alpha} + \frac{0.6}{\beta}\right) Q_\beta^{1.2(\alpha-0.67)}$	For bending
Q_β	$Q_\beta = 1.0$	For $\beta \le 0.6$
(needed for Q_q)	$Q_\beta = \frac{0.3}{\beta(1-0.833\beta)}$	For $\beta > 0.6$
chord ovalizing	$\alpha = 1.0 + 0.7\ g/d_b$ $1.0 \le \alpha < 1.7$	For axial load in gap K-connections having all members in same plane and loads transverse to main member essentially balanced (See Note 3)
parameter	$\alpha = 1.7$ $\alpha = 2.4$	For axial load in T- and Y-connections For axial load in cross connections
α (needed for Q_q)	$\alpha = 0.67$ $\alpha = 1.5$	For in-plane bending (see Note 5) For out-of-plane bending (see Note 5)
Main member stress interaction term Q_f (See Notes 4 and 5)	$Q_f = 1.0 - \lambda\gamma\overline{U}^2$ $\lambda = 0.030$ $\lambda = 0.044$ $\lambda = 0.018$	 For axial load in branch member For in-plane bending in branch member For out-of-plane bending in branch member

Notes:
1. λ, β are geometry parameters defined by Figure 2.14 (M).
2. F_{yo} = the specified minimum yield strength of the main member, but not more than 2/3 the tensile strength.
3. Gap g is defined in Figures 2.14 (E), (F) and (H); d_b is branch diameter.
4. $\overline{U}$ is the utilization ratio (ratio of actual to allowable) for longitudinal compression (axial, bending) *in the main member* at the connection under consideration.

$$\overline{U}^2 = \left(\frac{f_a}{0.6F_{yo}}\right)^2 + \left(\frac{f_b}{0.6F_{yo}}\right)^2$$

5. For combinations of the in-plane bending and out-of-plane bending, use interpolated values of α and λ.
6. For general collapse (transverse compression) also see 2.40.1.2.

(2) LRFD Format (loads factored up to ultimate condition—see 2.36.5)

Branch member loadings at which plastic chord wall failure in the main member occurs are given by:

axial load: $P_u \sin\theta = t_c^2\ F_{yo}[6\pi\beta Q_q]\ Q_f$

bending moment:

$$M_u \sin\theta = t_c^2\ F_{yo}[d_b/4][6\pi\beta Q_q]\ Q_f$$

with the resistance factor $\Phi = 0.8$.

Q_f should be computed with $\overline{U}^2$ redefined as $(P_c/AF_{yo})^2 + (M_c/SF_{yo})^2$ where P_c and M_c are factored chord load and moment, A is area, S is section modulus.

These loadings are also subject to the chord material shear strength limits of:

$P_u \sin\theta \le \pi\ d_b t_c\ F_{yo}/\sqrt{3}$

$M_u \sin\theta \le d_b^2\ t_c\ F_{yo}/\sqrt{3}$

with $\Phi = 0.95$

where

t_c = chord wall thickness
d_b = branch member diameter and other terms are defined as 2.40.1.1 (1).

The limit state for combinations of axial load P and bending moment M is given by:

$(P/P_u)^{1.75} + M/M_u \le 1.0$

2.40.1.2 General Collapse. Strength and stability of a main member in a tubular connection, with any reinforcement, shall be investigated using available technology in accordance with the applicable design code. General collapse is particularly severe in cross connections and connections subjected to crushing loads, see Figure 2.14(G) and (J). Such connections may be reinforced by increasing the main member thickness, or by use of diaphragms, rings, or collars.

(1) For unreinforced circular cross connections, the allowable transverse chord load, due to compressive branch member axial load P, shall not exceed

$$P \sin \theta = t_c^2 \ F_y \ (1.9 + 7.2\ \beta) Q_\beta Q_f$$

(2) For circular cross connections reinforced by a "joint can" having increased thickness t_c, and length, L, the allowable branch axial load, P, may be employed as

$$P = P_{(1)} + [P_{(2)} - P_{(1)}]L/2.5D \qquad \text{for } L < 2.5/D$$

$$P = P_{(2)} \qquad \text{for } L \geq 2.5/D$$

where $P_{(1)}$ is obtained by using the nominal main member thickness in the equation in (1); and $P_{(2)}$ is obtained by using the joint can thickness in the same equation.

The ultimate limit state may be taken as 1.8 times the foregoing ASD allowable, with $\Phi = 0.8$.

(3) For circular K-connections in which the main member thickness required to meet the local shear provisions of 2.40.1.1 extends at least D/4 beyond the connecting branch member welds, general collapse need not be checked.

2.40.1.3 Uneven Distribution of Load (Weld Sizing)

(1) Due to differences in the relative flexibilities of the main member loaded normal to its surface, and the branch member carrying membrane stresses parallel to its surface, transfer of load across the weld is highly nonuniform, and local yielding can be expected before the connection reaches its design load. To prevent "unzipping" or progressive failure of the weld and ensure ductile behavior of the joint, the minimum welds provided in simple T-, Y-, or K-connections shall be capable of developing, at their ultimate breaking strength, the lesser of the brace member yield strength or local strength (punching shear) of the main member. The ultimate breaking strength of fillet welds and partial joint penetration groove welds shall be computed at 2.67 times the basic allowable stress for 60 ksi (410 MPa) or 70 ksi (480 MPa) tensile strength and at 2.2 times the basic allowable stress for higher strength levels. The ultimate punching shear shall be taken as 1.8 times the allowable V_p of 2.40.1.1.

(2) This requirement may be presumed to be met by the prequalified joint details of Figure 3.8 (complete penetration) and subsection 3.12.4 (partial penetration), when matching materials (Table 3.1) are used.

(3) Compatible strength of welds may also be presumed with the prequalified fillet weld details of Figure 3.2, when the following effective throat requirements are met:

(a) $E = 0.7\ t_b$ for elastic working stress design of mild steel circular steel tubes ($F_y \leq 40$ (280 MPa) joined with overmatched welds (classified strength $F_{EXX} = 70$ ksi))

(b) $E = 1.0\ t_b$ for ultimate strength design (LRFD) of circular or box tube connections of mild steel, $F_y \leq$ 40 ksi (280 MPa), with welds satisfying the matching strength requirements of Table 3.1.

(c) E = lesser of t_c or 1.07 t_b for all other cases

(4) Fillet welds smaller than those required in Figure 3.2 to match connection strength, but sized only to resist design loads, shall at least be sized for the following multiple of stresses calculated per 2.39.3, to account for nonuniform distribution of load:

	ASD	LRFD
E60XX and E70XX—	1.35	1.5
Higher strengths—	1.6	1.8

2.40.1.4 Transitions. Flared connections and tube size transitions not excepted below shall be checked for local stresses caused by the change in direction at the transition. (See note 4 to Table 2.6.) Exception, for static loads:

Circular tubes having D/t less than 30, and

Transition slope less than 1:4.

2.40.1.5 Other Configurations and Loads

(1) The term "T-, Y- and K-connections" is often used generically to describe tubular connections in which branch members are welded to a main member, or chord, at a structural node. Specific criteria are also given for cross (X-) connections (also referred to as double-tee) in 2.40.1.1 and 2.40.1.2. N-connections are a special case of K-connections in which one of the branches is perpendicular to the chord; the same criteria apply. See Commentary for multiplanar connections.

(2) Connection classifications as K, T, Y, or cross should apply to individual branch members according to the load pattern for each load case. To be considered a K-connection, the punching load in a branch member should be essentially balanced by loads on other braces in the same plane on the same side of the joint. In T- and Y-connections the punching load is reacted as beam shear in the chord. In cross connections the punching load is carried through the chord to braces on the opposite side. For branch members which carry part of their load as K-connections, and part as T-, Y-, or cross

connections, interpolate based on the portion of each in total, or use computed alpha (see Commentary.)

(3) For multiplanar connections, computed alpha as given in Appendix L may be used to estimate the beneficial or deleterious effect of the various branch member loads on main member ovalizing. However, for similarly loaded connections in adjacent planes, e.g., paired TT and KK connections in delta trusses, no increase in capacity over that of the corresponding uniplanar connections shall be taken.

2.40.1.6 Overlapping Connections. Overlapping joints, in which part of the load is transferred directly from one branch member to another through their common weld, shall include the following checks:

(1) The *allowable* individual member load component, $P_{\perp}$ perpendicular to the main member axis shall be taken as $P_{\perp} = (V_p\ t_c\ l_1) + (2V_w\ t_w\ l_2)$ where V_p is the allowable punching shear as defined in 2.40.1.1, and

t_c = the main member thickness

l_1 = actual weld length for that portion of the branch member which contacts the main member

V_p = allowable punching shear for the main member as K-connection ($\alpha = 1.0$)

V_w = allowable shear stress for the weld between branch members (Table 2.5)

t'_w = the lesser of the weld size (effective throat) or the thickness t_b of the thinner branch member

l_2 = the projected chord length (one side) of the overlapping weld, measured perpendicular to the main member.

These terms are illustrated in Figure 2.18.

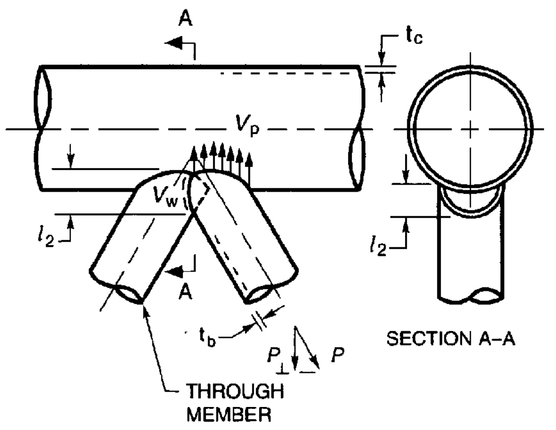


Figure 2.18—Detail of Overlapping Joint (see 2.40.1.6)

The *ultimate* limit state may be taken as 1.8 times the foregoing ASD allowable, with $\Phi = 0.8$.

(2) The allowable combined load component parallel to the main member axis shall not exceed $V_w\ t_w\ \Sigma l_1$, where Σl_1 is the sum of the actual weld lengths for all braces in contact with the main member.

(3) The overlap shall preferably be proportioned for at least 50% of the acting $P_{\perp}$. In no case shall the branch member wall thickness exceed the main member wall thickness.

(4) Where the branch members carry substantially different loads, or one branch member has a wall thickness greater than the other, or both, the thicker or more heavily loaded branch member shall preferably be the through member with its full circumference welded to the main member.

(5) Net transverse load on the combined footprint shall satisfy 2.40.1.1 and 2.40.1.2.

(6) Minimum weld size for fillet welds shall provide effective throat of 1.0 t_b for $F_y < 40$ ksi, 1.2 t_b for $F_y > 40$ ksi.

2.40.2 Box T-, Y, and K-Connections (See 2.42.1.1). Criteria given in this section are all in ultimate load format, with the safety factor removed. Resistance factors for LRFD are given throughout. For ASD, the allowable capacity shall be the ultimate capacity, divided by a safety factor of $1.44/\Phi$. The choice of loads and load factors shall be in accordance with the governing design specification; see 2.1.2 and 2.36.5. Connections shall be checked for each of the failure modes described below.

These criteria are for connections between box sections of uniform wall thickness, in planar trusses where the branch members loads are primarily axial. If compact sections, ductile material, and compatible strength welds are used, secondary branch member bending may be neglected. (Secondary bending is that due to joint deformation or rotation in fully triangulated trusses. Branch member bending due to applied loads, sidesway of unbraced frames, etc., cannot be neglected and must be designed for. See 2.40.2.5.)

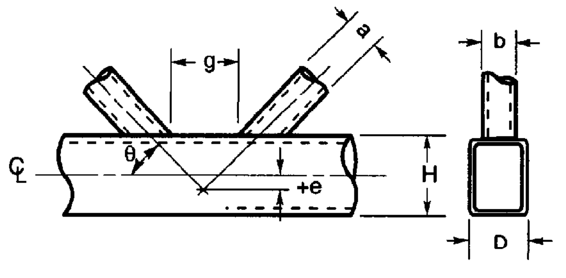
Criteria in this section are subject to the limitations shown in Figure 2.19.

2.40.2.1 Local Failure. Branch member axial load P_u at which plastic chord wall failure in the main member occurs is given by:

$$P_u \sin\theta = F_{yo}\ t_c^2 \left[\frac{2\eta}{1-\beta} + \frac{4}{\sqrt{(1-\beta)}}\right] Q_f$$

for cross, T-, and Y-connections with $0.25 \le \beta < 0.85$ and $\Phi = 1.0$.

Also, $P_u \sin\theta = F_{yo}\ t_c^2\ [9.8\ \beta_{eff}\ \sqrt{\gamma}]\ Q_f$



$-0.55h \le e \le 0.25H$
$\theta \ge 30°$
H/t_c AND $D/t_c \le 35$ (40 FOR OVERLAP K- AND N-CONNECTIONS)
a/t_b AND $b/t_b \le 35$
$F_{yo} \le 52$ ksi (360 MPa)
$0.5 \le H/D \le 2.0$
$F_{yo}/F_{ult} \le 0.8$

Figure 2.19—Limitations for Box T-, Y-, and K-Connections (see 2.40.2)

with $\Phi = 0.9$

for gap K- and N-connections with least

$$\beta_{eff} \ge 0.1 + \frac{\gamma}{50} \text{ and } g/D = \zeta \ge 0.5\ (1-\beta)$$

where F_{yo} is specified minimum yield strength of the main member, t_c is chord wall thickness, γ is $D/2t_c$ (D = chord face width); β, η, θ and ζ are connection topology parameters as defined in Figure 2.14(M) and Figure C2.26; (β_{eff} is equivalent β defined below); and $Q_f = 1.3–0.4U/\beta (Q_f \le 1.0)$; use $Q_f = 1.0$ (for chord in tension) with U being the chord utilization ratio.

$$U = \left|\frac{f_a}{F_{yo}}\right| + \left|\frac{f_b}{F_{yo}}\right|$$

$$\beta_{eff} = (b_{\substack{compression\\branch}} + a_{\substack{compression\\branch}} + b_{\substack{tension\\branch}} + a_{\substack{tension\\branch}})/4D$$

These loadings are also subject to the chord material shear strength limits of

$$P_u \sin\theta = (F_{yo}/\sqrt{3})\, t_c D\, [2\eta + 2\,\beta_{eop}]$$

for cross, T-, or Y-connections with $\beta > 0.85$, using $\Phi = 0.95$, and

$$P_u \sin\theta = (F_{yo}/\sqrt{3})\, t_c D\, [2\eta + \beta_{eop} + \beta_{gap}]$$

for gap K- and N-connections with $\beta \ge 0.1 + \gamma/50$, using $\Phi = 0.95$ (this check is unnecessary if branch members are square and equal width), where:

$\beta_{gap} = \beta$ for K- and N-connections with $\zeta \ge 1.5\ (1-\beta)$
$\beta_{gap} = \beta_{eop}$ for all other connections

β_{eop} (effective outside punching) = $5\beta/\gamma$
but not more than β

2.40.2.2 General Collapse. Strength and stability of a main member in a tubular connection, with any reinforcement, shall be investigated using available technology in accordance with the applicable design code.

(1) General collapse is particularly severe in cross connections and connections subjected to crushing loads. Such connections may be reinforced by increasing the main member thickness or by use of diaphragms, gussets, or collars.

For unreinforced matched box connections, the ultimate load normal to the main member (chord) due to branch axial load P shall be limited to:

$$P_u \sin\theta = 2t_c\, F_{yo}(a_x + 5\, t_c)$$

with $\Phi = 1.0$ for tension loads,
and $\Phi = 0.8$ for compression.

and

$$P_u \sin\theta = \frac{47\, t_c^3}{H - 4t_c}\sqrt{EF_{yo}}(Q_f)$$

with $\Phi = 0.8$ for cross connections, end post reactions, etc., in compression, and E = modulus of elasticity

or

$$P_u \sin\theta = 1.5\, t_c^2\, [1 + 3a_x/H]\, \sqrt{EF_{yo}}\, (Q_f)$$

with $\Phi = 0.75$ for all other compression branch loads (ksi units)

(2) For gap K- and N-connections, beam shear adequacy of the main member to carry transverse loads across the gap region shall be checked including interaction with axial chord forces. This check is not required for $U \le 0.44$ in stepped box connections having $\beta + \eta \le H/D$ (H is height of main member in plane of truss).

2.40.2.3 Uneven Distribution of Load (Effective Width). Due to differences in the relative flexibilities of the main member loaded normal to its surface and the branch member carrying membrane stresses parallel to its surface, transfer of load across the weld is highly nonuniform, and local yielding can be expected before the connection reaches its design load. To prevent progressive failure and ensure ductile behavior of the joint, both the branch members and the weld shall be checked, as follows:

(1) Branch Member Check. The effective width axial capacity P_u of the branch member shall be checked for all gap K- and N-connections, and other connections having $\beta > 0.85$. (Note that this check is unnecessary if branch members are square and equal width).

$P_u = F_y t_b [2a + b_{gap} + b_{eoi} - 4t_b]$

with $\Phi = 0.95$

where

F_y = specified minimum yield strength of branch
t_b = branch wall thickness
a, b = branch dimensions (see Figure 2.14(B))
b_{gap} = b for K- and N-connections with $\zeta \leq 1.5(1-\beta)$
$b_{gap} = b_{eoi}$ for all other connections

$$b_{eoi} = \left(\frac{5b}{\gamma\tau}\right)\frac{F_{yo}}{F_y} \leq b$$

Note: $\tau \leq 1.0$ and $F_y \leq F_{yo}$ are presumed.

(2) Weld Checks. The minimum welds provided in simple T-, Y-, or K-connections shall be capable of developing at their ultimate breaking strength, the lesser of the branch member yield strength or local strength of the main member.

This requirement may be presumed to be met by the prequalified joint details of Figure 3.6 (complete penetration and partial penetration), when matching materials (Table 3.1) are used,

(3) Fillet welds shall be checked as described in 2.39.5.

2.40.2.4 Overlapping Connections. Lap joints reduce the design problems in the main member by transferring most of the transverse load directly from one branch member to the other. See Figure 2.20.

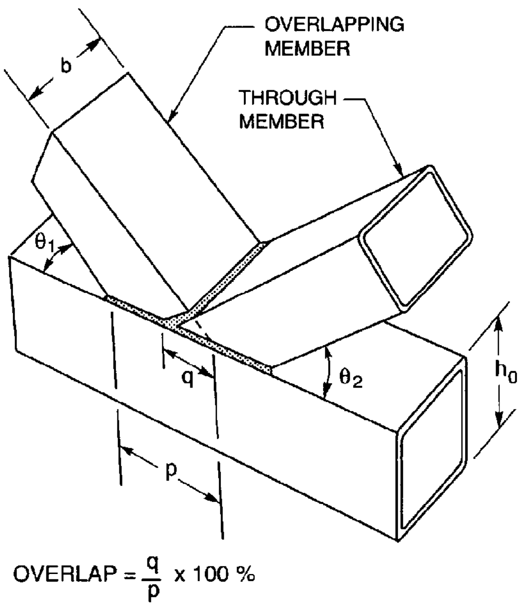


Figure 2.20—Overlapping T-, Y-, and K-Connections (see 2.40.2.4)

The criteria of this section are applicable to statically loaded connections meeting the following limitations:

(1) The larger, thicker branch is the thru member.

(2) $\beta \geq 0.25$.

(3) The overlapping branch member is 0.75 to 1.0 times the size of the through member with at least 25% of its side faces overlapping the through member.

(4) Both branch members have the same yield strength.

(5) All branch and chord members are compact box tubes with width/thickness ≤ 35 for branches, and ≤ 40 for chord.

The following checks shall be made:

(1) Axial capacity P_u of the overlapping tube, using

$\Phi = 0.95$ with

$P_u = F_y\, t_b\, [Q_{OL}\, (2a - 4t_b) + b_{eo} + b_{et}]$

for 25% to 50% overlap, with

$$Q_{OL} = \frac{\%\ \text{overlap}}{50\%}$$

$P_u = F_y\, t_b\, [(2a - 4t_b) + b_{eo} + b_{et}]$

for 50% to 80% overlap.

$P_u = F_y\, t_b\, [(2a - 4t_b) + b + b_{et}]$

for 80% to 100% overlap.

$P_u = F_y t_b\, [(2a - 4t_b) + 2b_{et}]$

for more than 100% overlap

where b_{eo} is effective width for the face welded to the chord,

$$b_{eo} = \frac{(5b)\,F_{yo}}{\gamma(\tau)\,F_y} \leq b$$

and b_{et} is effective width for the face welded to the through brace.

$$b_{et} = \frac{5b}{\gamma_t \tau_t} \leq b$$

$\gamma_t = b/(2t_b)$ of the through brace

$\tau_t = t_{overlap}/t_{through}$

and other terms are as previously defined.

(2) Net transverse load on the combined footprint, treated as a T- or Y-connection.

(3) For more than 100% overlap, longitudinal shearing shall be checked, considering only the sidewalls of the thru branch footprint to be effective.

2.40.2.5 Bending. Primary bending moment, M, due to applied load, cantilever beams, sidesway of unbraced frames, etc., shall be considered in design as an additional axial load, P:

$$P = \frac{M}{JD \sin \theta}$$

In lieu of more rational analysis (see Commentary), JD may be taken as η D/4 for in-plane bending, and as βD/4 for out-of-plane bending. The effects of axial load, in-plane bending and out-of-plane bending shall be considered as additive. Moments are to be taken at the branch member footprint.

2.40.2.6 Other Configurations. Cross T-, Y-, gap K-, and gap N-connections with compact circular branch tubes framing into a box section main member may be designed using 78.5% of the capacity given in 2.40.2.1 and 2.40.2.2, by replacing the box dimension "a" and "b" in each equation by branch diameter, d_b (limited to compact sections with $0.4 \leq \beta \leq 0.8$).

2.41 Thickness Transition

Tension butt joints in axially aligned primary members of different material thicknesses or size shall be made in such a manner that the slope through the transition zone does not exceed 1 in 2-1/2. The transition shall be accomplished by chamfering the thicker part, sloping the weld metal, or by any combination of these methods (see Figure 2.4).

2.42 Material Limitations

Tubular connections are subject to local stress concentrations which may lead to local yielding and plastic strains at the design load. During the service life, cyclic loading may initiate fatigue cracks, making additional demands on the ductility of the steel, particularly under dynamic loads. These demands are particularly severe in heavy-wall joint-cans designed for punching shear. See Commentary C2.42.2.2.

2.42.1 Limitations

2.42.1.1 Yield Strength. The design provisions of 2.40 for welded tubular connections are not intended for use with circular tubes having a specified minimum yield, F_y, over 60 ksi (415 MPa) or for box sections over 52 ksi (360 MPa).

2.42.1.2 ASTM A500 Precaution. Products manufactured to this specification may not be suitable for those applications such as dynamically loaded elements in welded structures, etc., where low-temperature notch toughness properties may be important. Special investigation or heat treatment may be required if this product is applied to tubular T-,Y-, and K-connections.

2.42.1.3 Reduced Effective Yield. Reduced effective yield shall be used as F_{yo} in the design of tubular connections (see Note 2 of Table 2.9) for the following steels:

ASTM A514	ASTM A618, Grades II and III
ASTM A517	(Grade I if the properties
ASTM A537	are suitable for welding)
ASTM A572	ASTM A633
ASTM A588	ASTM A709
ASTM A595	ASTM A710, Grade A
	ASTM A808
	API 5L, Grades X42 and X52

2.42.1.4 Suitability for Tubular Connections. In the absence of a notch toughness requirement, the following steels may be unsuitable for use as the main member in a tubular connection. (See 2.42.2.2):

ASTM A514
ASTM A517
ASTM A572
ASTM A588
ASTM A595
ASTM A709
API 5L, Grades X42 and X52

2.42.1.5 Box T-,Y-, and K-Connections. The designer should consider special demands which are placed on the steel used in box T-, Y-, and K-connections.

2.42.2 Tubular Base-Metal Notch Toughness

2.42.2.1 Charpy V-Notch Requirements. Welded tubular members in tension shall be required to demonstrate Charpy V-notch absorbed energy of 20 ft·lb at 70°F(27 J@20°C) for the following conditions:

(1) Base-metal thickness of 2 in. (50 mm) or greater with a specified minimum yield strength of 40 ksi (280 MPa) or greater.

Charpy V-notch testing shall be in accordance with ASTM A673 (Frequency H, heat lot). For the purposes of this subsection, a tension member is defined as one having more than 10 ksi (70 MPa) tensile stress due to design loads.

2.42.2.2 LAST Requirements. Tubulars used as the main member in structural nodes, whose design is governed by cyclic or fatigue loading (e.g., the joint-can in T-, Y-, and K-connections) shall be required to demonstrate Charpy V-notch absorbed energy of 20 ft·lb at the

Lowest Anticipated Service Temperature (LAST) for the following conditions:

(1) Base-metal thickness of 2 in. (50 mm) or greater.

(2) Base-metal thickness of 1 in. (25 mm) or greater with a specified yield strength of 50 ksi or greater.

When the LAST is not specified, or the structure is not governed by cyclic or fatigue loading, testing shall be at a temperature not greater than 40°F (4°C). Charpy V-notch testing shall normally represent the as-furnished tubulars, and be tested in accordance with ASTM A673 Frequency H (heat lot).

2.42.2.3 Alternative Notch Toughness. Alternative notch toughness requirements shall apply when specified in contract documents. The Commentary gives additional guidance for designers. Toughness should be considered in relation to redundancy versus criticality of structure at an early stage in planning and design.

3. Prequalification of WPSs

3.1 Scope

Prequalification of WPSs (Welding Procedure Specifications) shall be defined as exemption from the WPS qualification testing required in section 4. All prequalified WPSs shall be written. In order for a WPS to be prequalified, conformance with all of the applicable requirements of section 3 shall be required. WPSs that do not conform to the requirements of section 3 may be qualified by tests in conformance with section 4. (See Annex IV—Table IV-1). The use of a prequalified joint shall not exempt the Engineer from using engineering judgement in determining the suitability of application of these joints to a welded assembly or connection. For convenience, Annex H lists provisions to be included in a prequalified WPS, and which should be addressed in the fabricator's or contractor's welding program.

Welders, welding operators and tack welders that use prequalified WPSs shall be qualified in conformance with section 4, Part C.

3.2 Welding Processes

3.2.1 Prequalified Processes. Shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW) (except GMAW-S, short circuiting transfer), and flux cored arc welding (FCAW) WPSs which conform to all of the provisions of section 3 shall be deemed as prequalified and are therefore approved for use without performing WPS qualification tests for the process. For WPS prequalification, conformance with all of the applicable provisions of section 3 shall be required (see 3.1).

3.2.2 Code Approved Processes. Electroslag (ESW), electrogas (EGW), gas tungsten arc welding (GTAW) and gas metal arc welding (short circuiting) [GMAW-S] welding may be used, provided the WPSs are qualified in conformance with the requirements of section 4. See Annex A for GMAW-S. Note that the essential variable limitations in Table 4.5 for GMAW also apply to GMAW-S.

3.2.3 Other Welding Processes. Other welding processes not covered by 3.2.1 and 3.2.2 may be used, provided the WPSs are qualified by applicable tests as prescribed in section 4 and approved by the Engineer. In conjunction with the tests, the WPSs and limitation of essential variables applicable to the specific welding process shall be established by the contractor developing the WPS. The range of essential variables shall be based on documented evidence of experience with the process, or a series of tests shall be conducted to establish the limit of essential variables. Any change in essential variables outside the range so established shall require requalification.

3.3 Base Metal/Filler Metal Combinations

Only base metals and filler metals listed in Table 3.1 may be used in prequalified WPSs. (For the qualification of listed base metals and filler metals, and for base metals and filler metals not listed in Table 3.1, see 4.1.1.)

The base metal/filler metal strength relationships below shall be used in conjunction with Table 3.1 to determine whether matching or undermatching filler metals are required.

Relationship	Base Metal(s)	Filler Metal Strength Relationship Required
Matching	Any steel to itself or any steel to another in the same group	Any filler metal listed in the same group
	Any steel in one group to any steel in another	Any filler metal listed for a lower strength group. [SMAW electrodes shall be the low-hydrogen classification]
Under-matching	Any steel to any steel in any group	Any filler metal listed for a lower strength group. [SMAW electrodes shall be the low-hydrogen classification]

Note: See Tables 2.3 or 2.5 to determine the filler metal strength requirements to match or undermatch base metal strength.

Table 3.1
Prequalified Base Metal—Filler Metal Combinations for Matching Strength[8] (see 3.3)

Group	Steel Specification Requirements						Filler Metal Requirements				
			Minimum Yield Point/Strength		Tensile Range			Minimum Yield Point/Strength		Tensile Strength Range	
	Steel Specification[1, 2]		ksi	MPa	ksi	MPa	Electrode Specification[3, 6]	ksi	MPa	ksi	MPa
	ASTM A36[4]		36	250	58–80	400–550					
	ASTM A53	Grade B	35	240	60 min	415 min	SMAW				
	ASTM A106	Grade B	35	240	60 min	415 min	AWS A5.1				
	ASTM A131	Grades A, B, CS, D, DS, E	34	235	58–71	400–490	E60XX	48	331	60 min	414 min
	ASTM A139	Grade B	35	241	60 min	414 min	E70XX	53–72	365–496	70 min	482 min
	ASTM A381	Grade Y35	35	240	60 min	415 min	AWS A5.5[7]				
	ASTM A500	Grade A	33	228	45 min	310 min	E70XX-X	57–60	390–415	70–75 min	480–520 min
		Grade B	42	290	58 min	400 min	SAW				
	ASTM A501		36	250	58 min	400 min	AWS A5.17				
	ASTM A516	Grade 55	30	205	55–75	380–515	F6XX-EXXX	48	330	60–80	415–550
		Grade 60	32	220	60–80	415–550	F7XX-EXXX	58	400	70–95	480–650
	ASTM A524	Grade I	35	240	60–85	415–586	AWS A5.23[7]				
		Grade II	30	205	55–80	380–550	F7XX-EXX-XX	58	400	70–95	480–660
I	ASTM A529		42	290	60–85	415–585					
	ASTM A570	Grade 30	30	205	49 min	340 min	GMAW				
		Grade 33	33	230	52 min	360 min	AWS A5.18				
		Grade 36	36	250	53 min	365 min	ER70S-X	58	400	70 min	480 min
		Grade 40	40	275	55 min	380 min					
		Grade 45	45	310	60 min	415 min					
		Grade 50	50	345	65 min	450 min					
	ASTM A573	Grade 65	35	240	65–77	450–530	FCAW				
		Grade 58	32	220	58–71	400–490	AWS A5.20				
	ASTM A709	Grade 36[4]	36	250	58–80	400–550	E6XT-X	48	330	60 min	415 min
	API 5L	Grade B	35	240	60	415	E7XT-X	58	400	70 min	480 min
		Grade X42	42	290	60	415	(Except -2, -3, -10, -13, -14, -GS)				
	ABS	Grades A, B, D, CS, DS			58–71	400–490	AWS A5.29[7]				
		Grade E[5]			58–71	400–490	E7XTX-XX	58	400	70–90	490–620

(continued)

Table 3.1 (Continued)

Group	Steel Specification Requirements: Steel Specification[1,2]		Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Range ksi	Tensile Range MPa	Filler Metal Requirements: Electrode Specification[3,6]	Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Strength Range ksi	Tensile Strength Range MPa
	ASTM A131	Grades AH32, DH32, EH32	46	315	68–85	470–585	SMAW				
		Grades AH36, DH36, EH36	51	350	71–90	490–620	AWS A5.1				
	ASTM A441		40–50	275–345	60–70	415–485	E7015, E7016	58	399	70 min	482 min
	ASTM A516	Grade 65	35	240	65–85	450–585	E7018, E7028				
		Grade 70	38	260	70–90	485–620	AWS A5.5[7]				
	ASTM A537	Class 1	45–50	310–345	65–90	450–620	E7015-X, E7016-X	57–60	390–415	70–75 min	480–520 min
	ASTM A572	Grade 42	42	290	60 min	415 min	E7018-X				
	ASTM A572	Grade 50	50	345	65 min	450 min	SAW				
	ASTM A588[5]	(4 in. and under)	50	345	70 min	485 min	AWS A5.17				
	ASTM A595	Grade A	55	380	65 min	450 min	F7XX-EXXX	58	400	70–95	480–650
		Grades B and C	60	415	70 min	480 min	AWS A5.23[7]				
	ASTM A606[5]		45–50	310–340	65 min	450 min	F7XX-EXX-XX	58	400	70–95	480–660
	ASTM A607	Grade 45	45	310	60 min	410 min	GMAW				
		Grade 50	50	345	65 min	450 min	AWS A5.18				
		Grade 55	55	380	70 min	480 min	ER70S-X	58	400	70 min	480 min
	ASTM A618	Grades Ib, II, III	46–50	315–345	65 min	450 min					
	ASTM A633	Grade A	42	290	63–83	430–570					
II		Grades C, D	50	345	70–90	485–620	FCAW				
		(2-1/2 in. and under)					AWS A5.20				
	ASTM A709	Grade 50	50	345	65 min	450 min	E7XT-X	58	400	70 min	480 min
		Grade 50W	50	345	70 min	485 min	(Except -2, -3, -10, -13, -14, -GS)				
	ASTM A710	Grade A, Class 2 > 2 in.	55	380	65 min	450 min	AWS A5.29[7]				
	ASTM A808	(2-1/2 in. and under)	42	290	60 min	415 min	E7XTX-X	58	400	70–90	490–620
	ASTM A913	Grade 50	50	345	65 min	450 min					
	API 2H[6]	Grade 42	42	290	62–80	430–550					
		Grade 50	50	345	70 min	485 min					
	API 2W	Grade 42	42–67	290–462	62 min	427 min					
		Grade 50	50–75	345–517	65 min	448 min					
		Grade 50T	50–80	345–552	70 min	483 min					
	API 2Y	Grade 42	42–67	290–462	62 min	427 min					
		Grade 50	50–75	345–517	65 min	448 min					
		Grade 50T	50–80	345–552	70 min	483 min					
	API 5L	Grade X52	52	360	66–72	455–495					
	ABS	Grades AH32, DH32, EH32	45.5	315	71–90	490–620					
		Grades AH36, DH36, EH36[5]	51	350	71–90	490–620					

(continued)

Table 3.1 (Continued)

Group	Steel Specification Requirements: Steel Specification[1, 2]		Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Range ksi	Tensile Range MPa	Filler Metal Requirements: Electrode Specification[3, 6]	Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Strength Range ksi	Tensile Strength Range MPa
III	API 2W	Grade 60	60–90	414–621	75 min	517 min	SMAW AWS A5.5[7]				
	API 2Y	Grade 60	60–90	414–621	75 min	517 min	E8015-X, E8016-X	67–80	460–550	80 min	550 min
	ASTM A572	Grade 60	60	415	75 min	515 min	E8018-X				
		Grade 65	65	450	80 min	550 min	SAW				
	ASTM A537	Class 2[5]	46–60	315–415	80–100	550–690	AWS A5.23[7]				
	ASTM A633	Grade E[5]	55–60	380–415	75–100	515–690	F8XX-EXX-XX	68	470	80–100	550–690
	ASTM A710	Grade A, Class 2 ≤ 2 in.	60–65	415–450	72 min	495 min	GMAW				
	ASTM A710	Grade A, Class 3 > 2 in.	60–65	415–450	70 min	485 min	AWS A5.28[7]				
	ASTM A913[9]	Grade 60	60	415	75 min	520 min	ER80S-X	68	470	80 min	550 min
		Grade 65	65	450	80 min	550 min	FCAW AWS A5.29[7]				
							E8XTX-X	68	470	80–100	550–690

Notes:
1. In joints involving base metals of different groups, either of the following filler metals may be used: (1) that which matches the higher strength base metal, or (2) that which matches the lower strength base metal and produces a low-hydrogen deposit. Preheating shall be in conformance with the requirements applicable to the higher strength group.
2. Match API standard 2B (fabricated tubes) according to steel used.
3. When welds are to be stress-relieved, the deposited weld metal shall not exceed 0.05 percent vanadium.
4. Only low-hydrogen electrodes shall be used when welding A36 or A709 Grade 36 steel more than 1 in. (25.4 mm) thick for cyclically loaded structures.
5. Special welding materials and WPS (e.g., E80XX-X low-alloy electrodes) may be required to match the notch toughness of base metal (for applications involving impact loading or low temperature), or for atmospheric corrosion and weathering characteristics (see 3.7.3).
6. The designation of ER70S-1B has been reclassified as ER80S-D2 in A5.28-79. Prequalified WPSs prepared prior to 1981 and specifying AWS A5.18, ER70S-1B, may now use AWS A5.28-79 ER80S-D2 when welding steels in Groups I and II.
7. Filler metals of alloy group B3, B3L, B4, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, or B9 in ANSI/AWS A5.5, A5.23, A5.28, or A5.29 are not prequalified for use in the as-welded condition.
8. See Tables 2.3 and 2.5 for allowable stress requirements for matching filler metal.
9. The heat input limitations of 5.7 shall not apply to ASTM A913 Grade 60 or 65.

3.4 Engineer's Approval for Auxiliary Connections

The Engineer may approve unlisted materials for auxiliary attachments or components which fall within the chemical composition range of a listed material to be welded with prequalified WPSs. The filler metal and preheat required shall be in conformance with the requirements of 3.5 based upon the similar material strength and chemical composition.

3.5 Minimum Preheat and Interpass Temperature Requirements

The preheat and interpass temperature shall be sufficient to prevent cracking. Table 3.2 shall be used to determine the minimum preheat and interpass temperatures for steels listed in the code.

3.5.1 Base Metal/Thickness Combination. The minimum preheat or interpass temperature applied to a joint composed of base metals with different minimum preheats from Table 3.2 (based on Category and thickness) shall be the highest of these minimum preheats.

3.5.2 Annex XI Option. Optionally, minimum preheat and interpass temperature may be established on the basis of steel composition. Recognized methods of prediction or guidelines such as those provided in Annex XI, or other methods approved by the Engineer, may be used. However, should the use of these guidelines result in preheat temperatures lower than those of Table 3.2, WPS qualification in conformance with section 4 shall be required.

The methods of Annex XI are based on laboratory cracking tests and may predict preheat temperatures higher than the minimum temperature shown in Table 3.2. The guide may be of value in identifying situations where the risk of cracking is increased due to composition, restraint, hydrogen level or lower welding heat input where higher preheat may be warranted. Alternatively, the guide may assist in defining conditions under which hydrogen cracking is unlikely and where the minimum requirements of Table 3.2 may be safely relaxed.

3.5.3 Alternate SAW Preheat and Interpass Temperatures. Preheat and interpass temperatures for parallel or multiple electrode SAW shall be selected in conformance with Table 3.2. For single-pass groove or fillet welds, for combinations of metals being welded and the heat input involved, and with the approval of the Engineer, preheat and interpass temperatures may be established which are sufficient to reduce the hardness in the heat-affected zones of the base metal to less than 225 Vickers hardness number for steel having a minimum specified tensile strength not exceeding 60 000 psi (415 MPa), and 280 Vickers hardness number for steel having a minimum specified tensile strength greater than 60 000, but not exceeding 70 000 psi (485 MPa).

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

3.5.3.1 Hardness Requirements. Hardness determination of the heat-affected zone will be made on the following:

(1) Initial macroetch cross sections of a sample test specimen.

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

(a) The frequency of such heat-affected zone testing shall be at least one test area per weldment of the thicker metal involved in a joint of each 50 ft (15 m) of groove welds or pair of fillet welds.

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

3.6 Limitation of WPS Variables

All prequalified WPSs to be used shall be prepared by the manufacturer, fabricator, or contractor as written prequalified WPSs, and shall be available to those authorized to use or examine them. The written WPS may follow any convenient format (see Annex E for examples). The welding parameters set forth in (1) through (4) of this subsection shall be specified on the written WPSs within the limitation of variables prescribed in Table 4.5 for each applicable process. Changes in these parameters, beyond those specified on the written WPS, shall be considered essential changes and shall require a new or revised prequalified written WPS:

(1) Amperage (wire feed speed)
(2) Voltage
(3) Travel Speed
(4) Shielding Gas Flow Rate

3.6.1 Combination of WPSs. A combination of qualified and prequalified WPSs may be used without qualification of the combination, provided the limitation of essential variables applicable to each process is observed.

3.7 General WPS Requirements

All the requirements of Table 3.7 shall be met for prequalified WPSs.

Table 3.2
Prequalified Minimum Preheat and Interpass Temperature[3] (see 3.5)

Category	Steel Specification				Welding Process	Thickness of Thickest Part at Point of Welding: in.	Thickness of Thickest Part at Point of Welding: mm	Minimum Preheat and Interpass Temperature: °F	Minimum Preheat and Interpass Temperature: °C
A	ASTM A36		ASTM A516			1/8 to 3/4 incl.	3 to 19 incl.	None[1]	
	ASTM A53	Grade B	ASTM A524	Grades I & II					
	ASTM A106	Grade B	ASTM A529			Over 3/4	Over 19		
	ASTM A131	Grades A, B,	ASTM A570	All grades	Shielded metal arc	thru 1-1/2 incl.	thru 38.1 incl.	150	66
		CS, D, DS, E	ASTM A573	Grade 65	welding with other				
	ASTM A139	Grade B	ASTM A709	Grade 36	than low-hydrogen	Over 1-1/2	Over 38.1		
	ASTM A381	Grade Y35	API 5L	Grade B	electrodes	thru 2-1/2 incl.	thru 63.5 incl.	225	107
	ASTM A500	Grade A		Grade X42					
		Grade B	ABS	Grades A, B, D, CS, DS					
	ASTM A501			Grade E		Over 2-1/2	Over 63.5	300	150
B	ASTM A36		ASTM A570	All grades					
	ASTM A53	Grade B	ASTM A572	Grades 42, 50					
	ASTM A106	Grade B	ASTM A573	Grade 65					
	ASTM A131	Grades A, B,	ASTM A588						
		CS, D, DS, E	ASTM A595	Grades A, B, C		1/8 to 3/4 incl.	3 to 19 incl.	None[1]	
		AH 32 & 36	ASTM A606						
		DH 32 & 36	ASTM A607	Grades 45, 50, 55					
		EH 32 & 36	ASTM A618	Grades Ib, II, III					
	ASTM A139	Grade B	ASTM A633	Grades A, B					
				Grades C, D	Shielded metal arc	Over 3/4	Over 19 thru		
	ASTM A381	Grade Y35	ASTM A709	Grades 36, 50, 50W	welding with low-	thru 1-1/2 incl.	38.1 incl.	50	10
			ASTM A710	Grade A, Class 2 (> 2 in.)	hydrogen electrodes,				
			ASTM A808		submerged arc				
			ASTM A913	Grade 50	welding,[2] gas metal				
	ASTM A441		API 5L	Grade B	arc welding, flux				
	ASTM A500	Grade A		Grade X42	cored arc welding				
		Grade B	API Spec. 2H	Grades 42, 50		Over 1-1/2	Over 38.1 thru		
			API 2W	Grades 42, 50, 50T					
			API 2Y	Grades 42, 50, 50T					
	ASTM A501		ABS	Grades AH 32 & 36		thru 2-1/2 incl.	63.5 incl.	150	66
	ASTM A516	Grades 55 & 60		DH 32 & 36					
		65 & 70		EH 32 & 36					
	ASTM A524	Grades I & II	ABS	Grades A, B, D,					
	ASTM A529			CS, DS		Over 2-1/2	Over 63.5	225	107
	ASTM A537	Classes 1 & 2		Grade E					

(continued)

Table 3.2 (Continued)

Category	Steel Specification		Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Preheat and Interpass Temperature	
				in.	mm	°F	°C
C	ASTM A572	Grades 60, 65	Shielded metal arc welding with low-hydrogen electrodes, submerged arc welding,[2] gas metal arc welding, flux cored arc welding	1/8 to 3/4 incl.	3 to 19 incl.	50	10
	ASTM A633	Grade E		Over 3/4 thru 1-1/2 incl.	Over 19 thru 38.1 incl.	150	66
	API 5L	Grade X52		Over 1-1/2 thru 2-1/2 incl.	Over 38.1 thru 63.5 incl.	225	107
	ASTM A913[4]	Grades 60, 65		Over 2-1/2	Over 63.5	300	150
	ASTM A710	Grade A, Class 2 (≤2 in.)					
	ASTM A710	Grade A, Class 3 (>2 in.)					
	API 2W	Grade 60					
	API 2Y	Grade 60					
D	ASTM A710	Grade A (All classes)	SMAW, SAW, GMAW, and FCAW with electrodes or electrode-flux combinations capable of depositing weld metal with a maximum diffusible hydrogen content of 8 ml/100 g (H8), when tested according to ANSI/ AWS A4.3.	no preheat is required			
	ASTM A913[4]	Grades 50, 60, 65					

Notes:
1. When the base metal temperature is below 32°F (0°C), the base metal shall be preheated to at least 70°F (21°C) and this minimum temperature maintained during welding.
2. For modification of preheat requirements for submerged arc welding with parallel or multiple electrodes, see 3.5.3.
3. See 5.12.2 and 5.6 for ambient and base-metal temperature requirements.
4. The heat input limitations of 5.7 shall not apply to ASTM A913 Grade 60 or 65.

3.7.1 Vertical-Up Welding Requirements. The progression for all passes in vertical position welding shall be upward, except that undercut may be repaired vertically downwards when preheat is in accordance with Table 3.2, but not lower than 70°F (21°C). However, when tubular products are welded, the progression of vertical welding may be upwards or downwards, but only in the direction(s) for which the welder is qualified.

3.7.2 Width/Depth Pass Limitation. Neither the depth nor the maximum width in the cross section of weld metal deposited in each weld pass shall exceed the width at the surface of the weld pass (see Figure 3.1).

3.7.3 Weathering Steel Requirements. For exposed, bare, unpainted applications of A588 steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode or electrode-flux combination shall conform to Table 3.3.

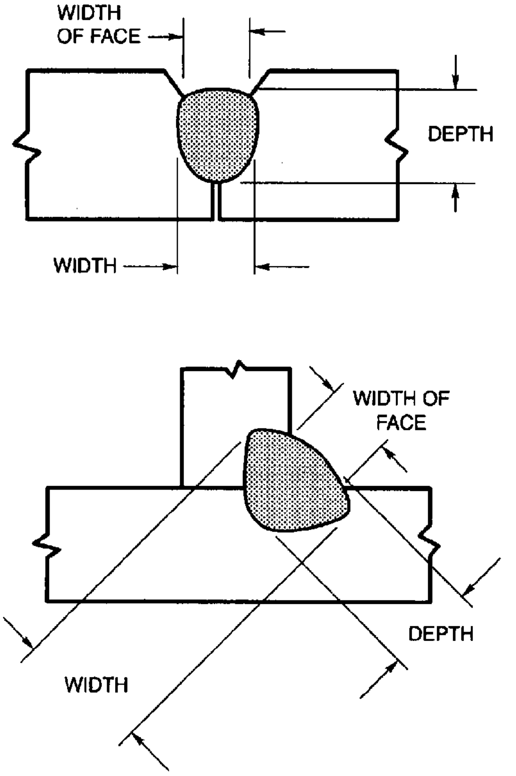


Figure 3.1—Weld Bead in which Depth and Width Exceed the Width of the Weld Face (see 3.7.2)

Table 3.3 (see 3.7.3)
Filler Metal Requirements for Exposed Bare Applications of ASTM A588 Steel

Process	AWS Filler Metal Specification	Approved Electrodes[1]
SMAW	A5.5	All electrodes that deposit weld metal meeting a B2L, C1, C1L, C2, C2L, C3 or W analysis per A5.5.
SAW[3]	A5.23	All electrode-flux combinations that deposit weld metal with a Ni1, Ni2, Ni3, Ni4 or W analysis per A5.23.
FCAW	A5.29	All electrodes that deposit weld metal with a B2L, K2, Ni1, Ni2, Ni3, Ni4, or W analysis per A5.29.
GMAW[3]	A5.28	All electrodes that meet filler metal composition requirements of B2L, G (see Note 2), Ni1, Ni2, Ni3, analysis per A5.28.

Notes:
1. Filler metals shall meet requirements of Table 3.1 in addition to the compositional requirements listed above. The use of the same type of filler metal having next higher tensile strength as listed in AWS filler metal specification is permitted.
2. Deposited weld metal shall have a chemical composition the same as that for any one of the weld metals in this table.
3. Composite (metal cored) electrodes are designated as follows:
SAW: Insert letter "C" between the letters "E" and "X", e.g., E7AX-ECXXX-Ni1.
GMAW: Replace the letter "S" with the letter "C", and omit the letter "R", e.g., E80C-Ni1.

The exceptions to this requirement are as follows:

3.7.3.1 Single-Pass Groove Welds. Groove welds made with a single pass or a single pass each side may be made using any of the filler metals for Group II base metals in Table 3.1.

3.7.3.2 Single-Pass Fillet Welds. Single-pass fillet welds up to the following sizes may be made using any of the filler metals for Group II base metals listed in Table 3.1:

SMAW	1/4 in.
SAW	5/16 in.
GMAW/FCAW	5/16 in.

3.8 Common Requirements for Parallel Electrode and Multiple Electrode SAW

3.8.1 GMAW Root Pass. Welds may also be made in the root of groove or fillet welds using GMAW, followed by parallel or multiple electrode submerged arcs, provided that the GMAW conforms to the requirements of this section, and providing the spacing between the gas metal shielded arc and the following submerged arc does not exceed 15 in. (380 mm).

3.9 Fillet Weld Requirements

See Table 5.8 for minimum fillet weld sizes.

3.9.1 Details (Nontubular). See Figure 2.1 and Figure 2.5 for the limitations for prequalified fillet welds.

3.9.2 Details (Tubular). For prequalified status, fillet welded tubular connections shall conform to the following provisions:

(1) Prequalified WPSs. Fillet welded tubular connections made by shielded metal arc, gas metal arc or flux cored arc welding processes that may be used without performing WPS qualification tests are detailed in Figure 3.2. (See 2.39.1.2 for limitations). These details may also be used for GMAW-S qualified in accordance with 4.12.4.3.

(2) Prequalified fillet weld details in lap joints are shown in Figure 2.15.

3.9.3 Skewed T-Joints. Welds in skewed T-joint configurations that may be used without performing the WPS qualification test prescribed in section 4, are detailed in Figure 3.11, and are subject to the limitation specified in 3.2.

3.9.3.1 Dihedral Angle Limitations. The obtuse side of skewed T-joints with dihedral angles greater than 100° shall be prepared as shown in Figure 3.11, Detail C, to permit placement of a weld of the required size. The amount of machining or grinding, etc., of Figure 3.11, Detail C, should not be more than that required to achieve the required weld size (W).

3.9.3.2 Minimum Weld Size. The minimum weld size for skewed T-joint welds shown in Figure 3.11, Details A, B, and C, shall be as shown in Table 5.8. The minimum size applies if it is sufficient to satisfy design requirements.

3.10 Plug and Slot Weld Requirements

The details of plug and slot welds made by the SMAW, GMAW (except short circuiting transfer), or FCAW processes are listed in 3.10.1 through 3.10.3, 2.5.2 through 2.5.4, and 2.5.6, and they may be used without performing the WPS qualification prescribed in section 4, provided the technique provisions of 5.25 are met.

3.10.1 Diameter Limitations. The minimum diameter of the hole for a plug weld shall be no less than the thickness of the part containing it plus 5/16 in. (8 mm), preferably rounded to the next greater odd 1/16 in. (1.6 mm). The maximum diameter shall equal the minimum diameter plus 1/8 in. (3 mm) or 2-1/4 times the thickness of the member, whichever is greater.

3.10.2 Slot Length. 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 5/16 in. (8 mm), preferably rounded to the next greater odd 1/16 in. (1.6 mm). The maximum width shall equal the minimum width plus 1/8 in. (3 mm) or 2-1/4 times the thickness of the member, whichever is greater.

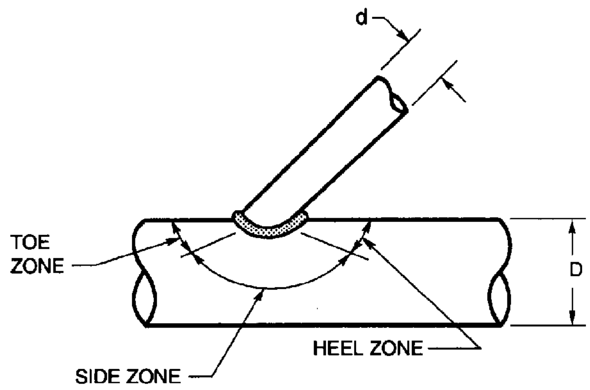
3.10.3 Depth of Filling. The depth of filling of plug or slot welds in metal 5/8 in. (15.9 mm) thick or less shall be equal to the thickness of the material. In metal over 5/8 in. thick, it shall be at least one-half the thickness of the material, but no less than 5/8 in.

3.11 Common Requirements of Partial and Complete Joint Penetration Groove Welds

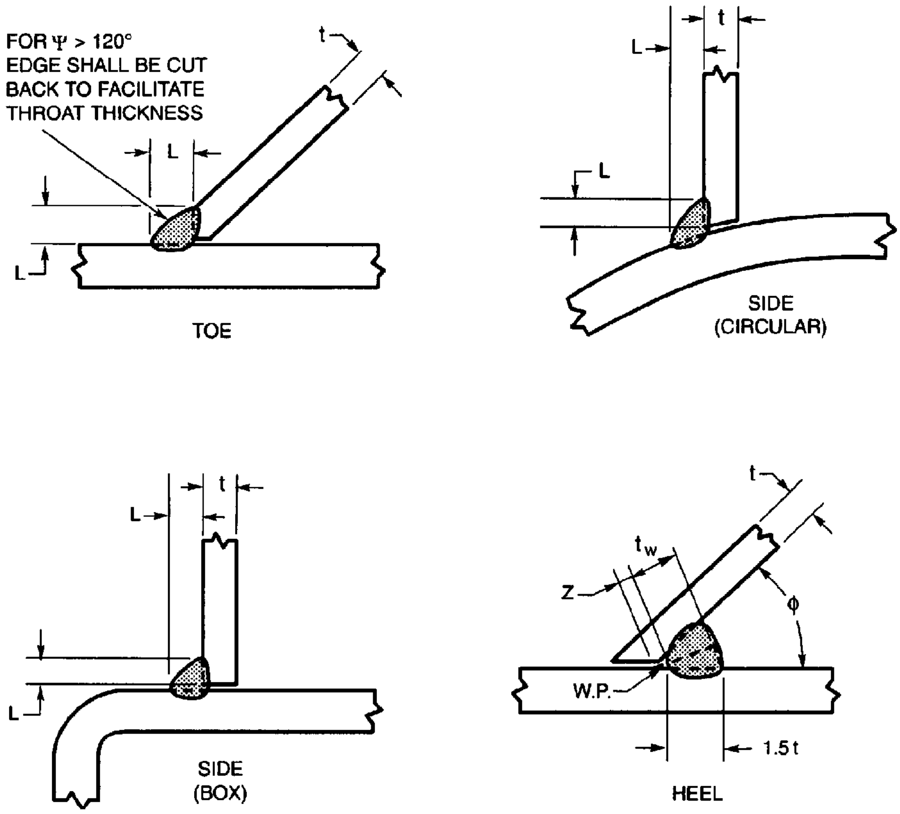
3.11.1 FCAW/GMAW in SMAW Joints. Groove preparations detailed for prequalified SMAW joints may be used for prequalified GMAW or FCAW.

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

3.11.3 Root Openings. Joint root openings may vary as noted in 3.12.3 and 3.13.1. However, for automatic or machine welding using FCAW, GMAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) may not exceed 1/8 in. (3 mm). Variations greater than 1/8 in. shall be locally corrected prior to automatic or machine welding.



	MIN L FOR		
	E = 0.7t	E = t	E = 1.07t
HEEL < 60°	1.5t	1.5t	LARGER OF 1.5t OR 1.4t + Z
SIDE ≤ 100°	t	1.4t	1.5t
SIDE 100–110°	1.1t	1.6t	1.75t
SIDE 110–120°	1.2t	1.8t	2.0t
TOE > 120°	t BEVEL	1.4t BEVEL	FULL BEVEL 60–90° GROOVE



Notes:
1. t = thickness of thinner part.
2. L = minimum size (see 2.40.1.3 which may require increased weld size for combinations other than 36 ksi (250 MPa) base metal and 70 ksi (480 MPa) electrodes).
3. Root opening 0 to 3/16 in. (5 mm) — See 5.22.
4. ϕ = 15° min. Not prequalified for under 30°. For ϕ < 60°, loss dimension (Table 2.8) and special welder qualifications (Table 4.8) apply.
5. See 2.39.1.2 for limitations on β = d/D.

Figure 3.2—Fillet Welded Prequalified Tubular Joints Made by Shielded Metal Arc, Gas Metal Arc, and Flux Cored Arc Welding (see 3.9.2)

3.12 Partial Joint Penetration Requirements

Partial joint penetration groove welds which may be used without performing the WPS qualification tests prescribed in section 4 are detailed in Figure 3.3 and are subject to the joint dimension limitations specified in 3.12.3.

3.12.1 Definition. Except as provided in 3.13.4 and Figure 3.4 (B-L1-S), groove welds without steel backing, welded from one side, and groove welds welded from both sides, but without backgouging, are considered partial joint penetration groove welds.

3.12.2 Weld Size. The weld size (E) of a prequalified partial joint penetration groove shall be as shown in Figure 3.3 for the particular welding process, joint designation, groove angle, and welding position proposed for use in welding fabrication.

3.12.2.1 Minimum Prequalified Weld Sizes. The minimum weld size of partial joint penetration, single-, or double-V-, bevel-, J-, and U-, groove welds shall be as shown in Table 3.4. The PJP square butt weld B-P1 and flare-bevel groove weld BTC-P10 minimum weld sizes are to be calculated from Figure 3.3. Shop or working drawings shall specify the design groove depths (S) applicable for the weld size (E) required per 3.12.2.

3.12.3 Joint Dimensions. Dimensions of groove welds specified in 3.12 may vary on design or detail drawings within the limits of tolerances shown in the "As Detailed" column in Figure 3.3. Fit-up tolerances of Figure 3.3 may be applied to the dimensions shown on the detail drawing. J-and U- grooves may be prepared before or after assembly.

3.12.4 Details (Tubular). Details for partial joint penetration tubular groove welds that are accorded prequalified status shall conform to the following provisions:

(1) PJP tubular groove welds, other than T-, Y-, and K-connections, may be used without performing the WPS qualification tests, when these can be applied and meet all of the joint dimension limitations as specified in Figure 3.3.

(2) PJP T-, Y-, and K-tubular connections, welded only by the SMAW, GMAW or FCAW process, may be used without performing the WPS qualification tests, when they can be applied and meet all of the joint dimension limitations as specified in Figure 3.5. These details may also be used for GMAW-S qualified in accordance with 4.12.4.3.

Legend for Figures 3.3 and 3.4

Symbols for joint types

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

Symbols for base metal thickness and penetration

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

Symbol for weld types

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

Symbols for welding processes if not shielded metal arc

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

Welding processes

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

Welding positions

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

Dimensions

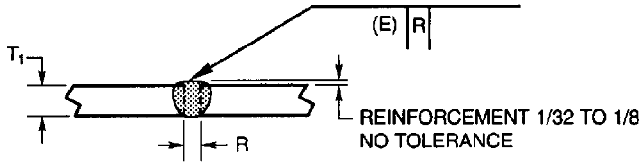
R = Root Opening
α, β = Groove Angles
f = Root Face
r = J- or U-groove Radius
S, S_1, S_2 = PJP Groove Weld Depth of Groove
E, E_1, E_2 = PJP Groove Weld Sizes corresponding to S, S_1, S_2, respectively

Joint Designation

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

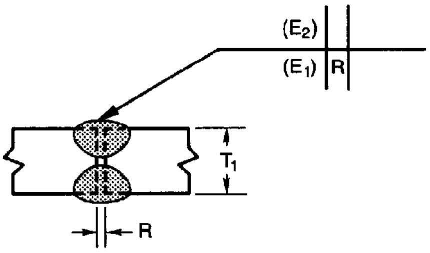
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	B-P1a	1/8 max	—	R = 0 to 1/16	+1/16, −0	±1/16	All	T_1 − 1/32	B, D
	B-P1c	1/4 max	—	$R = \frac{T_1}{2}$ min	+1/16, −0	±1/16	All	$\frac{T_1}{2}$	B, D

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



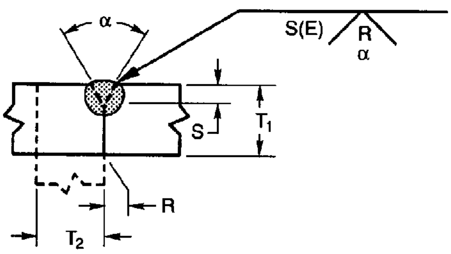
$E_1 + E_2$ MUST NOT EXCEED $\frac{3T_1}{4}$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	B-P1b	1/4 max	—	$R = \frac{T_1}{2}$	+1/16, −0	±1/16	All	$\frac{3T_1}{4}$	D

Figure 3.3—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

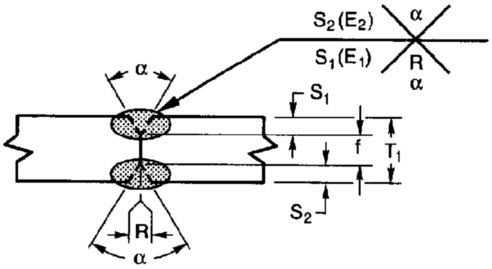
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW	BC-P2	1/4 min	U	R = 0 f = 1/32 min α = 60°	0, +1/16 +U, −0 +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	S	B, D, E, N
GMAW FCAW	BC-P2-GF	1/4 min	U	R = 0 f = 1/8 min α = 60°	0, +1/16 +U, −0 +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	S	A, B, E, N
SAW	BC-P2-S	7/16 min	U	R = 0 f = 1/4 min α = 60°	±0 +U, −0 +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	S	B, E, N

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

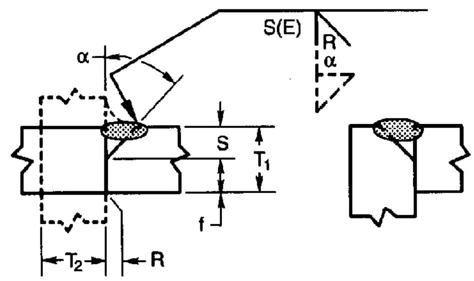


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	B-P3	1/2 min	—	R = 0 f = 1/8 min α = 60°	+1/16, −0 +U, −0 +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	D, E, Mp, N
GMAW FCAW	B-P3-GF	1/2 min	—	R = 0 f = 1/8 min α = 60°	+1/16, −0 +U, −0 +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	A, E, Mp, N
SAW	B-P3-S	3/4 min	—	R = 0 f = 1/4 min α = 60°	±0 +U, −0 +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, Mp, N

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

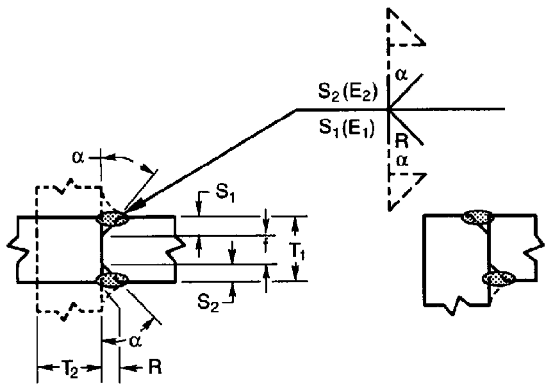
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	BTC-P4	U	U	R = 0 f = 1/8 min α = 45°	+1/16, −0 unlimited +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	S−1/8	B, D, E, J, N, V
GMAW FCAW	BTC-P4-GF	1/4 min	U	R = 0 f = 1/8 min α = 45°	+1/16, −0 unlimited +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	F, H	S	A, B, E, J, N, V
							V, OH	S−1/8	
SAW	TC-P4-S	7/16 min	U	R = 0 f = 1/4 min α = 60°	±0 +U, −0 +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	S	B, E, J, N, V

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

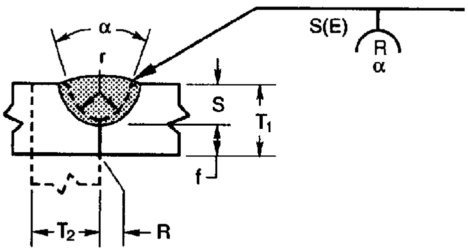


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	BTC-P5	5/16 min	U	R = 0 f = 1/8 min α = 45°	+1/16, −0 unlimited + 10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$ −1/4	D, E, J, Mp, N, V
GMAW FCAW	BTC-P5-GF	1/2 min	U	R = 0 f = 1/8 min α = 45°	+1/16, −0 unlimited +10°, −0°	+1/8, −1/16 ±1/16 +10°, −5°	F, H	$S_1 + S_2$	A, E, J, Mp, N, V
							V, OH	$S_1 + S_2$ −1/4	
SAW	TC-P5-S	3/4 min	U	R = 0 f = 1/4 min α = 60°	±0 +U, −0 +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, J, Mp, N, V

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

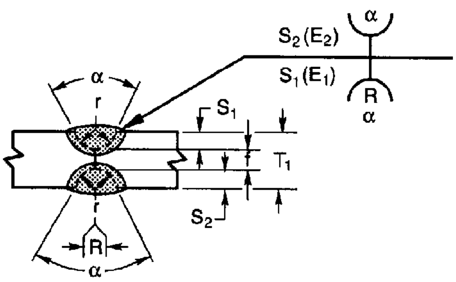
See Notes on Page 88

Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening / Root Face / Groove Radius / Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW	BC-P6	1/4 min	U	R = 0 f = 1/32 min r = 1/4 α = 45°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	B, D, E, N
GMAW FCAW	BC-P6-GF	1/4 min	U	R = 0 f = 1/8 min r = 1/4 α = 20°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	A, B, E, N
SAW	BC-P6-S	7/16 min	U	R = 0 f = 1/4 min r = 1/4 α = 20°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	S	B, E, N

Double-U-groove weld (7)
Butt joint (B)

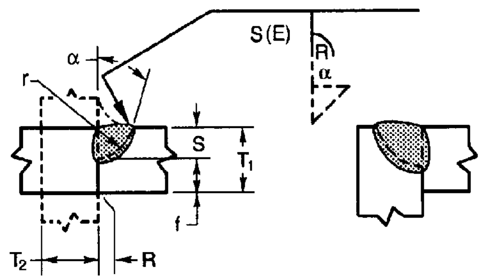


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening / Root Face / Groove Radius / Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	B-P7	1/2 min	—	R = 0 f = 1/8 min r = 1/4 α = 45°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	D, E, Mp, N
GMAW FCAW	B-P7-GF	1/2 min	—	R = 0 f = 1/8 min r = 1/4 α = 20°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	A, E, Mp, N
SAW	B-P7-S	3/4 min	—	R = 0 f = 1/4 min r = 1/4 α = 20°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, Mp, N

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

See Notes on Page 88

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



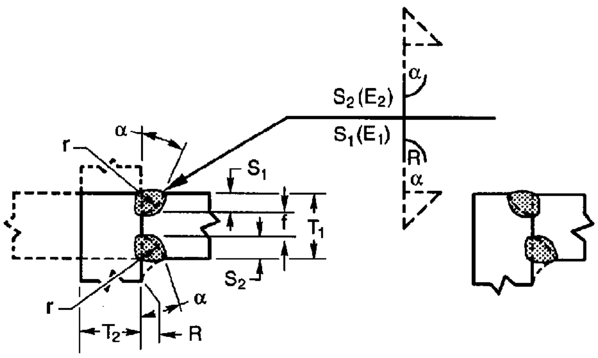
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T1	T2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	TC-P8*	1/4 min	U	R = 0 f = 1/8 min r = 3/8 α = 45°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	D, E, J, N, V
SMAW	BC-P8**	1/4 min	U	R = 0 f = 1/8 min r = 3/8 α = 30°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	D, E, J, N, V
GMAW FCAW	TC-P8-GF*	1/4 min	U	R = 0 f = 1/8 min r = 3/8 α = 45°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	A, E, J, N, V
GMAW FCAW	BC-P8-GF**	1/4 min	U	R = 0 f = 1/8 min r = 3/8 α = 30°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	S	A, E, J, N, V
SAW	TC-P8-S*	7/16 min	U	R = 0 f = 1/4 min r = 1/2 α = 45°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	S	E, J, N, V
SAW	C-P8-S**	7/16 min	U	R = 0 f = 1/4 min r = 1/2 α = 20°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	S	E, J, N, V

*Applies to inside corner joints.
**Applies to outside corner joints.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

See Notes on Page 88

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



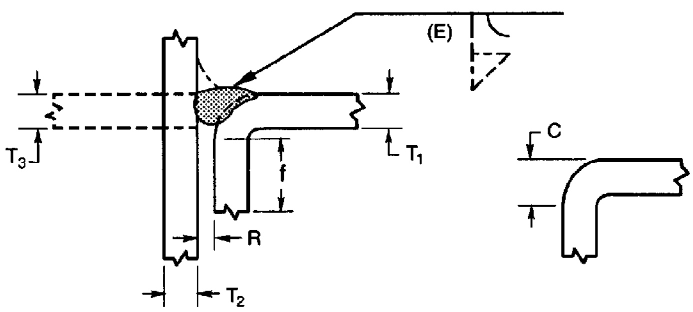
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Root Opening Root Face Groove Radius Groove Angle	Tolerances As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	BTC-P9*	1/2 min	U	R = 0 f = 1/8 min r = 3/8 α = 45°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	D, E, J, Mp, N, V
GMAW FCAW	BTC-P9-GF**	1/2 min	U	R = 0 f = 1/8 min r = 3/8 α = 30°	+1/16, −0 +U, −0 +1/4, −0 + 10°, −0°	+1/8, −1/16 ±1/16 ±1/16 +10°, −5°	All	$S_1 + S_2$	A, J, Mp, N, V
SAW	C-P9-S*	3/4 min	U	R = 0 f = 1/4 min r = 1/2 α = 45°	±0 +U, −0 +1/4, −0 + 10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, J, Mp, N, V
SAW	C-P9-S**	3/4 min	U	R = 0 f = 1/4 min r = 1/2 α = 20°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, J, Mp, N, V
SAW	T-P9-S	3/4 min	U	R = 0 f = 1/4 min r = 1/2 α = 45°	±0 +U, −0 +1/4, −0 +10°, −0°	+1/16, −0 ±1/16 ±1/16 +10°, −5°	F	$S_1 + S_2$	E, J, Mp, N

*Applies to inside corner joints.
**Applies to outside corner joints.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

See Notes on Page 88

Flare-bevel-groove weld (10)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)			Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	T_3	Root Opening Root Face Bend Radius*	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	BTC-P10	3/16 min	U	T_1 min	R = 0 f = 3/16 min $C = \frac{3T_1}{2}$ min	+1/16, −0 +U, −0 −0, +Not-Limited	+1/8, −1/16 +U, −1/16 −0, +Not-Limited	All	$5/8T_1$	D, J, N, Z
GMAW FCAW	BTC-P10-GF	3/16 min	U	T_1 min	R = 0 f = 3/16 min $C = \frac{3T_1}{2}$ min	+1/16, −0 +U, −0 −0, +Not-Limited	+1/8, −1/16 +U, −1/16 −0, +Not-Limited	All	$5/8T_1$	A, J, N, Z
SAW	T-P10-S	1/2 min	1/2 min	N/A	R = 0 f = 1/2 min $C = \frac{3T_1}{2}$ min	±0 +U, −0 −0, +Not-Limited	+1/16, −0 +U, −1/16 −0, +Not-Limited	F	$5/8T_1$	J, N, Z

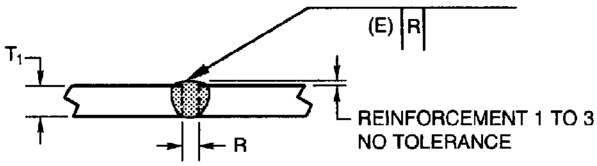
*For cold formed (A500) rectangular tubes, C dimension is not limited. See the following:

Effective Weld Size of Flare-Bevel-Groove Welded Joints. Tests have been performed on cold formed ASTM A500 material exhibiting a "c" dimension as small as T_1 with a nominal radius of 2t. As the radius increases, the "c" dimension also increases. The corner curvature may not be a quadrant of a circle tangent to the sides. The corner dimension, "c", may be less than the radius of the corner.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12)

See Notes on Page 88

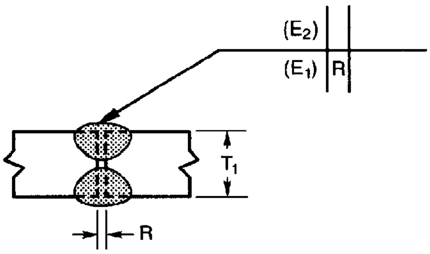
Square-groove weld (1)
Butt joint (B)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	B-P1a	3.2 max	—	R = 0 to 1.6	+1.6, –0	±1.6	All	$T_1 - 1$	B, D
	B-P1c	6.4 max	—	$R = \frac{T_1}{2}$ min	+1.6, –0	±1.6	All	$\frac{T_1}{2}$	B, D

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



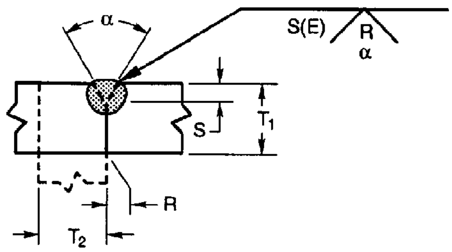
$E_1 + E_2$ MUST NOT EXCEED $\frac{3T_1}{4}$
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	B-P1b	6.4 max	—	$R = \frac{T_1}{2}$	+1.6, –0	±1.6	All	$\frac{3T_1}{4}$	D

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

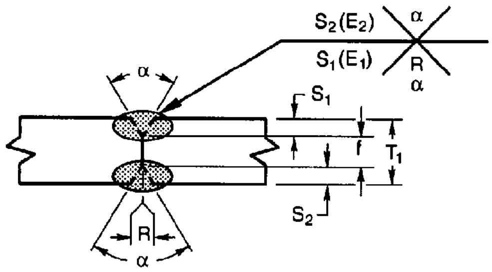
Single-V-groove weld (2)
Butt joint (B)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW	BC-P2	6.4 min	U	R = 0 f = 1 min α = 60°	0, +1.6 +U, −0 +10°, −0°	+3, −1.6 ±1/16 +10°, −5°	All	S	B, D, E, N
GMAW FCAW	BC-P2-GF	6.4 min	U	R = 0 f = 3 min α = 60°	0, +1.6 +U,−0 +10°, −0°	+3, −1.6 ±1/16 +10°, −5°	All	S	A, B, E, N
SAW	BC-P2-S	11.1 min	U	R = 0 f = 6 min α = 60°	±0 +U, −0 +10°, −0°	+1.6, −0 ±1.6 +10°, −5°	F	S	B, E, N

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



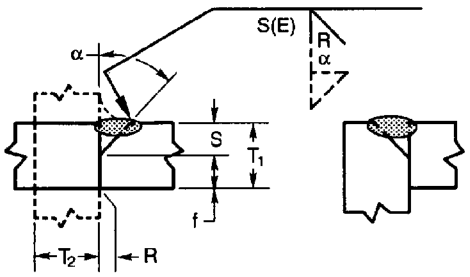
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	B-P3	12.7 min	—	R = 0 f = 3 min α = 60°	+1.6, −0 +U, −0 +10°, −0°	+3, −1.6 ±1.6 +10°, −5°	All	$S_1 + S_2$	D, E, Mp, N
GMAW FCAW	B-P3-GF	12.7 min	—	R = 0 f = 3 min α = 60°	+1.6, −0 +U, −0 +10°, −0°	+3, −1.6 ±1.6 +10°, −5°	All	$S_1 + S_2$	A, E, Mp, N
SAW	B-P3-S	19.0 min	—	R = 0 f = 6 min α = 60°	±0 +U, −0 +10°, −0°	+1.6, −0 ±1.6 +10°, −5°	F	$S_1 + S_2$	E, Mp, N

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

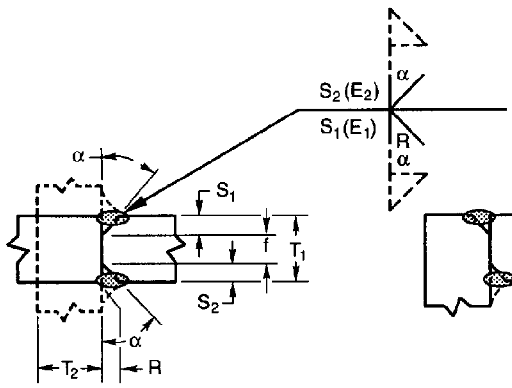
Single-bevel-groove (4)
Butt joint (B)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW	BTC-P4	U	U	R = 0 f = 3 min α = 45°	+1.6, –0 unlimited +10°, –0°	+3, –1.6 ±1.6 +10°, –5°	All	S–3	B, D, E, J, N, V
GMAW FCAW	BTC-P4-GF	6.4 min	U	R = 0 f = 3 min α = 45°	+1.6, –0 unlimited +10°, –0°	+3, –1.6 ±1.6 +10°, –5°	F, H V, OH	S S–3	A, B, E, J, N, V
SAW	TC-P4-S	11.1 min	U	R = 0 f = 6 min α = 60°	±0 +U, –0 +10°, –0°	+1.6, –0 ±1.6 +10°, –5°	F	S	B, E, J, N, V

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



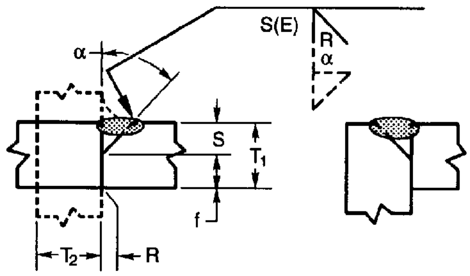
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	BTC-P5	8.0 min	U	R = 0 f = 3 min α = 45°	+1.6, –0 unlimited + 10°, –0°	+3, –1.6 ±1.6 +10°, –5°	All	$S_1 + S_2$ –6	D, E, J, Mp, N, V
GMAW FCAW	BTC-P5-GF	12.7 min	U	R = 0 f = 3 min α = 45°	+1.6, –0 unlimited +10°, –0°	+3, –1.6 ±1.6 +10°, –5°	F, H V, OH	$S_1 + S_2$ $S_1 + S_2$ –6	A, E, J, Mp, N, V
SAW	TC-P5-S	19.0 min	U	R = 0 f = 6 min α = 60°	±0 +U, –0 +10°, –0°	+1.6, –0 ±1.6 +10°, –5°	F	$S_1 + S_2$	E, J, Mp, N, V

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

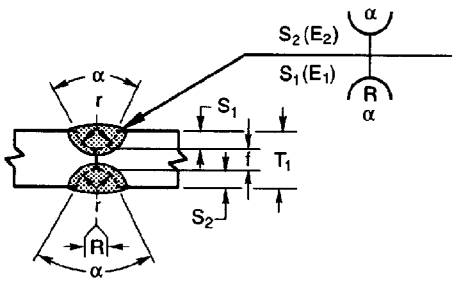
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	BC-P6	6.4 min	U	R = 0 f = 1 min r = 6 α = 45°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	B, D, E, N
GMAW FCAW	BC-P6-GF	6.4 min	U	R = 0 f = 3 min r = 6 α = 20°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	A, B, E, N
SAW	BC-P6-S	11.1 min	U	R = 0 f = 6 min r = 6 α = 20°	±0 +U, −0 +6, −0 +10°, −0°	+1.6, −0 ±1.6 ±1.6 +10°, −5°	F	S	B, E, N

Double-U-groove weld (7)
Butt joint (B)



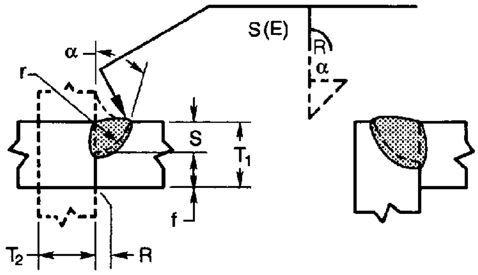
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)			
SMAW	B-P7	12.7 min	—	R = 0 f = 3 min r = 6 α = 45°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	$S_1 + S_2$	D, E, Mp, N
GMAW FCAW	B-P7-GF	12.7 min	—	R = 0 f = 3 min r = 6 α = 20°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	$S_1 + S_2$	A, E, Mp, N
SAW	B-P7-S	19.0 min	—	R = 0 f = 6 min r = 6 α = 20°	±0 +U, −0 +6, −0 +10°, −0°	+1.6, −0 ±1.6 ±1.6 +10°, −5°	F	$S_1 + S_2$	E, Mp, N

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

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



ALL DIMENSIONS IN mm

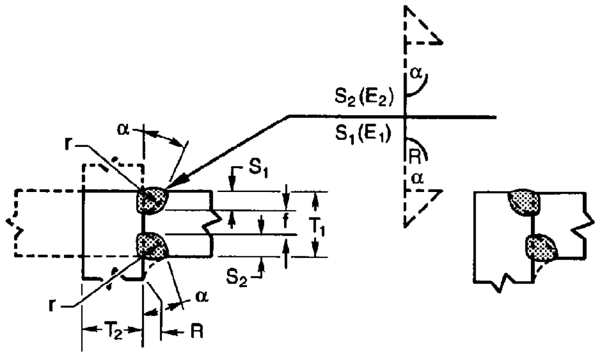
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening / Root Face / Groove Radius / Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW	TC-P8*	6.4 min	U	R = 0 f = 3 min r = 10 α = 45°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	D, E, J, N, V
SMAW	BC-P8**	6.4 min	U	R = 0 f = 3 min r = 10 α = 30°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	D, E, J, N, V
GMAW FCAW	TC-P8-GF*	6.4 min	U	R = 0 f = 3 min r = 10 α = 45°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	A, E, J, N, V
GMAW FCAW	BC-P8-GF**	6.4 min	U	R = 0 f = 3 min r = 10 α = 30°	+1.6, −0 +U, −0 +6, −0 + 10°, −0°	+3, −1.6 ±1.6 ±1.6 +10°, −5°	All	S	A, E, J, N, V
SAW	TC-P8-S*	11.1 min	U	R = 0 f = 6 min r = 13 α = 45°	±0 +U, −0 +6, −0 +10°, −0°	+1.6, −0 ±1.6 ±1.6 +10°, −5°	F	S	E, J, N, V
SAW	C-P8-S**	11.1 min	U	R = 0 f = 6 min r = 13 α = 20°	±0 +U, −0 +6, −0 +10°, −0°	+1.6, −0 ±1.6 ±1.6 +10°, −5°	F	S	E, J, N, V

*Applies to inside corner joints.
**Applies to outside corner joints.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

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



ALL DIMENSIONS IN mm

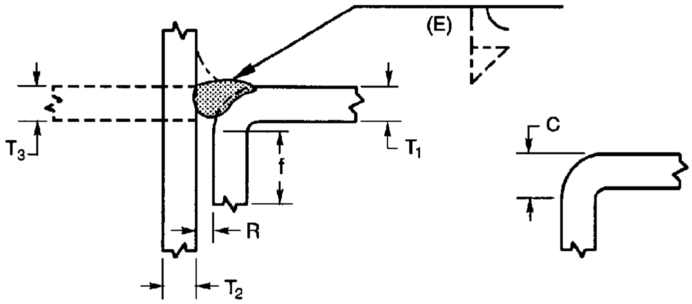
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.12.3)	Tolerances: As Fit-Up (see 3.12.3)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW	BTC-P9*	12.7 min	U	R = 0 f = 3 min r = 10 α = 45°	+1.6, –0 +U, –0 +6, –0 + 10°, –0°	+3, –1.6 ±1.6 ±1.6 +10°, –5°	All	$S_1 + S_2$	D, E, J, Mp, N, V
GMAW FCAW	BTC-P9-GF**	6.4 min	U	R = 0 f = 3 min r = 10 α = 30°	+1.6, –0 +U, –0 +6, –0 + 10°, –0°	+3, –1.6 ±1.6 ±1.6 +10°, –5°	All	$S_1 + S_2$	A, J, Mp, N, V
SAW	C-P9-S*	19.0 min	U	R = 0 f = 6 min r = 13 α = 45°	±0 +U, –0 +6, –0 + 10°, –0°	+1.6, –0 ±1.6 ±1.6 +10°, –5°	F	$S_1 + S_2$	A, E, J, N, V
SAW	C-P9-S**	19.0 min	U	R = 0 f = 6 min r = 13 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+1.6, –0 ±1.6 ±1.6 +10°, –5°	F	$S_1 + S_2$	E, J, Mp, N, V
SAW	T-P9-S	19.0 min	U	R = 0 f = 6 min r = 13 α = 45°	±0 +U, –0 +6, –0 +10°, –0°	+1.6, –0 ±1.6 ±1.6 +10°, –5°	F	$S_1 + S_2$	E, J, Mp, N

*Applies to inside corner joints.
**Applies to outside corner joints.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

Flare-bevel-groove weld (10)
Butt joint (B)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)			Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
					Root Opening Root Face Bend Radius*	Tolerances				
		T_1	T_2	T_3		As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)			
SMAW	BTC-P10	4.8 min	U	T_1 min	R = 0 f = 5 min $C = \frac{3T_1}{2}$ min	+1.6, −0 +U, −0 −0, +Not-Limited	+3, −1.6 +U, −1.6 −0, +Not-Limited	All	$5/8T_1$	D, J, N, Z
GMAW FCAW	BTC-P10-GF	4.8 min	U	T_1 min	R = 0 f = 5 min $C = \frac{3T_1}{2}$ min	+1.6, −0 +U, −0 −0, +Not-Limited	+3, −1.6 +U, −1.6 −0, +Not-Limited	All	$5/8T_1$	A, J, N, Z
SAW	T-P10-S	12.7 min	12.7 min	N/A	R = 0 f = 13 min $C = \frac{3T_1}{2}$ min	±0 +U, −0 −0, +Not-Limited	+1.6, −0 +U, −1.6 −0, +Not-Limited	F	$5/8T_1$	J, N, Z

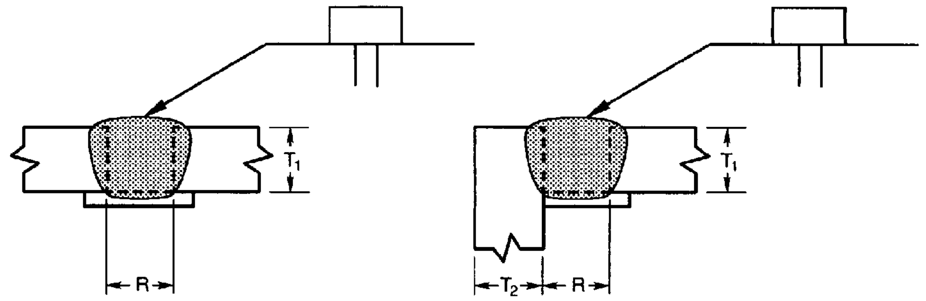
*For cold formed (A500) rectangular tubes, C dimension is not limited. See the following:

Effective Weld Size of Flare-Bevel-Groove Welded Joints. Tests have been performed on cold formed ASTM A500 material exhibiting a "c" dimension as small as T_1 with a nominal radius of 2t. As the radius increases, the "c" dimension also increases. The corner curvature may not be a quadrant of a circle tangent to the sides. The corner dimension, "c", may be less than the radius of the corner.

Figure 3.3 (Continued)—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details (see 3.12) (Dimensions in Millimeters)

See Notes on Page 88

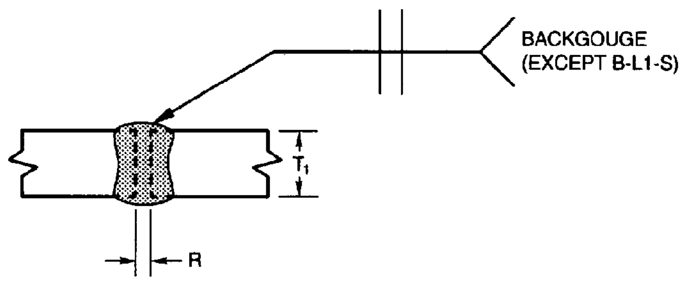
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



B-L1a C-L1a

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	B-L1a	1/4 max	—	$R = T_1$	+1/16, −0	+1/4, −1/16	All	—	D, N
SMAW	C-L1a	1/4 max	U	$R = T_1$	+1/16, −0	+1/4, −1/16	All	—	D, N
FCAW GMAW	B-L1a-GF	3/8 max	—	$R = T_1$	+1/16, −0	+1/4, −1/16	All	Not required	A, N

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

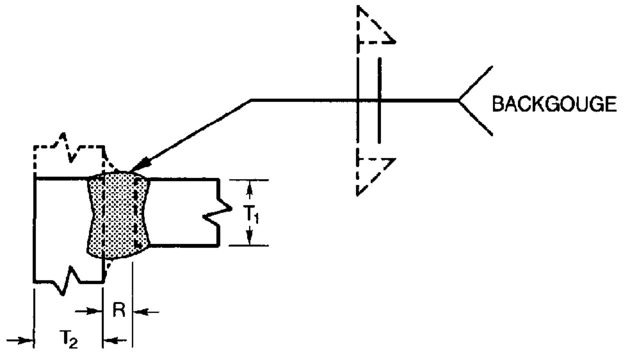


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	B-L1b	1/4 max	—	$R = \frac{T_1}{2}$	+1/16, −0	+1/16, −1/8	All	—	C, D, N
GMAW FCAW	B-L1b-GF	3/8 max	—	R = 0 to 1/8	+1/16, −0	+1/16, −1/8	All	Not required	A, C, N
SAW	B-L1-S	3/8 max	—	R = 0	±0	+1/16, −0	F	—	N
SAW	B-L1a-S	5/8 max	—	R = 0	±0	+1/16, −0	F	—	C, N

Figure 3.4—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

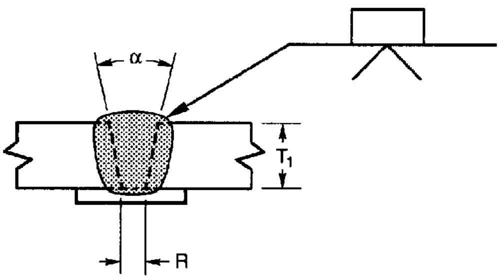
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation	Tolerances		Permitted Welding Positions	Gas Shielding for FCAW	Notes
					As Detailed	As Fit-Up			
SMAW	TC-L1b	1/4 max	U	$R = \frac{1}{2}$	+1/16, −0	+1/16, −1/8	All	—	C, D, J
GMAW FCAW	TC-L1-GF	3/8 max	U	R = 0 to 1/8	+1/16, −0	+1/16, −1/8	All	Not required	A, C, J
SAW	TC-L1-S	3/8 max	U	R = 0	±0	+1/16, −0	F	—	C, J

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



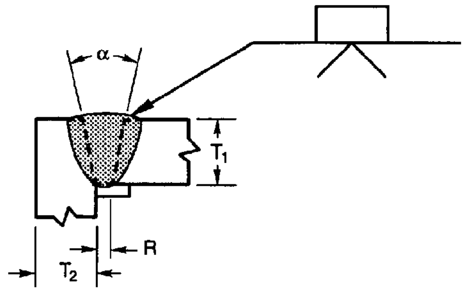
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/4, −1/16
α = +10°, −0°	+10°, −5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation Root Opening	Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U2a	U	—	R = 1/4	α = 45°	All	—	D, N
				R = 3/8	α = 30°	F, V, OH	—	D, N
				R = 1/2	α = 20°	F, V, OH	—	D, N
GMAW FCAW	B-U2a-GF	U	—	R = 3/16	α = 30°	F, V, OH	Required	A, N
				R = 3/8	α = 30°	F, V, OH	Not req.	A, N
				R = 1/4	α = 45°	F, V, OH	Not req.	A, N
SAW	B-L2a-S	2 max	—	R = 1/4	α = 30°	F	—	N
SAW	B-U2-S	U	—	R = 5/8	α = 20°	F	—	N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

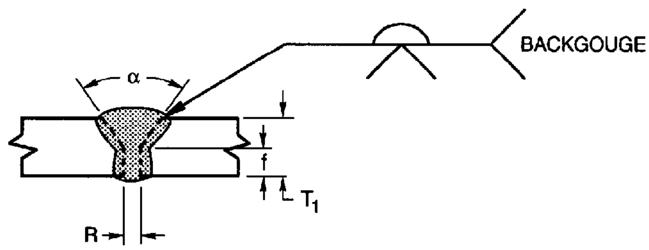
Single-V-groove weld (2)
Corner joint (C)



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/4, −1/16
α = +10°, −0°	+10°, −5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	C-U2a	U	U	R = 1/4	α = 45°	All	—	D, N
				R = 3/8	α = 30°	F, V, OH	—	D, N
				R = 1/2	α = 20°	F, V, OH	—	D, N
GMAW FCAW	C-U2a-GF	U	U	R = 3/16	α = 30°	F, V, OH	Required	A
				R = 3/8	α = 30°	F, V, OH	Not req.	A, N
				R = 1/4	α = 45°	F, V, OH	Not req.	A, N
SAW	C-L2a-S	2 max	U	R = 1/4	α = 30°	F	—	N
SAW	C-U2-S	U	U	R = 5/8	α = 20°	F	—	N

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

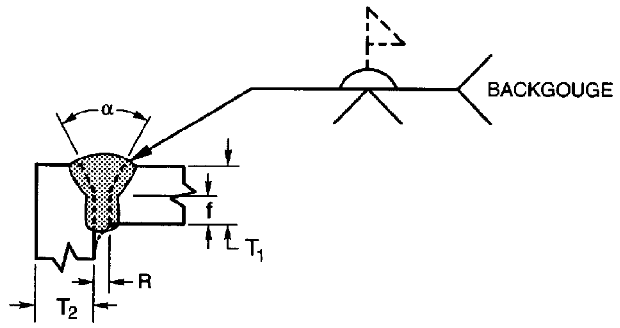


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening / Root Face / Groove Angle	Tolerances: As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U2	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, −0 +1/16, −0 + 10°, −0°	+1/16, −1/8 Not limited +10°, −5°	All	—	C, D, N
GMAW FCAW	B-U2-GF	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, −0 +1/16, −0 + 10°, −0°	+1/16, −1/8 Not limited +10°, −5°	All	Not required	A, C, N
SAW	B-L2c-S	Over 1/2 to 1	—	R = 0 f = 1/4 max α = 60°	R = ±0 f = +0, −f α = +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	—	C, N
		Over 1 to 1-1/2	—	R = 0 f = 1/2 max α = 60°					
		Over 1-1/2 to 2	—	R = 0 f = 5/8 max α = 60°					

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

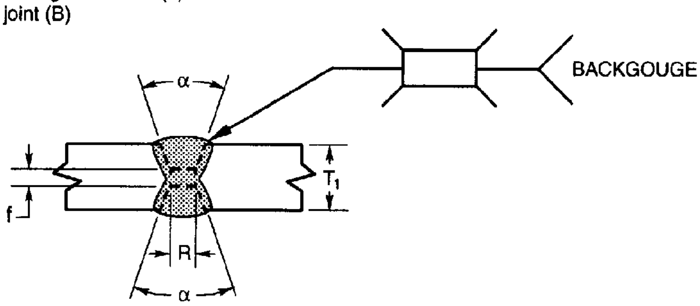
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	C-U2	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 + 10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	—	C, D, J, N
GMAW FCAW	C-U2-GF	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 + 10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	Not required	A, C, J, N
SAW	C-U2b-S	U	U	R = 0 to 1/8 f = 1/4 max α = 60°	±0 +0, –1/4 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	—	C, J, N

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



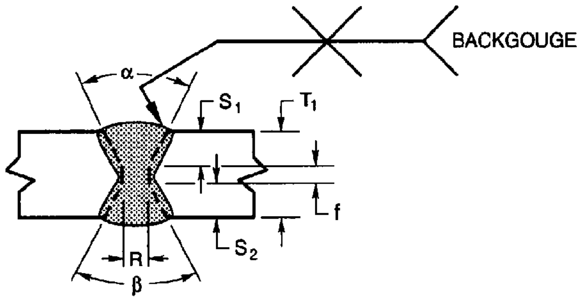
		Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)
		R = ±0	+1/4, –0
		f = ±0	+1/16, –0
		α = +10°, –0°	+10°, –5°
Spacer	SAW	±0	+1/16, –0
Spacer	SMAW	±0	+1/8, –0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Root Face	Groove Angle			
SMAW	B-U3a	U Spacer = 1/8 × R	—	R = 1/4	f = 0 to 1/8	α = 45°	All	—	C, D, M, N
				R = 3/8	f = 0 to 1/8	α = 30°	F, V, OH	—	
				R = 1/2	f = 0 to 1/8	α = 20°	F, V, OH	—	
SAW	B-U3a-S	U Spacer = 1/4 × R	—	R = 5/8	f = 0 to 1/4	α = 20°	F	—	C, M, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

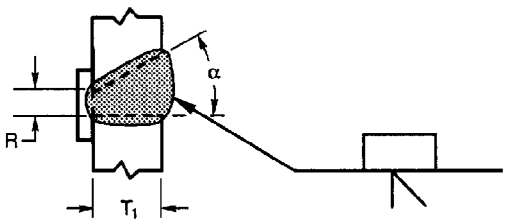
Double-V-groove weld (3)
Butt joint (B)



For B-U3c-S only		
T_1		S_1
Over	to	
2	2-1/2	1-3/8
2-1/2	3	1-3/4
3	3-5/8	2-1/8
3-5/8	4	2-3/8
4	4-3/4	2-3/4
4-3/4	5-1/2	3-1/4
5-1/2	6-1/4	3-3/4
For $T_1 > 6\text{-}1/4$ or $T_1 \leq 2$ $S_1 = 2/3\ (T_1 - 1/4)$		

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	B-U3b	U	—	R = 0 to 1/8 f = 0 to 1/8 α = β = 60°	+1/16, −0 +1/16, −0 +10°, −0°	+1/16, −1/8 Not limited +10°, −5°	All	—	C, D, M, N
GMAW FCAW	B-U3-GF						All	Not required	A, C, M, N
SAW	B-U3c-S	U	—	R = 0 f = 1/4 min α = β = 60°	+1/16, −0 +1/4, −0 +10°, −0°	+1/16, −0 +1/4, −0 +10°, −5°	F	—	C, M, N
				To find S_1 see table above: $S_2 = T_1 - (S_1 + f)$					

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



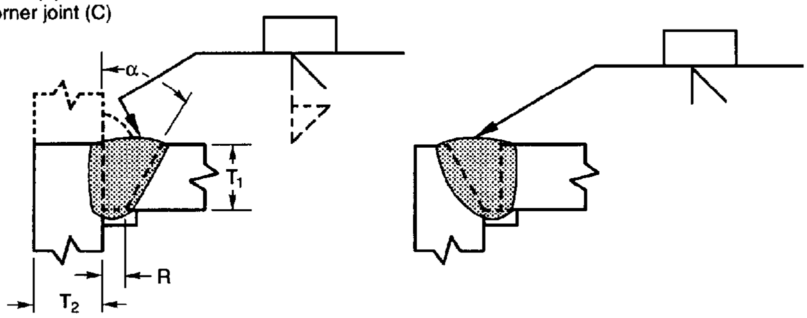
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/4, −1/16
α = +10°, −0°	+10°, −5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	B-U4a	U	—	R = 1/4	α = 45°	All	—	Br, D, N
				R = 3/8	α = 30°	All	—	Br, D, N
GMAW FCAW	C-U4a-GF	U	—	R = 3/16	α = 30°	All	Required	A, Br, N
				R = 1/4	α = 45°	All	Not req.	A, Br, N
				R = 3/8	α = 30°	F	Not req.	A, Br, N
SAW	B-U4a-S	U	U	R = 3/8	α = 30°	F	—	Br, N
				R = 1/4	α = 45°			

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

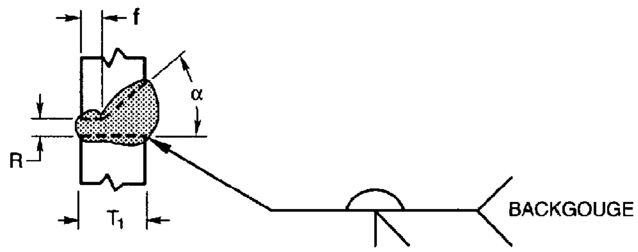
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/4, −1/16
a = +10°, −0°	+10°, −5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	TC-U4a	U	U	R = 1/4	α = 45°	All	—	D, J, N, V
				R = 3/8	α = 30°	F, V, OH	—	D, J. N, V
GMAW FCAW	TC-U4a-GF	U	U	R = 3/16	α = 30°	All	Required	A, J, N, V
				R = 3/8	α = 30°	F	Not req.	A, J, N, V
				R = 1/4	α = 45°	All	Not req.	A, J, N, V
SAW	TC-U4a-S	U	U	R = 3/8 R = 1/4	α = 30° α = 45°	F	—	J, N, V

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

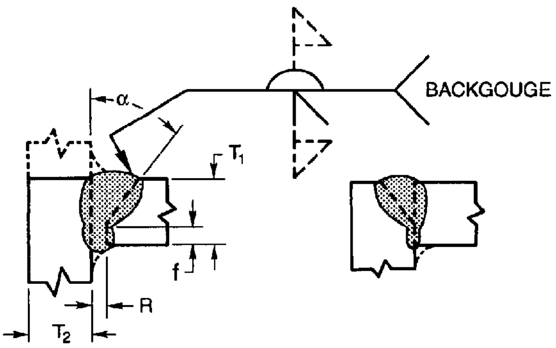


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	B-U4b	U	—	R = 0 to 1/8	+1/16, −0	+1/16, −1/8	All	—	Br, C, D, N
GMAW FCAW	B-U4b-GF	U	—	f = 0 to 1/8 α = 45°	+1/16, −0 +10°, −0°	Not limited 10°, −5°	All	Not required	A, Br, C, N
SAW	B-U4b-S	U	U	R = 0 f = 1/4 max α = 60°	±0 +0, −1/8 +10°, −0°	+1/4, −0 ±1/16 10°, −5°	F	—	Br, C, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

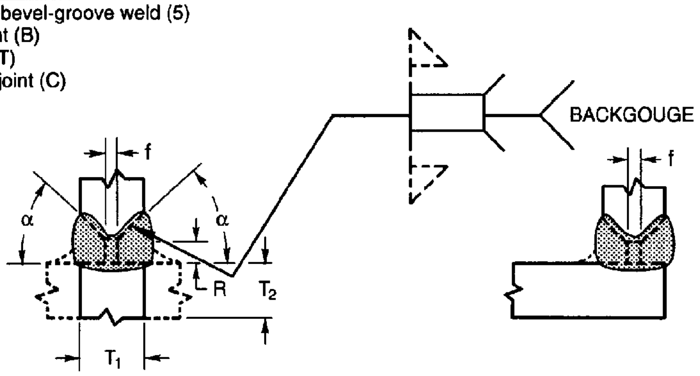
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
					Tolerances				
		T_1	T_2	Root Opening Root Face Groove Angle	As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	TC-U4b	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 45°	+1/16, −0 +1/16, −0 +10°, −0°	+1/16, −1/8 Not limited 10°, −5°	All	—	C, D, J, N, V
GMAW FCAW	TC-U4b-GF	U	U				All	Not required	A, C, J, N, V
SAW	TC-U4b-S	U	U	R = 0 f = 1/4 max α = 60°	±0 +0, −1/8 +10°, −0°	+1/4, −0 ±1/16 10°, −5°	F	—	C, J, N, V

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



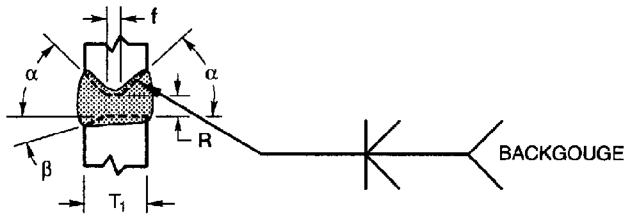
	Tolerances	
	As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
	R = ±0	+1/4, −0
	f = +1/16, −0	±1/16
	α = +10°, −0°	+10°, −5°
Spacer	+1/16, −0	+1/8, −0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Root Face	Groove Angle			
SMAW	B-U5b	U Spacer = 1/8 × R	U	R = 1/4	f = 0 to 1/8	α = 45°	All	—	Br, C, D, M, N
	TC-U5a	U Spacer = 1/4 × R	U	R = 1/4	f = 0 to 1/8	α = 45°	All	—	C, D, J, M, N, V
				R = 3/8	f = 0 to 1/8	α = 30°	F, OH	—	C, D, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

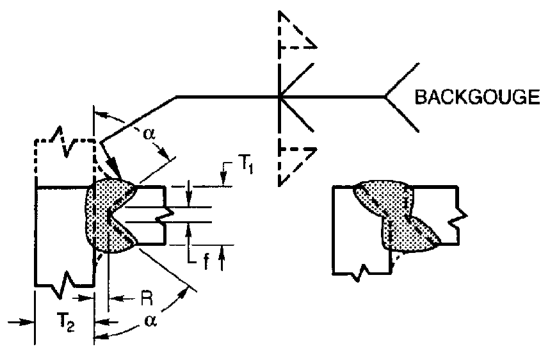
See Notes on Page 88

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



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U5a	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 45° β = 0° to 15°	+1/16, −0 +1/16, −0 $\alpha + \beta {}^{+10°}_{-0°}$	+1/16, −1/8 Not limited $\alpha + \beta {}^{+10°}_{-5°}$	All	—	Br, C, D, M, N
GMAW FCAW	B-U5-GF	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 45° β = 0° to 15°	+1/16, −0 +1/16, −0 α + β = +10°, −0°	+1/16, −1/8 Not limited α + β = +10°, −5°	All	Not required	A, Br, C, M, N

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

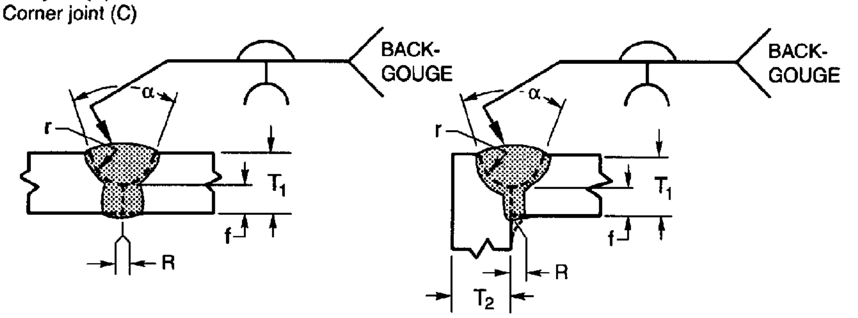


Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U5b	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 45°	+1/16, −0 +1/16, −0 + 10°, −0°	+1/16, −1/8 Not limited +10°, −5°	All	—	C, D, J, M, N, V
GMAW FCAW	TC-U5-GF	U	U				All	Not required	A, C, J, M, N, V
SAW	TC-U5-S	U	U	R = 0 f = 3/16 max α = 60°	±0 +0, −3/16 +10°, −0°	+1/16, −0 ±1/16 +10°, −5°	F	—	C, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

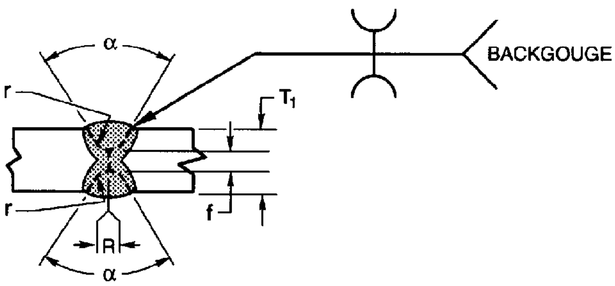
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = ±1/16	Not Limited
r = +1/8, −0	+1/8, −0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U6	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	C, D, N
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	C, D, N
	C-U6	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	C, D, J, N
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	C, D, J, N
GMAW FCAW	B-U6-GF	U	U	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not req.	A, C, N
	C-U6-GF	U	U	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not req.	A, C, J, N

Double-U-groove weld (7)
Butt joint (B)



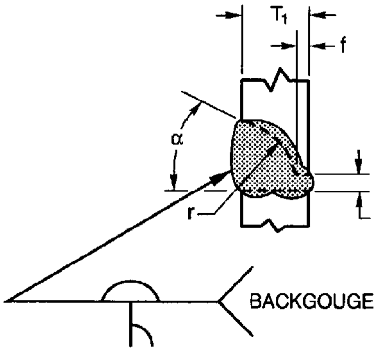
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
For B-U7 and B-U7-GF	
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = ±1/16, −0	Not Limited
r = +1/4, −0	±1/16
For B-U7-S	
R = ±0	+1/16, −0
f = +0, −1/4	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U7	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	C, D, M, N
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	C, D, M, N
GMAW FCAW	B-U7-GF	U	—	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not required	A, C, N, M
SAW	B-U7-S	U	—	R = 0	α = 20°	f = 1/4 max	r = 1/4	F	—	C, M, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

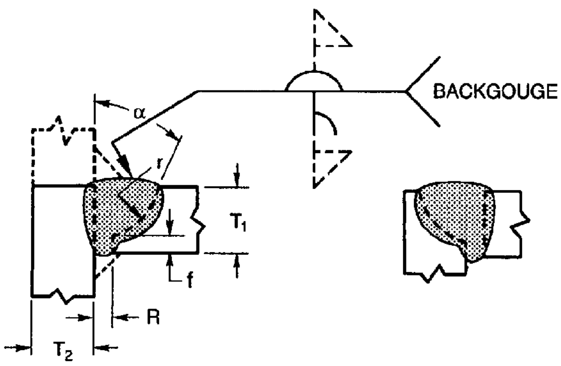
Single-J-groove weld (8)
Butt joint (B)



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/16, −0	Not Limited
r = +1/4, −0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U8	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	Br, C, D, N
GMAW FCAW	B-U8-GF	U	—	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not req.	A, Br, C, N
SAW	B-U8-S	U	U	R = 0 f = 1/4 max α = 45°	±0 +0, −1/8 +10°, −0°	+1/4, −0 ±1/16 +10°, −5°	r = 3/8	F	—	Br, C, N

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



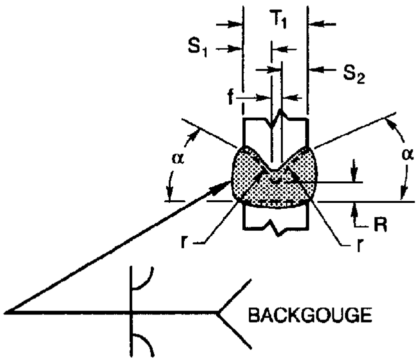
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/16, −0	Not Limited
r = +1/4, −0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U8a	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	C, D, J, N, V
				R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	F, OH	—	C, D, J, N, V
GMAW FCAW	TC-U8a-GF	U	U	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not required	A, C, J, N, V
SAW	TC-U8a-S	U	U	R = 0 f = 1/4 max α = 45°	±0 +0, −1/8 +10°, −0°	+1/4, −0 ±1/16 +10°, −5°	r = 3/8	F	—	C, J, R, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

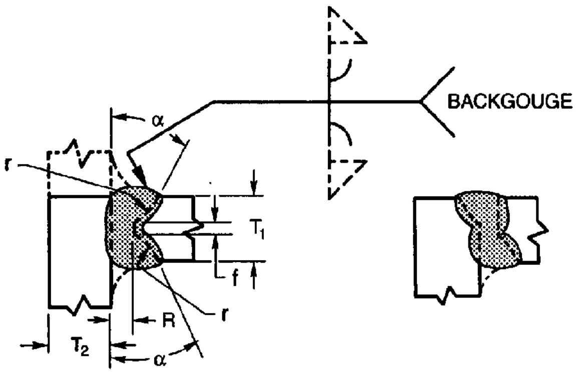
Double-J-groove weld (9)
Butt joint (B)



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/16, −0	Not Limited
r = +1/8, −0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U9	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	Br, C, D, M, N
GMAW FCAW	B-U9-GF	U	—	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not required	A, Br, C, M, N

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



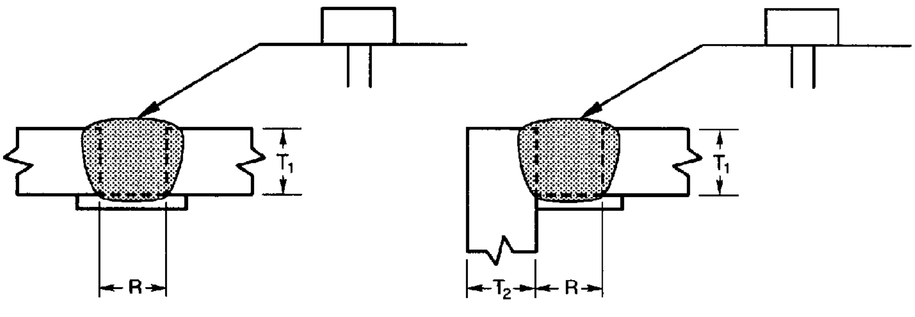
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/16, −0	Not Limited
r = 1/8, −0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U9a	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	C, D, J, M, N, V
				R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	F, OH	—	C, D, J, M, V
GMAW FCAW	TC-U9a-GF	U	U	R = 0 to 1/8	α = 30°	f = 1 /8	r = 3/8	All	Not required	A, C, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13)

See Notes on Page 88

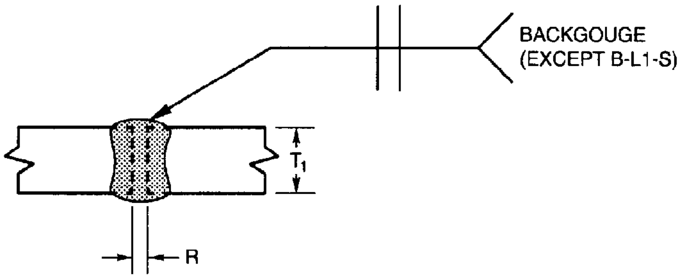
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	B-L1a	6.4 max	—	$R = T_1$	+1.6, -0	+6, -1.6	All	—	D, N
	C-L1a	6.4 max	U	$R = T_1$	+1.6, -0	+6, -1.6	All	—	D, N
FCAW GMAW	B-L1a-GF	9.5 max	—	$R = T_1$	+1.6, -0	+6, -1.6	All	Not required	A, N

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



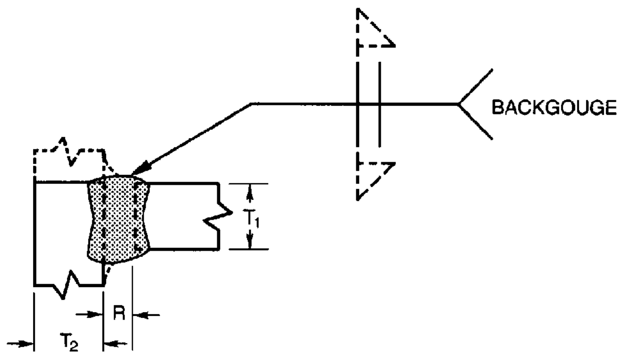
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	B-L1b	6.4 max	—	$R = \frac{T_1}{2}$	+1.6, -0	+1.6, -3	All	—	C, D, N
GMAW FCAW	B-L1b-GF	9.5 max	—	R = 0 to 3	+1.6, -0	+1.6, -3	All	Not required	A, C, N
SAW	B-L1-S	9.5 max	—	R = 0	±0	+1.6, -0	F	—	N
SAW	B-L1a-S	15.9 max	—	R = 0	±0	+1.6, -0	F	—	C, N

Figure 3.4—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

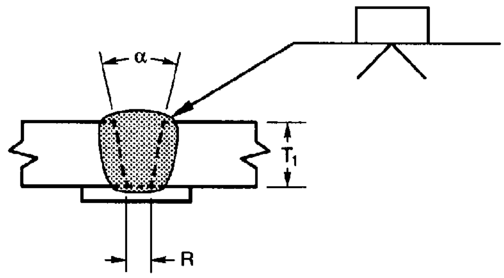
Square-groove weld (1)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-L1b	6.4 max	U	$R = \frac{T_1}{2}$	+1.6, –0	+1.6, –3	All	—	C, D, J
GMAW FCAW	TC-L1-GF	9.5 max	U	R = 0 to 3	+1.6, –0	+1.6, –3	All	Not required	A, C, J
SAW	TC-L1-S	9.5 max	U	R = 0	±0	+1.6, –0	F	—	C, J

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



Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+6, –1.6
α = +10°, –0°	+10°, –5°

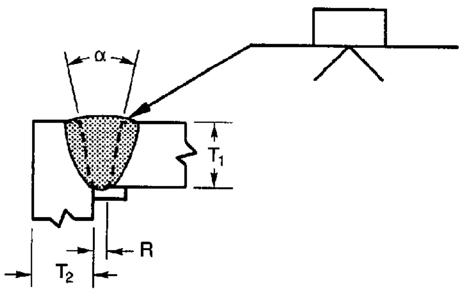
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U2a	U	—	R = 6	α = 45°	All	—	D, N
				R = 10	α = 30°	F, V, OH	—	D, N
				R = 13	α = 20°	F, V, OH	—	D, N
GMAW FCAW	B-U2a-GF	U	—	R = 5	α = 30°	F, V, OH	Required	A, N
				R = 10	α = 30°	F, V, OH	Not req.	A, N
				R = 6	α = 45°	F, V, OH	Not req.	A, N
SAW	B-L2a-S	50.8 max	—	R = 6	α = 30°	F	—	N
SAW	B-U2-S	U	—	R = 16	α = 20°	F	—	N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

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

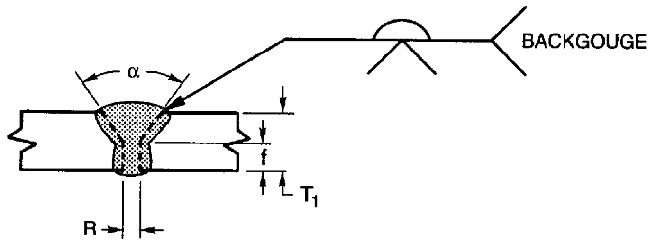


Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+6, –1.6
a = +10°, –0°	+10°, –5°

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	C-U2a	U	U	R = 6	α = 45°	All	—	D, N
				R = 10	α = 30°	F, V, OH	—	D, N
				R = 13	α = 20°	F, V, OH	—	D, N
GMAW FCAW	C-U2a-GF	U	U	R = 5	α = 30°	F, V, OH	Required	A
				R = 10	α = 30°	F, V, OH	Not req.	A, N
				R = 6	α = 45°	F, V, OH	Not req.	A, N
SAW	C-L2a-S	50.8 max	U	R = 6	α = 30°	F	—	N
SAW	C-U2-S	U	U	R = 16	α = 20°	F	—	N

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



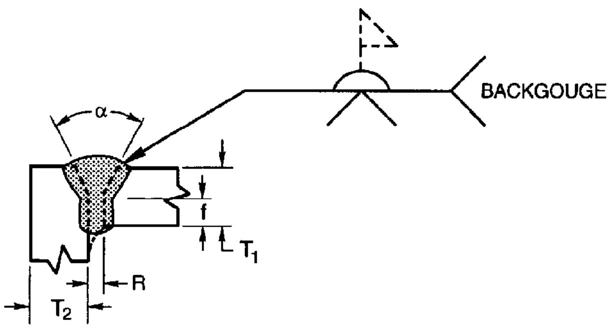
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	B-U2	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+1.6, –0 +1.6, –0 + 10°, –0°	+1.6, –3 Not limited +10°, –5°	All	—	C, D, N
GMAW FCAW	B-U2-GF	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+1.6, –0 +1.6, –0 + 10°, –0°	+1.6, –3 Not limited +10°, –5°	All	Not required	A, C, N
SAW	B-L2c-S	Over 12.7 to 25.4	—	R = 0 f = 6 max α = 60°	R = ±0 f = +0, –f α = +10°, –0°	+1.6, –0 ±1.6 +10°, –5°	F	—	C, N
		Over 25.4 to 38.1	—	R = 0 f = 13 max α = 60°					
		Over 38.1 to 50.8	—	R = 0 f = 16 max α = 60°					

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

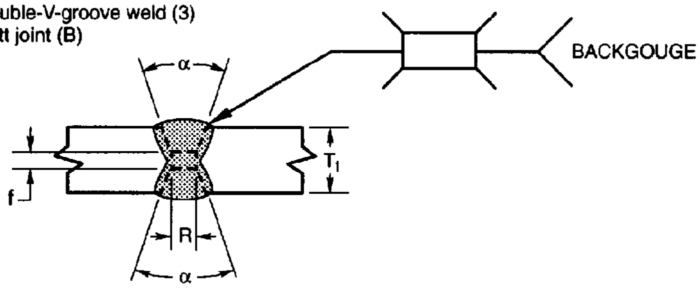
Single-V-groove weld (2)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening, Root Face, Groove Angle	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	C-U2	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+1.6, −0 +1.6, −0 + 10°, −0°	+1.6, −3 Not limited +10°, −5°	All	—	C, D, J, N
GMAW FCAW	C-U2-GF	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+1.6, −0 +1.6, −0 + 10°, −0°	+1.6, −3 Not limited +10°, −5°	All	Not required	A, C, J. N
SAW	C-U2b-S	U	U	R = 0 to 3 f = 6 max α = 60°	±0 +0, −6 +10°, −0°	+1.6, −0 ±1/16 +10°, −5°	F	—	C, J, N

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



	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)
R = ±0		+6, −0
f = ±0		+1.6, −0
a = +10°, −0°		+10°, −5°
Spacer SAW	±0	+1.6, −0
Spacer SMAW	±0	+3, −0

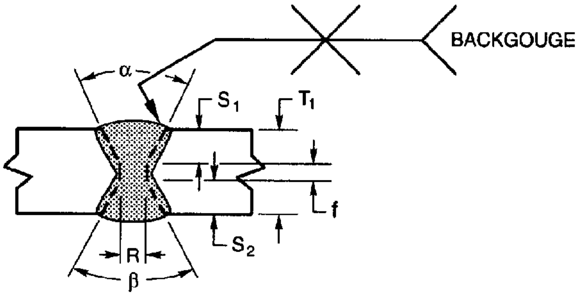
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening	Root Face	Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U3a	U Spacer = 3 × R	—	R = 6	f = 0 to 3	α = 45°	All	—	C, D, M, N
				R = 10	f = 0 to 3	α = 30°	F, V, OH	—	
				R = 13	f = 0 to 3	α = 20°	F, V, OH	—	
SAW	B-U3a-S	U Spacer = 6 × R	—	R = 16	f = 0 to 6	α = 20°	F	—	C, M, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

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

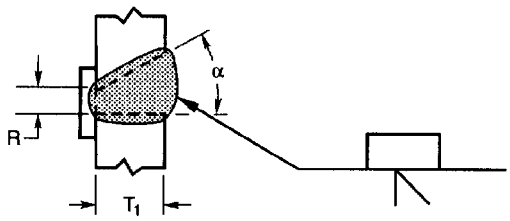


ALL DIMENSIONS IN mm

For B-U3c-S only		
T_1		S_1
Over	to	
50.8	63.5	35
63.5	76.2	44
76.2	92.1	54
92.1	101.6	60
101.6	120.7	70
120.7	139.7	83
139.7	158.8	95
For T_1 > 158.8 or $T_1 \le 50.8$ $S_1 = 2/3 (T_1 - 6)$		

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.13.1)	Tolerances: As Fit-Up (see 3.13.1)			
SMAW	B-U3b	U	—	R = 0 to 3 f = 0 to 3 α = β = 60°	+1.6, −0 +1.6, −0 +10°, −0°	+1.6, −3 Not limited +10°, −5°	All	—	C, D, M, N
GMAW FCAW	B-U3-GF						All	Not required	A, C, M, N
SAW	B-U3c-S	U	—	R = 0 f = 6 min α = β = 60°	+1.6, −0 +6, −0 +10°, −0°	+1.6, −0 +6, −0 +10°, −5°	F	—	C, M, N
				To find S_1 see table above: $S_2 = T_1 - (S_1 + f)$					

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



ALL DIMENSIONS IN mm

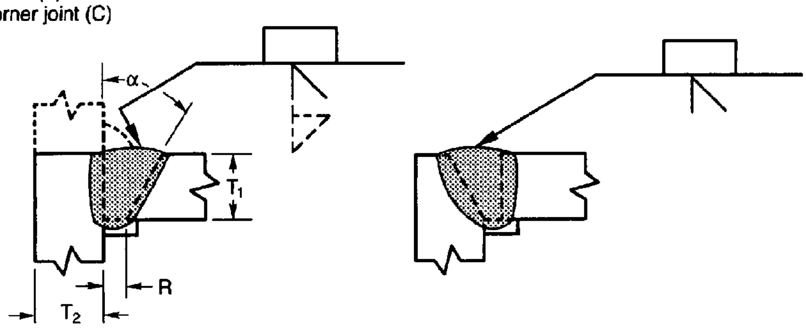
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, −0	+6, −1.6
a = +10°, −0°	+10°, −5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U4a	U	—	R = 6	α = 45°	All	—	Br, D, N
				R = 10	α = 30°	All	—	Br, D, N
GMAW FCAW	B-U4a-GF	U	—	R = 5	α = 30°	All	Required	A, Br, N
				R = 6	α = 45°	All	Not req.	A, Br, N
				R = 10	α = 30°	F	Not req.	A, Br, N
SAW	B-U4a-S	U	U	R = 10	α = 30°	F	—	Br, N
				R = 6	α = 45°			

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

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

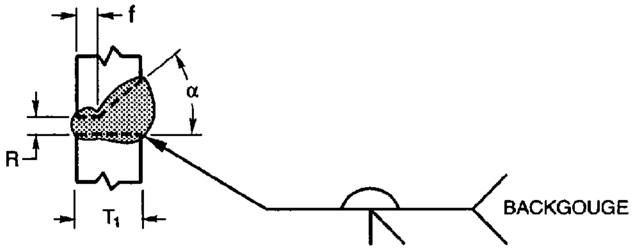


Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+6, –1.6
α = +10°, –0°	+10°, –5°

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	TC-U4a	U	U	R = 6	α = 45°	All	—	D, J, N, V
				R = 10	α = 30°	F, V, OH	—	D, J, N, V
GMAW FCAW	TC-U4a-GF	U	U	R = 5	α = 30°	All	Required	A, J, N, V
				R = 10	α = 30°	F	Not req.	A, J, N, V
				R = 6	α = 45°	All	Not req.	A, J, N, V
SAW	TC-U4a-S	U	U	R = 10	α = 30°	F	—	J, N, V
				R = 6	α = 45°			

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



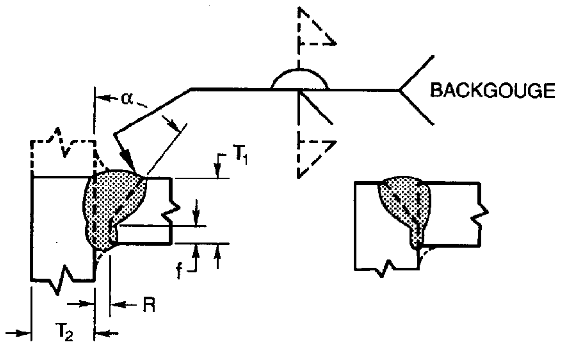
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	B-U4b	U	—	R = 0 to 3 f = 0 to 3 α = 45°	+1.6, –0 +1.6, –0 +10°, –0°	+1.6, –3 Not limited 10°, –5°	All	—	Br, C, D, N
GMAW FCAW	B-U4b-GF	U	—				All	Not required	A, Br, C, N
SAW	B-U4b-S	U	U	R = 0 f = 6 max α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±1.6 10°, –5°	F	—	Br, C, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

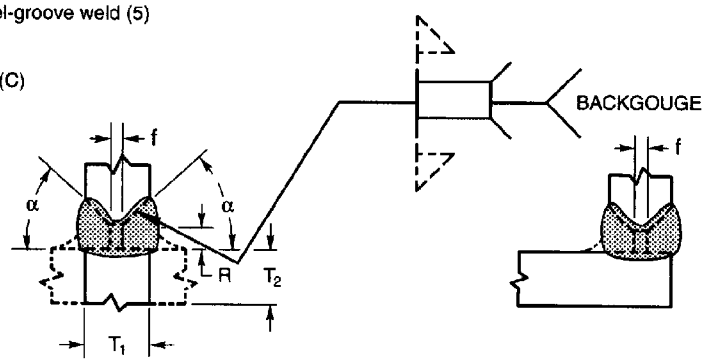
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U4b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+1.6, −0 +1.6, −0 +10°, −0°	+1.6, −3 Not limited 10°, −5°	All	—	C, D, J, N, V
GMAW FCAW	TC-U4b-GF	U	U				All	Not required	A, C, J, N, V
SAW	TC-U4b-S	U	U	R = 0 f = 6 max α = 60°	±0 +0, −3 +10°, −0°	+6, −0 ±1.6 10°, −5°	F	—	C, J, N, V

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



	Tolerances: As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
	R = ±0	+6, −0
	f = +1.6, −0	±1.6
	α = +10°, −0°	+10°, −5°
Spacer	+1.6, −0	+3, −0

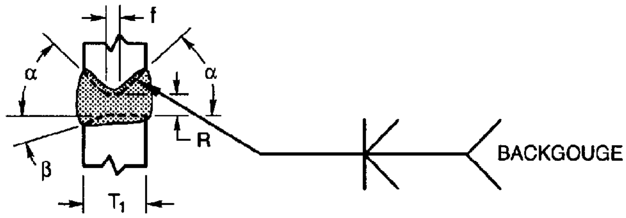
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Root Face	Groove Angle	Permitted Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U5b	U Spacer = 3 × R	U	R = 6	f = 0 to 3	α = 45°	All	—	Br, C, D, M, N
	TC-U5a	U Spacer = 6 × R	U	R = 6	f = 0 to 3	α = 45°	All	—	C, D, J. M, N, V
				R = 10	f = 0 to 3	α = 30°	F, OH	—	C, D, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

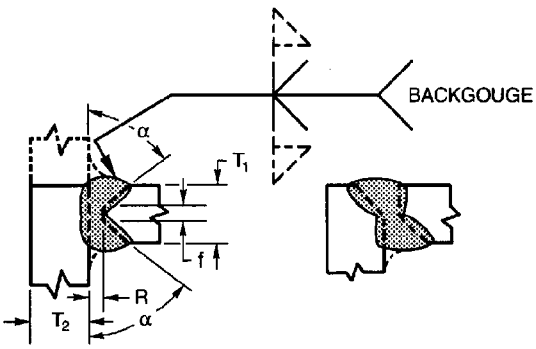
Double-bevel-groove weld (5)
Butt joint (B)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	B-U5a	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+1.6, −0 +1.6, −0 $\alpha + \beta^{+10°}_{-0°}$	+1.6, −3 Not limited $\alpha + \beta^{+10°}_{-5°}$	All	—	Br, C, D, M, N
GMAW FCAW	B-U5-GF	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+1.6, −0 +1.6, −0 α + β = +10°, −0°	+1.6, −3 Not limited α + β = +10°, −5°	All	Not required	A, Br, C, M, N

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



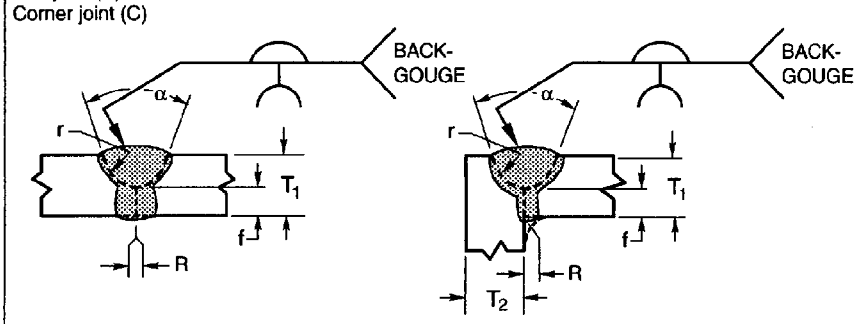
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)			
SMAW	TC-U5b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+1.6, −0 +1.6, −0 + 10°, −0°	+1.6, −3 Not limited +10°, −5°	All	—	C, D, J, M, N, V
GMAW FCAW	TC-U5-GF	U	U				All	Not required	A, C, J, M, N, V
SAW	TC-U5-S	U	U	R = 0 f = 5 max α = 60°	±0 +0, −5 +10°, −0°	+1.6, −0 ±1.6 +10°, −5°	F	—	C, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)

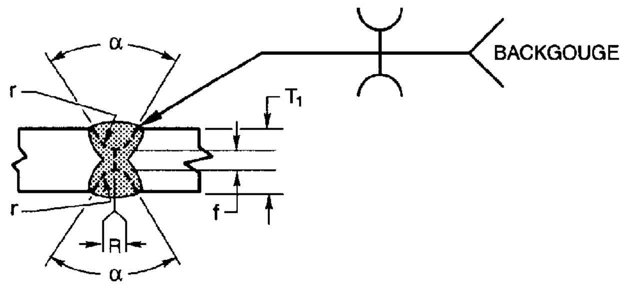


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, −0	+1.6, −3
α = +10°, −0°	+10°, −5°
f = ±1.6	Not Limited
r = +3, −0	+3, −0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U6	U	U	R = 0 to 3	α = 45°	f = 3	r = 6	All	—	C, D, N
				R = 0 to 3	α = 20°	f = 3	r = 6	F, OH	—	C, D, N
	C-U6	U	U	R = 0 to 3	α = 45°	f = 3	r = 6	All	—	C, D, J, N
				R = 0 to 3	α = 20°	f = 3	r = 6	F, OH	—	C, D, J, N
GMAW FCAW	B-U6-GF	U	U	R = 0 to 3	α = 20°	f = 3	r = 6	All	Not req.	A, C, N
	C-U6-GF	U	U	R = 0 to 3	α = 20°	f = 3	r = 6	All	Not req.	A, C, J, N

Double-U-groove weld (7)
Butt joint (B)



ALL DIMENSIONS IN mm

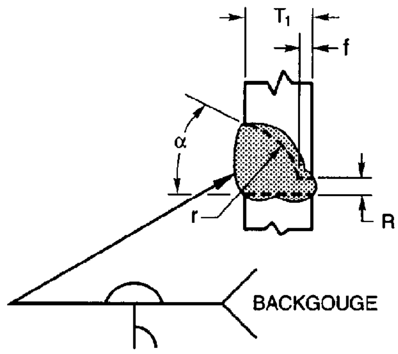
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
For B-U7 and B-U7-GF	
R = +1.6, −0	+1.6, −3
α = +10°, −0°	+10°, −5°
f = ±1.6, −0	Not Limited
r = +6, −0	±1.6
For B-U7-S	
R = ±0	+1.6, −0
f = +0, −6	±1.6

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U7	U	—	R = 0 to 3	α = 45°	f = 3	r =6	All	—	C, D, M, N
				R = 0 to 3	α = 20°	f = 3	r =6	F, OH	—	C, D, M, N
GMAW FCAW	B-U7-GF	U	—	R = 0 to 3	α = 20°	f = 3	r =6	All	Not required	A, C, M, N
SAW	B-U7-S	U	—	R = 0	α = 20°	f = 6 max	r =6	F	—	C, M, N

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

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

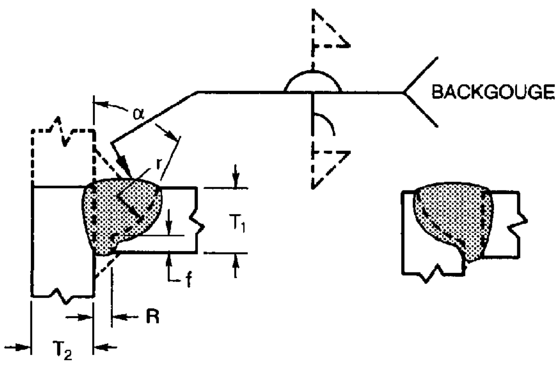


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+1.6, –3
α = +10°, –0°	+10°, –5°
f = +1.6, –0	Not Limited
r = +6, –0	±1.6

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U8	U	—	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	Br, C, D, N
GMAW FCAW	B-U8-GF	U	—	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not req.	A, Br, C, N
SAW	B-U8-S	U	U	R = 0 f = 6 max α = 45°	±0 +0, –3 +10°, –0°	+6, –0 ±1.6 +10°, –5°	r = 10	F	—	Br, C, N

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



ALL DIMENSIONS IN mm

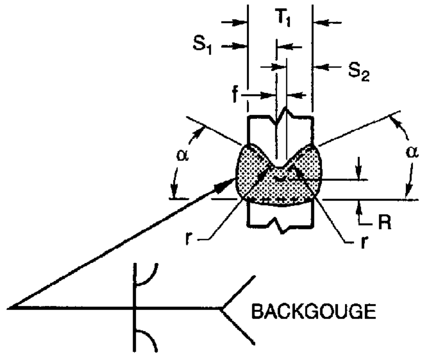
Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+1.6, –3
α = +10°, –0°	+10°, –5°
f = +1.6, –0	Not Limited
r = +6, –0	±1.6

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U8a	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	C, D, J, N, V
				R = 0 to 3	α = 45°	f = 3	r = 10	F, OH	—	C, D, J, N, V
GMAW FCAW	TC-U8a-GF	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	Not required	A, C, J, N, V
SAW	TC-U8a-S	U	U	R = 0 f = 6 max α = 45°	±0 +0, –3 +10°, –0°	+6, –0 ±1.6 +10°, –5°	r = 10	F	—	C, J, R, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

See Notes on Page 88

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

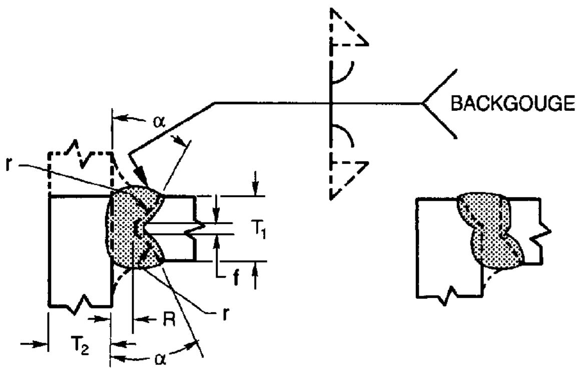


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+1.6, –3
α = +10°, –0°	+10°, –5°
f = +1.6, –0	Not Limited
r = +3, –0	±1.6

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U9	U	—	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	Br, C, D, M, N
GMAW FCAW	B-U9-GF	U	—	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not required	A, Br, C, M, N

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



ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.13.1)	As Fit-Up (see 3.13.1)
R = +1.6, –0	+1.6, –3
α = +10°, –0°	+10°, –5°
f = +1.6, –0	Not Limited
r = 3, –0	±1.6

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U9a	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	C, D, J, M, N, V
				R = 0 to 3	α = 30°	f = 3	r = 10	F, OH	—	C, D, J, M, N, V
GMAW FCAW	TC-U9a-GF	U	U	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not required	A, C, J, M, N, V

Figure 3.4 (Continued)—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details (see 3.13) (Dimensions in Millimeters)

Notes for Figures 3.3 and 3.4

Notes:
A: Not prequalified for gas metal arc welding using short circuiting transfer nor GTAW. Refer to Annex A.
B: Joint is welded from one side only.
Br: Cyclic load application limits these joints to the horizontal welding position (see 2.27.5).
C: Backgouge root to sound metal before welding second side.
D: SMAW detailed joints may be used for prequalified GMAW (except GMAW-S) and FCAW.
E: Minimum weld size (E) as shown in Table 3.4. S as specified on drawings.
J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, these shall be equal to 1/4 T_1, but need not exceed 3/8 in. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to 1/4 T_1, but not more than 3/8 in.
M: 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.
Mp: Double-groove welds may have grooves of unequal depth, provided these conform to the limitations of Note E. Also the weld size (E) applies individually to each groove.
N: The orientation of the two members in the joints may vary from 135° to 180° for butt joints, or 45° to 135° for corner joints, or 45° to 90° for T-joints.
V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.
Z: Weld size (E) is based on joints welded flush.

Table 3.4
Minimum Prequalified PJP Weld Sizes (see 3.12.2.1)

Base Metal Thickness of Thicker Part Joined	Minimum Weld Size*	
in. (mm)	in.	mm
1/8 (3.2) to 3/16 (4.8) incl.	1/16	2
Over 3/16 (4.8) to 1/4 (6.4) incl.	1/8	3
Over 1/4 (6.4) to 1/2 (12.7) incl.	3/16	5
Over 1/2 (12.7) to 3/4 (19.0) incl.	1/4	6
Over 3/4 (19.0) to 1-1/2 (38.1) incl.	5/16	8
Over 1-1/2 (38.1) to 2-1/4 (57.1) incl.	3/8	10
Over 2-1/4 (57.1) to 6 (152) incl.	1/2	13
Over 6 (152)	5/8	16

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

3.12.4.1 Matched Box Connections. Details for PJP groove welds in these connections, the corner dimensions and the radii of the main tube are shown in Figure 3.5. Fillet welds may be used in toe and heel zones. (See Figure 3.2.) If the corner dimension or the radius of the main tube, or both, are less than as shown if Figure 3.5, a sample joint of the side detail shall be made and sectioned to verify the weld size. The test weld shall be made in the horizontal position. This requirement may be waived if the branch tube is beveled as shown for CJP groove welds in Figure 3.6.

3.13 Complete Joint Penetration Groove Weld Requirements

Complete joint penetration groove welds which may be used without performing the WPS qualification test prescribed in section 4 are detailed in Figure 3.4 and are subject to the limitations specified in 3.13.1.

3.13.1 Joint Dimensions. Dimensions of groove welds specified in 3.13 may vary on design or detail drawings within the limits or tolerances shown in the "As Detailed" column in Figure 3.4. Fit up tolerance of Figure 3.4 may be applied to the dimension shown on the detail drawing.

3.13.2 J- and U-Groove Preparation. J- and U-grooves and the other side of partially welded double-V and double-bevel grooves may be prepared before or after assembly. After backgouging, the other side of partially welded double-V or double-bevel joints should resemble a prequalified U- or J-joint configuration at the joint root.

3.13.3 Tubular Butt Joints. For tubular groove welds to be given prequalified status, the following conditions shall apply:

(1) Prequalified WPSs. Where welding from both sides or welding from one side with backing is possible, any WPS and groove detail that is appropriately prequalified in conformance with section 3 may be used, except that SAW is only prequalified for diameters greater than or equal to 24 in. (610 mm). Welded joint details shall be in conformance with section 3.

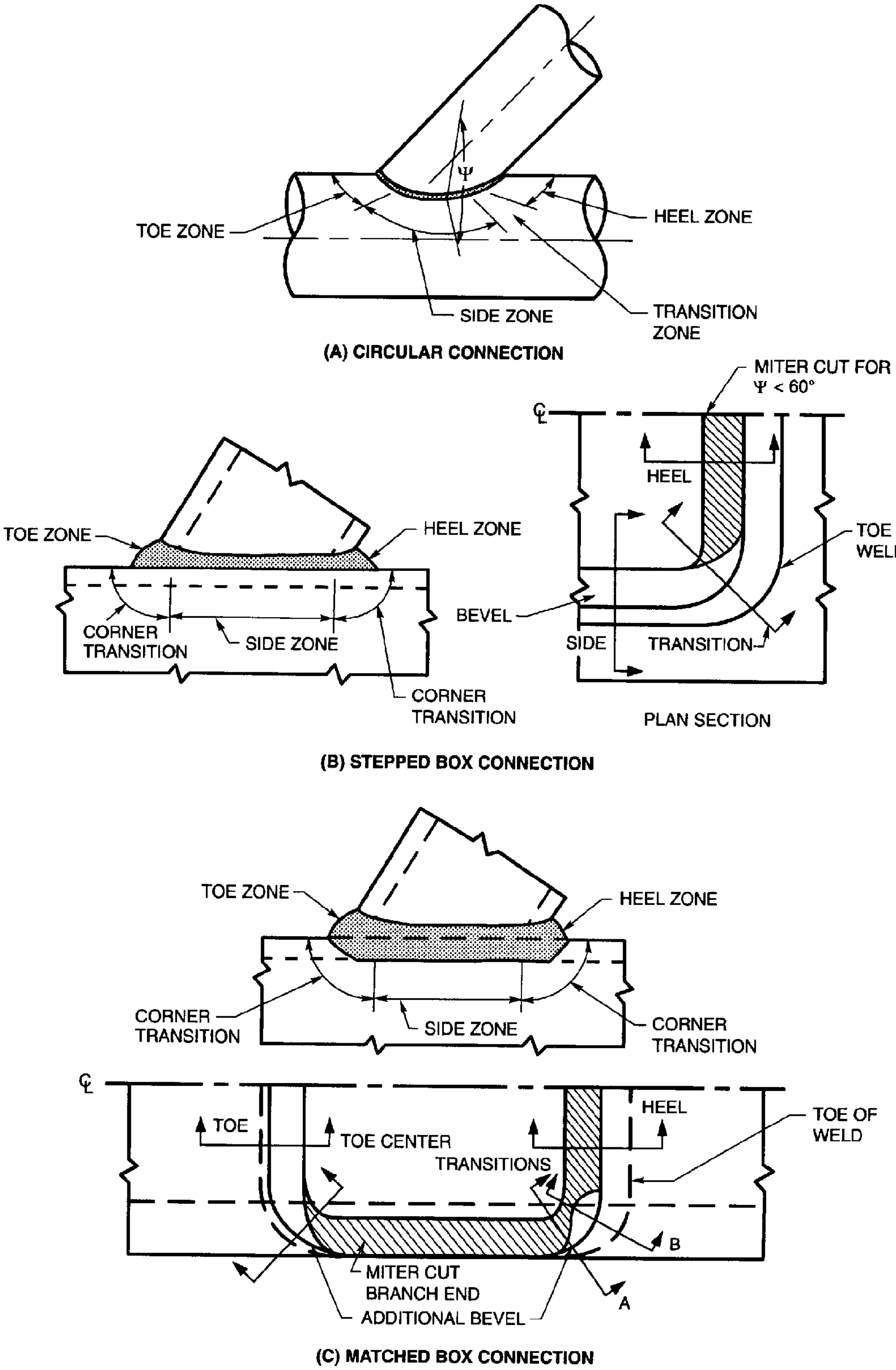


Figure 3.5—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 3.12.4)

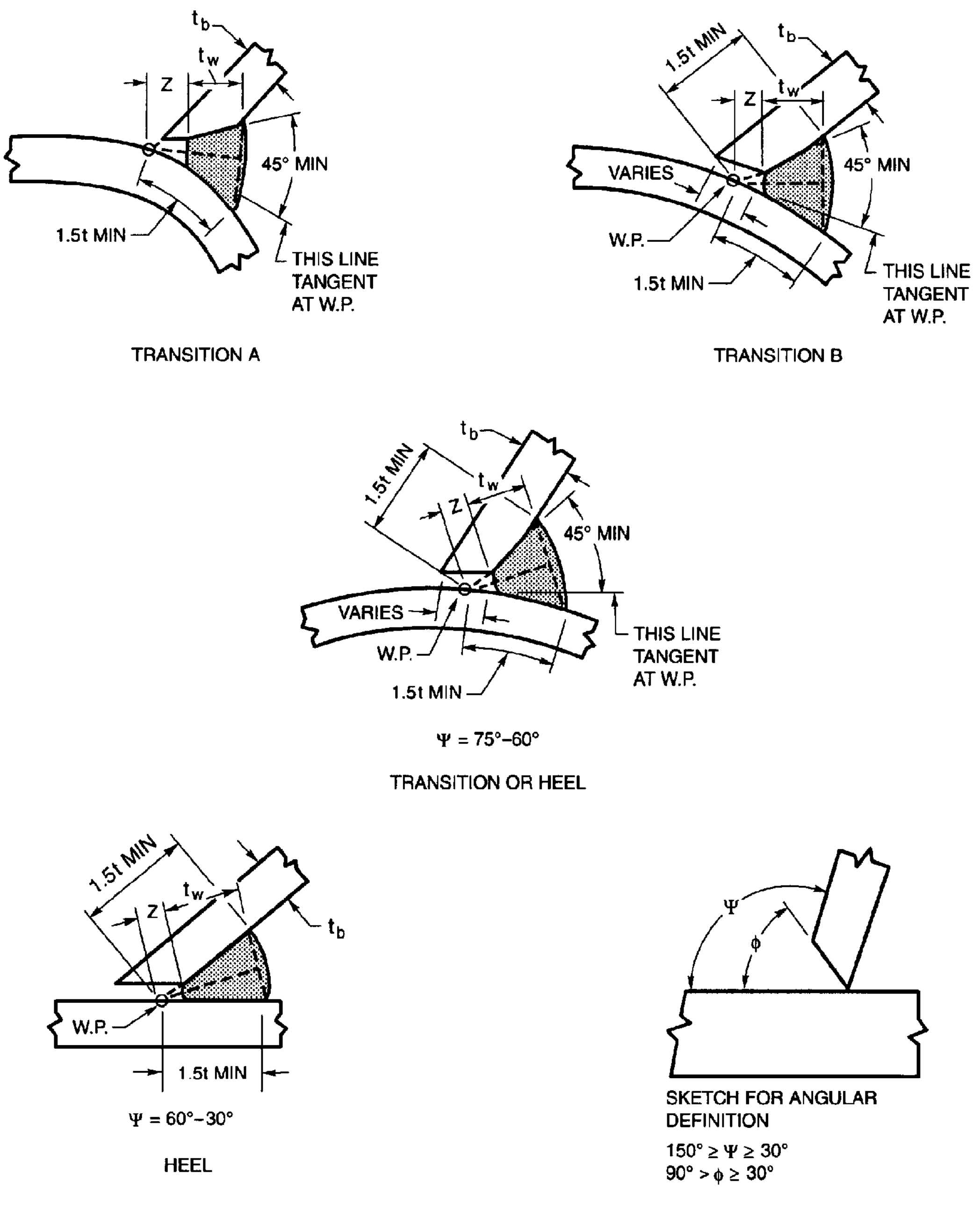
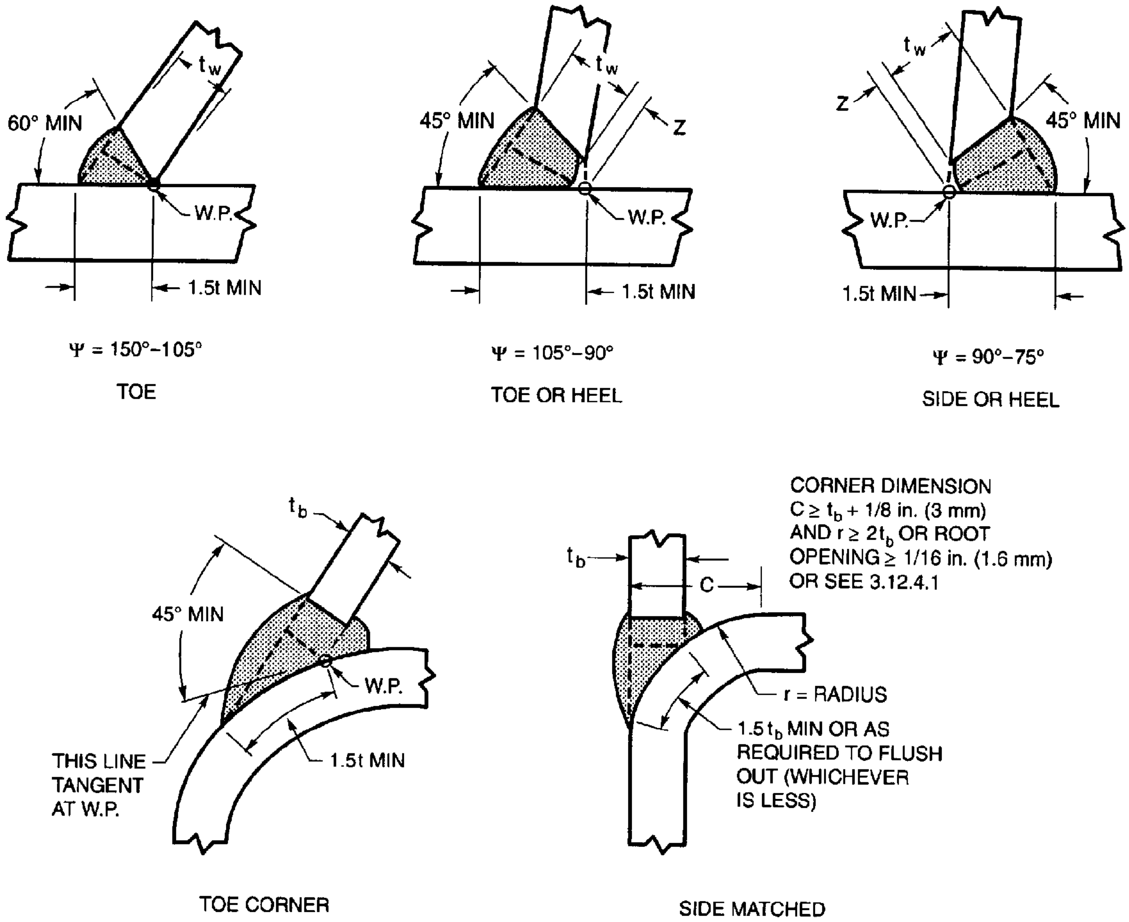
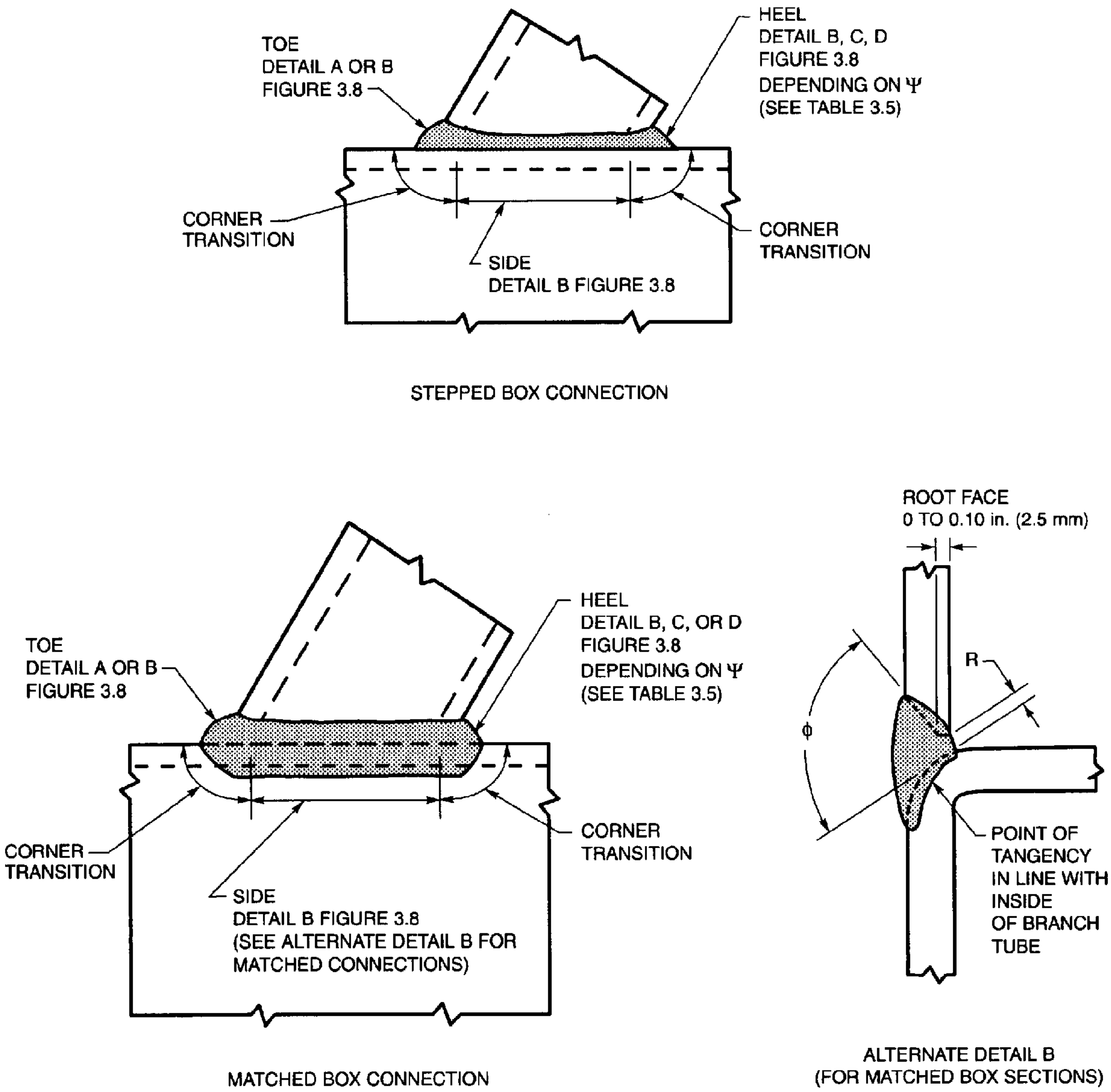


Figure 3.5 (Continued)—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 3.12.4)



Notes:
1. t = thickness of thinner section.
2. Bevel to feather edge except in transition and heel zones.
3. Root opening: 0 to 3/16 in. (5 mm).
4. Not prequalified for under 30°.
5. Weld size (effective throat) $t_w \geq t$; Z Loss Dimensions shown in Table 2.8.
6. Calculations per 2.40.1.3 shall be done for leg length less than 1.5t, as shown.
7. For Box Section, joint preparation for corner transitions shall provide a smooth transition from one detail to another. Welding shall be carried continuously around corners, with corners fully built up and all weld starts and stops within flat faces.
8. See Annex B for definition of local dihedral angle, Ψ.
9. W.P. = work point.

Figure 3.5 (Continued)—Prequalified Joint Details for PJP T-, Y-, and K-Tubular Connections (see 3.12.4)



Notes:
1. Details A, B, C, D as shown in Figure 3.8 and all notes from Table 3.6 apply.
2. Joint preparation for corner welds shall provide a smooth transition from one detail to another. Welding shall be carried continuously around corners, with corners fully built up and all arc starts and stops within flat faces.
3. References to Figure 3.8 include Figures 3.9 and 3.10 as appropriate to thickness (see 2.36.6.7).

Figure 3.6—Prequalified Joint Details for CJP T-, Y-, and K-Tubular Connections (see 3.13.4)

(2) Nonprequalified Joint Detail. There are no prequalified joint details for complete joint penetration groove welds in butt joints made from one side without backing. See 4.12.2.

3.13.4 Tubular T-, Y-, and K-Connections. Details for complete joint penetration groove welds welded from one side without backing in tubular T-, Y-, and K-connections used in circular tubes are described in this section. The applicable circumferential range of Details A, B, C, and D are shown in Figure 3.6 and Figure 3.7, and the ranges of local dihedral angles, [Ψ], corresponding to these are specified in Table 3.5.

Joint dimensions including groove angles are specified in Table 3.6 and Figure 3.8. When selecting a profile (compatible with fatigue category used in design) as a function of thickness, the guidelines of 2.36.6.7 shall be observed. Alternative weld profiles that may be required for thicker sections are shown in Figure 3.9. In the absence of special fatigue requirements, these profiles are applicable to branch thicknesses exceeding 5/8 in. (15.9 mm).

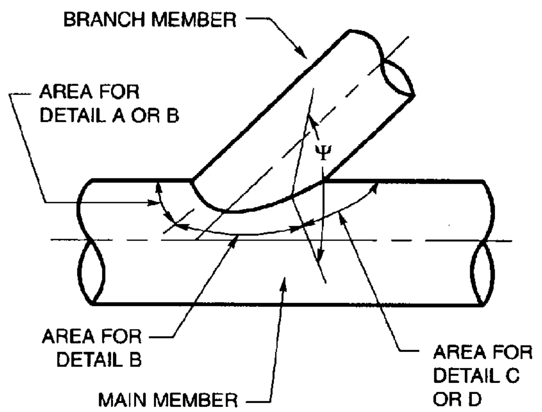


Figure 3.7—Definitions and Detailed Selections for Prequalified CJP T-, Y-, and K-Tubular Connections (see 3.13.4 and Table 3.5)

Table 3.5
Joint Detail Applications for Prequalified CJP T-, Y-, and K-Tubular Connections (see 3.13.4 and Figure 3.7)

Detail	Applicable Range of Local Dihedral Angle, Ψ	
A	180° to 135°	
B	150° to 50°	
C	75° to 30°	Not prequalified for groove angles under 30°
D	40° to 15°	Not prequalified for groove angles under 30°

Notes:
a. The applicable joint detail (A, B, C, or D) for a particular part of the connection is determined by the local dihedral angle, Ψ, which changes continuously in progressing around the branch member.
b. The angle and dimensional ranges given in Detail A, B, C, or D include maximum allowable tolerances.
c. See Annex B for definition of local dihedral angle.

Improved weld profiles meeting the requirements of 2.36.6.6 and 2.36.6.7 are shown in Figure 3.10. In the absence of special fatigue requirements, these profiles are applicable to branch thicknesses exceeding 1-1/2 in. (38.1 mm). (Not required for static compression loading).

Prequalified details for complete joint penetration groove welds in tubular T-, Y-, and K-connections, utilizing box sections, are further described in Figure 3.6. The foregoing details are subject to the limitation of 3.13.3.

Note: See the Commentary for engineering guidance in the selection of a suitable profile.

The joint dimensions and groove angles shall not vary from the ranges detailed in Table 3.6 and shown in Figure 3.6 and Figures 3.8 through 3.10. The root face of joints is zero unless dimensioned otherwise. It may be detailed to exceed zero or the specified dimension by not more than 1/16 in. (1.6 mm). It may not be detailed less than the specified dimensions.

3.13.4.1 Joint Details. Details for complete joint penetration groove welds in tubular T-, Y-, and K-connections are described in 3.13.4. These details are prequalified for shielded metal arc welding and flux cored arc welding. These details may also be used for GMAW-S qualified in accordance with 4.12.4.3.

Table 3.6
Prequalified Joint Dimensions and Groove Angles for Complete Joint Penetration Groove Welds in Tubular T-, Y-, and K-Connections Made by Shielded Metal Arc, Gas Metal Arc (Short Circuiting Transfer)[3] and Flux Cored Arc Welding (see 3.13.4)

		Detail A Ψ = 180° – 135°		Detail B Ψ = 150° – 50°		Detail C Ψ = 75° – 30°**	Detail D Ψ = 40° – 15°**
End preparation (ω)	max			90°*		*	
	min			10° or 45° for Ψ > 105°		10°	
		FCAW-S SMAW (1)	GMAW-S FCAW-G (2)	FCAW-S SMAW (1)	GMAW-S FCAW-G (2)	*** W max. / ϕ	
Fit-up or root opening (R)	max	3/16 in. (5 mm)	3/16 in. (5 mm)	1/4 in. (6 mm)	1/4 in. (6 mm) for ϕ > 45° 5/16 in. (8 mm) for $\phi \leq$ 45°	FCAW-S SMAW (1): 1/8 in. (3 mm) 25°–40° 3/16 in. (5 mm) 15°–25°	
	min	1/16 in. (1.6 mm) No min for ϕ > 90°	1/16 in. (1.6 mm) No min for ϕ > 120°	1/16 in. (1.6 mm)	1/16 in. (1.6 mm)	GMAW-S FCAW-G (2): 1/8 in. (3 mm) 30°–40° 1/4 in. (6 mm) 25°–30° 3/8 in. (10 mm) 20°–25° 1/2 in. (13 mm) 15°–20°	
Joint included angle ϕ	max	90°		60° for $\Psi \leq$ 105°		40°; if more use Detail B	
	min	45°		37-1/2°; if less use Detail C		1/2 Ψ	
Completed weld	t_w	$\geq t_b$		$\geq t_b$ for Ψ > 90° $\geq t_b$/sin Ψ for Ψ < 90°		$\geq t_b$/sin Ψ but need not exceed 1.75 t_b	$\geq 2t_b$
	L	$\geq t_b$/sin Ψ but need not exceed 1.75 t_b				Weld may be built up to meet this	

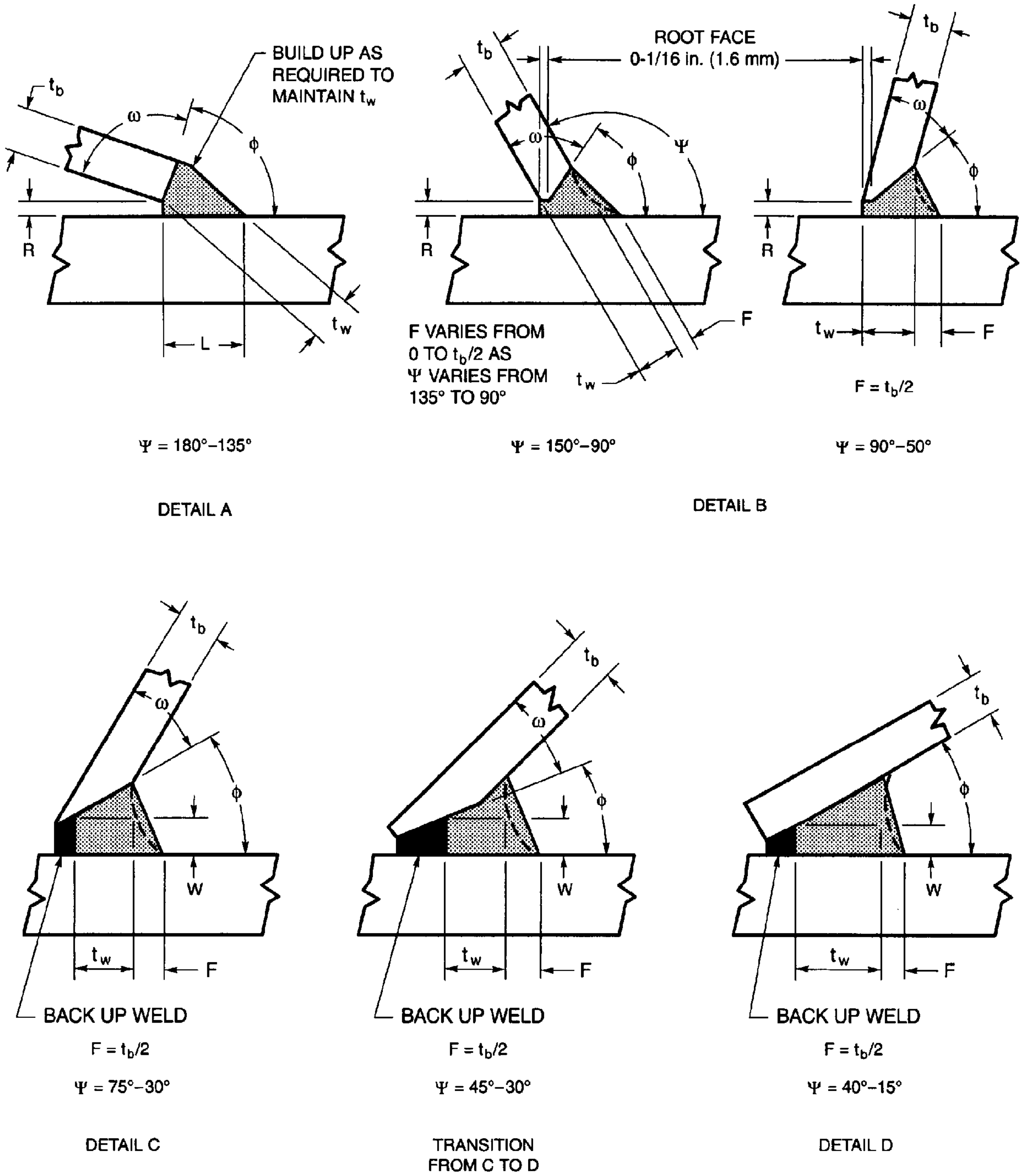
*Otherwise as needed to obtain required ϕ
**Not prequalified for groove angles (ϕ) under 30°
***Initial passes of back-up weld discounted until width of groove (W) is sufficient to assure sound welding; the necessary width of weld groove (W) provided by back-up weld

Notes:
1. These root details apply to SMAW and FCAW-S (self-shielded).
2. These root details apply to GMAW-S (short circuiting transfer) and FCAW-G (gas shielded).
3. For GMAW-S see 4.12.4.3. These details are not intended for GMAW (spray transfer).
4. See Figure 3.8 for minimum standard profile (limited thickness).
5. See Figure 3.9 for alternate toe-fillet profile.
6. See Figure 3.10 for improved profile (see 2.36.6.6 and 2.36.6.7).

Table 3.7
Prequalified WPS Requirements[6] (see 3.7)

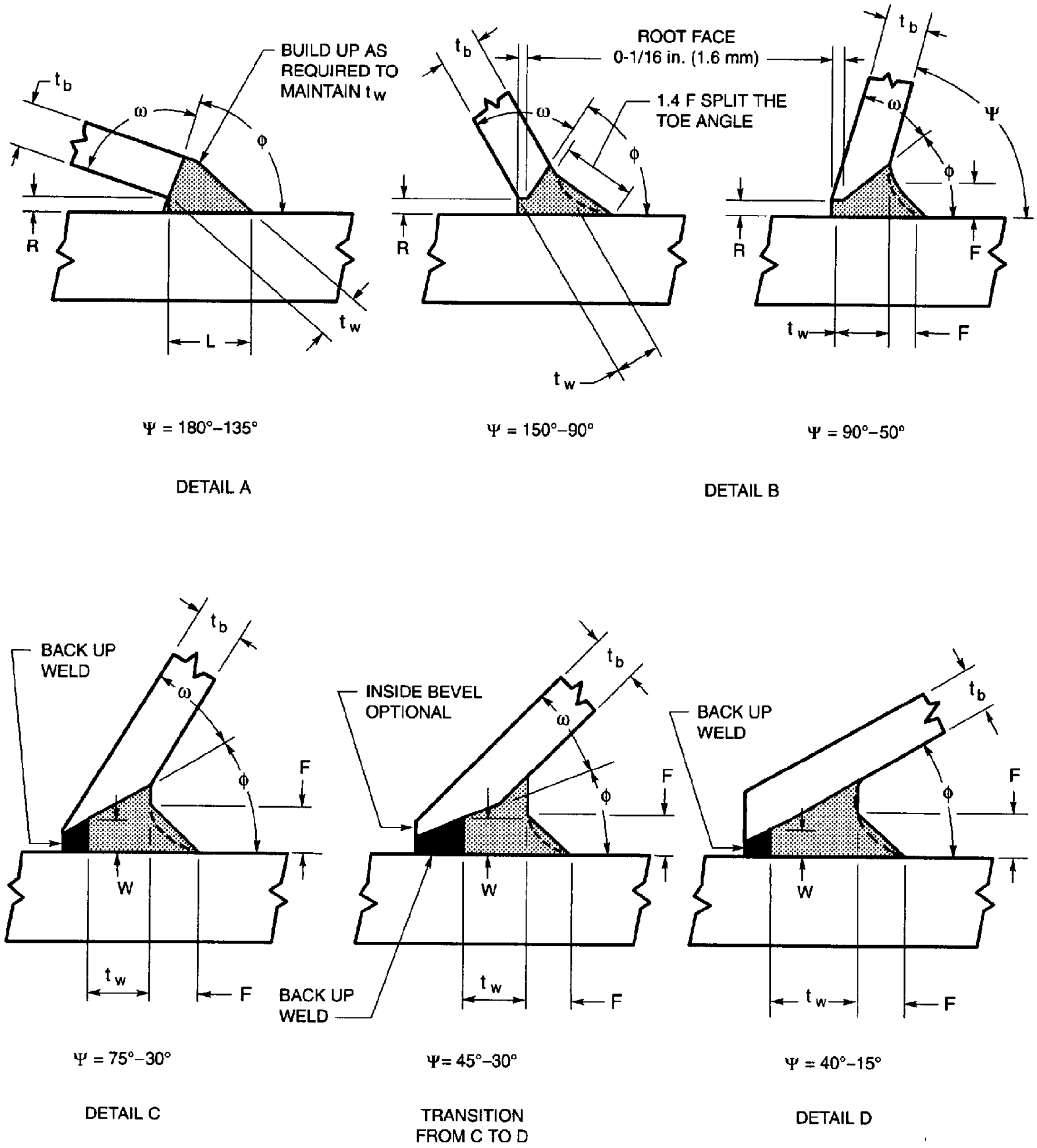
Variable	Position	Weld Type	SMAW	SAW[4]			GMAW/ FCAW[7]
				Single	Parallel	Multiple	
Maximum Electrode Diameter	Flat	Fillet (Note 1)	5/16 in.	1/4 in.			1/8 in.
		Groove (Note 1)	1/4 in.				
		Root pass	3/16 in.				
	Horizontal	Fillet	1/4 in.	1/4 in.			1/8 in.
		Groove	3/16 in.	Requires WPS Qualification Test			
	Vertical	All	3/16 in. (Note 2)				3/32 in.
	Overhead	All	3/16 in. (Note 2)				5/64 in.
Maximum Current	All	Fillet	Within the range of recommended operation by the filler metal manufacturer	1000 A	1200A	Unlimited	Within the range of recommended operation by the filler metal manufacturer
	All	Groove weld root pass with opening		600A	700A		
		Groove weld root pass without opening			900A		
		Groove weld fill passes			1200A		
		Groove weld cap pass		Unlimited			
Maximum Root Pass Thickness (Note 4)	Flat	All	3/8 in.	Unlimited			3/8 in.
	Horizontal		5/16 in.				5/16 in.
	Vertical		1/2 in.				1/2 in.
	Overhead		5/16 in.				5/16 in.
Maximum Fill Pass Thickness	All	All	3/16 in.	1/4 in.	Unlimited		1/4 in.
Maximum Single Pass Fillet Weld Size (Note 3)	Flat	Fillet	3/8 in.	Unlimited			1/2 in.
	Horizontal		5/16 in.	5/16 in.	5/16 in.	1/2 in.	3/8 in.
	Vertical		1/2 in.				1/2 in.
	Overhead		5/16 in.				5/16 in.
Maximum Single Pass Layer Width	All (for GMAW/FCAW) F & H (for SAW)	Root opening > 1/2 in., or		Split layers	Laterally displaced electrodes or split layer	Split layers	Split layers
		Any layer of width w		Split layers if w > 5/8 in.	Split layers with tandem electrodes if w > 5/8 in.	If w > 1 in., split layers	Note 5

Notes:
(1) Except root passes.
(2) 5/32 in. for EXX14 and low-hydrogen electrodes.
(3) See 3.7.3 for requirements for welding unpainted and exposed A588.
(4) See 3.7.2 for width-to-depth limitations.
(5) In the F, H, or OH positions for nontubulars, split layers when the layer width w > 5/8 in. (16 mm). In the vertical position for nontubulars or the 5G or 6G for tubulars, split layers when the width w > 1 in. (25 mm).
(6) Shaded area indicates nonapplicability.
(7) GMAW-S is not prequalified.



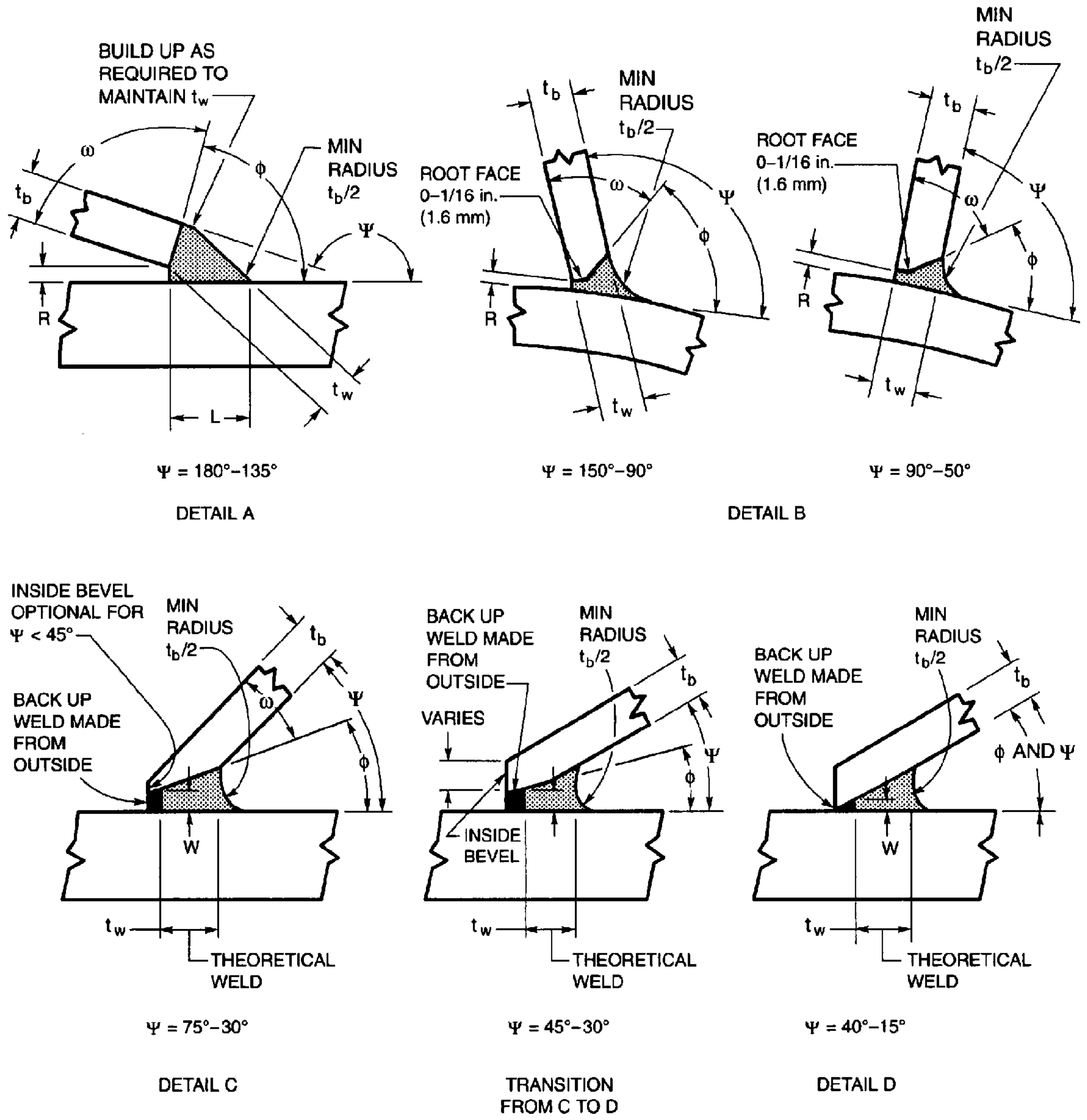
Notes:
1. See Table 3.6 for dimensions t_w, L, R, W, ω, ϕ.
2. Minimum standard flat weld profile as shown by solid line.
3. A concave profile, as shown by dashed lines, is also applicable.
4. Convexity, overlap, etc. are subject to the limitations of 5.24.
5. Branch member thickness, t_b, is subject to limitations of 2.36.6.7.

Figure 3.8—Prequalified Joint Details for Complete Joint Penetration Groove Welds in Tubular T-, Y-, and K-Connections—Standard Flat Profiles for Limited Thickness (see 3.13.4)



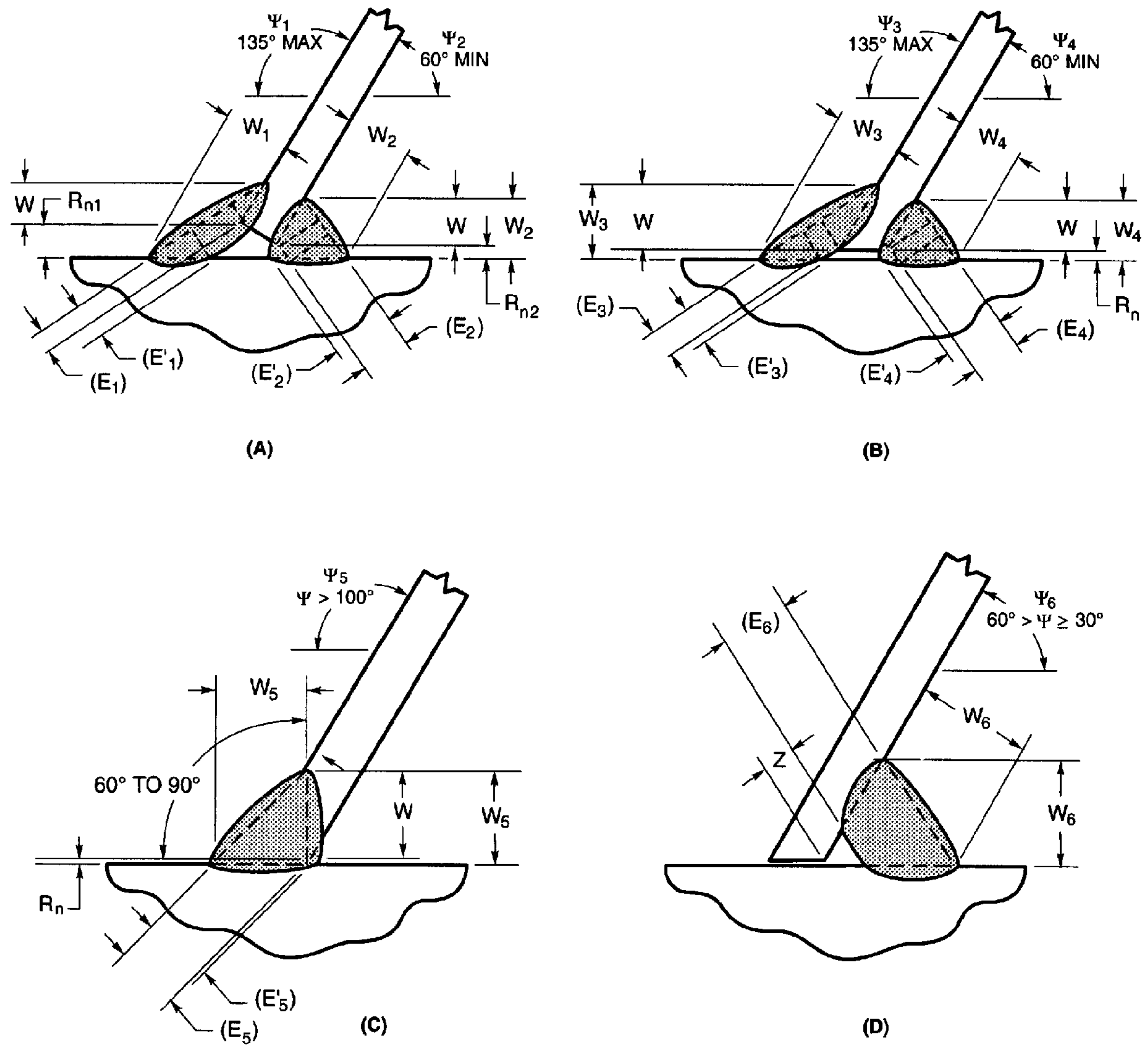
Notes:
1. Sketches illustrate alternate standard profiles with toe fillet.
2. See 2.36.6.7 for applicable range of thickness t_b.
3. Minimum fillet weld size, $F = t_b/2$, also subject to limits of Table 5.8.
4. See Table 3.6 for dimensions t_w, L, R, W, ω, ϕ.
5. Convexity and overlap are subject to the limitations of 5.24.
5. Concave profiles, as shown by dashed lines are also acceptable.

Figure 3.9—Prequalified Joint Details for Complete Joint Penetration Groove Welds in Tubular T-, Y-, and K-Connections—Profile with Toe Fillet for Intermediate Thickness (see 3.13.4)



Notes:
1. Illustrating improved weld profiles for 2.36.6.6(1) as welded and 2.36.6.6(2) fully ground.
2. For heavy sections or fatigue critical applications as indicated in 2.36.6.6.7.
3. See Table 3.6 for dimensions t_b, L, R, W, ω, ϕ.

Figure 3.10—Prequalified Joint Details for Complete Joint Penetration Groove Welds in Tubular T-, Y-, and K-Connections—Concave Improved Profile for Heavy Sections or Fatigue (see 3.13.4)



Notes:
1. (E_n), (E'_n) = Effective throats dependent on magnitude of root opening (R_n). See 5.22.1. (n) represents 1 through 5.
2. t = thickness of thinner part.
3. Not prequlified for gas metal arc welding using short circuiting transfer or GTAW. Refer to Annex A for GMAW-S.
4. Figure D. Apply Z loss dimension of Table 2.2 to determine effective throat.
5. Figure D, not prequalified for under 30°. For welder qualifications, see Table 4.8.

Figure 3.11—Prequalified Skewed T-Joint Details (Nontubular) (see 3.9.3)

4. Qualification

4.0 Scope

The requirements for qualification testing of welding procedure specifications (WPSs) and welding personnel are described as follows:

Part A — General Requirements. This part covers general requirements of both WPS and welding personnel performance requirements.

Part B — Welding Procedure Specification (WPS). This part covers the qualification of a welding procedure specification (WPS) that is not classified as prequalified in accordance with section 3.

Part C — Performance Qualification. This part covers the performance qualification tests required by the code to determine a welder's, welding operator's or tack welder's ability to produce sound welds.

Part A
General Requirements

4.1 General

The requirements for qualification testing of welding procedure specifications (WPSs) and welding personnel (defined as welders, welding operators and tack welders) are described in this section.

4.1.1 Welding Procedure Specification (WPS). Except for prequalified WPSs in conformance with section 3, a WPS for use in production welding shall be qualified in conformance with section 4, Part B, and shall be approved by the Engineer.Properly documented evidence of previous WPS qualification may be accepted with the Engineer's approval. The requirements listed in Annex IV, Table IV-1, Code Requirements That May be Changed by Procedure Qualification Tests, may be varied when the WPS is qualified by tests.

4.1.1.1 Qualification Responsibility. Each manufacturer or contractor shall conduct the tests required by this code to qualify the WPS.

4.1.1.2 Previous WPS Qualification. Properly documented WPSs qualified under the provisions of this code by a Company which later has a name change due to voluntary action or consolidation with a parent company may utilize the new name on its WPS documents.

4.1.1.3 Impact Test Requirements. When required by contract drawings or specifications, impact tests shall be included in the WPS qualification. The impact tests, requirements, and procedure shall be in conformance with the provisions of Annex III, or as specified in the contract documents.

4.1.2 Performance Qualification of Welding Personnel. Welders, welding operators and tack welders to be employed under this code, and using the shielded arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), flux cored arc welding (FCAW), electroslag welding (ESW), or electrogas welding (EGW) processes, shall have been qualified by the applicable tests as described in Part C of this section. See Commentary.

4.1.2.1 Previous Performance Qualification. Properly documented evidence of previous performance qualification of welders, welding operators and tack welders may be accepted with the Engineer's approval.

4.1.2.2 Qualification Responsibility. Each manufacturer or contractor shall be responsible for the qualification of welders, welding operators and tack welders, whether the qualification is conducted by the manufacturer, contractor, or an independent testing agency.

4.1.3 Period of Effectiveness

4.1.3.1 Welders and Welding Operators. The welder's or welding operator's qualification as specified in this code shall be considered as remaining in effect indefinitely unless (1) the welder is not engaged in a given process of welding for which the welder or welding operator is qualified for a period exceeding six months or unless (2) there is some specific reason to question a welder's or welding operator's ability. See 4.32.1.

4.1.3.2 Tack Welders. A tack welder who passes the test described in Part C or those tests required for welder qualification shall be considered eligible to perform tack welding indefinitely in the positions and with the process for which the tack welder is qualified unless there is some specific reason to question the tack welder's ability (see 4.32.2).

4.2 Common Requirements for WPS and Welding Personnel Performance Qualification

4.2.1 Qualification to Earlier Editions. Qualifications which were performed to and met the requirements of earlier editions of ANSI/AWS D1.1 or AWS D1.0 or AWS D2.0 while those editions were in effect are valid and may be used. It is not acceptable to use an earlier edition for new qualifications in lieu of the current edition, unless the specific early edition is a contractual requirement.

4.2.2 Aging. When permitted by the filler metal specification applicable to weld metal being tested, fully welded qualification test specimens may be aged at 200°F to 220°F (93°C to 104°C) for 48 ± 2 hours.

4.2.3 Records. Records of the test results shall be kept by the manufacturer or contractor and shall be made available to those authorized to examine them.

4.2.4 Positions of Welds. All welds shall be classified as flat (F), horizontal (H), vertical (V) and overhead (OH), in accordance with the definitions shown in Figures 4.1 and 4.2.

Test assembly positions are shown in:

(1) Figure 4.3 (groove welds in plate)

(2) Figure 4.4 (groove welds in pipe or tubing)

(3) Figure 4.5 (fillet welds in plate)

(4) Figure 4.6 (fillet welds in pipe or tubing)

Part B
Welding Procedure Specification (WPS)

4.3 Production Welding Positions Qualified

The production welding positions qualified by a WPS shall conform to the requirements of Table 4.1.

4.4 Type of Qualification Tests

The type and number of qualification tests required to qualify a WPS for a given thickness, diameter, or both, shall conform to Table 4.2 (CJP), Table 4.3 (PJP) or Table 4.4 (fillet). Details on the individual NDT and mechanical test requirements are found in the following subsections:

(1) Visual Inspection (see 4.8.1)

(2) Nondestructive (see 4.8.2)

(3) Face, root and side bend (see 4.8.3.1)

(4) Reduced Section (see 4.8.3.4)

(5) All-Weld-Metal Tension (see 4.8.3.6)

(6) Macroetch (see 4.8.4)

4.5 Weld Types for WPS Qualification

For the purpose of WPS qualification, weld types shall be classified as follows:

(1) Complete joint penetration (CJP) groove welds for Nontubular Connections (see 4.9)

(2) Partial joint penetration (PJP) groove welds for Nontubular Connections (see 4.10)

(3) Fillet Welds for Tubular and Nontubular Connections (see 4.11)

(4) CJP groove welds for Tubular Connections (see 4.12)

(5) PJP groove welds for Tubular T-, Y-, and K-connections and Butt Joints (see 4.13)

(6) Plug and Slot welds for Tubular and Nontubular Connections (see 4.14)

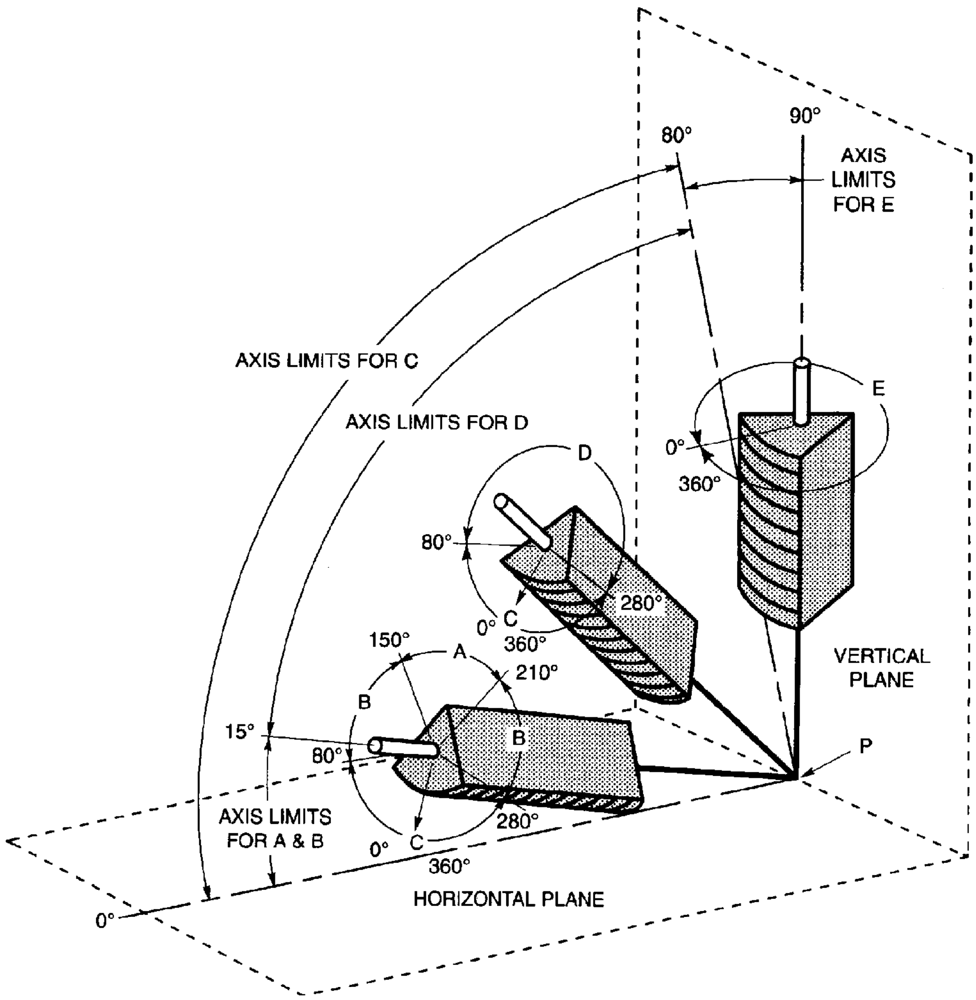
4.6 Preparation of WPS

The manufacturer or contractor shall prepare a written WPS that specifies all of the applicable essential variables referenced in 4.7. The specific values for these WPS variables shall be obtained from the procedure qualification record (PQR), which serves as written confirmation of a successful WPS qualification.

4.7 Essential Variables

4.7.1 SMAW, SAW, GMAW, GTAW, and FCAW. Changes beyond the limitations of PQR essential variables for the SMAW, SAW, GMAW, GTAW and FCAW processes shown in Table 4.5 shall require requalification of the WPS.

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



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

Figure 4.1—Positions of Groove Welds (see 4.2.4)

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

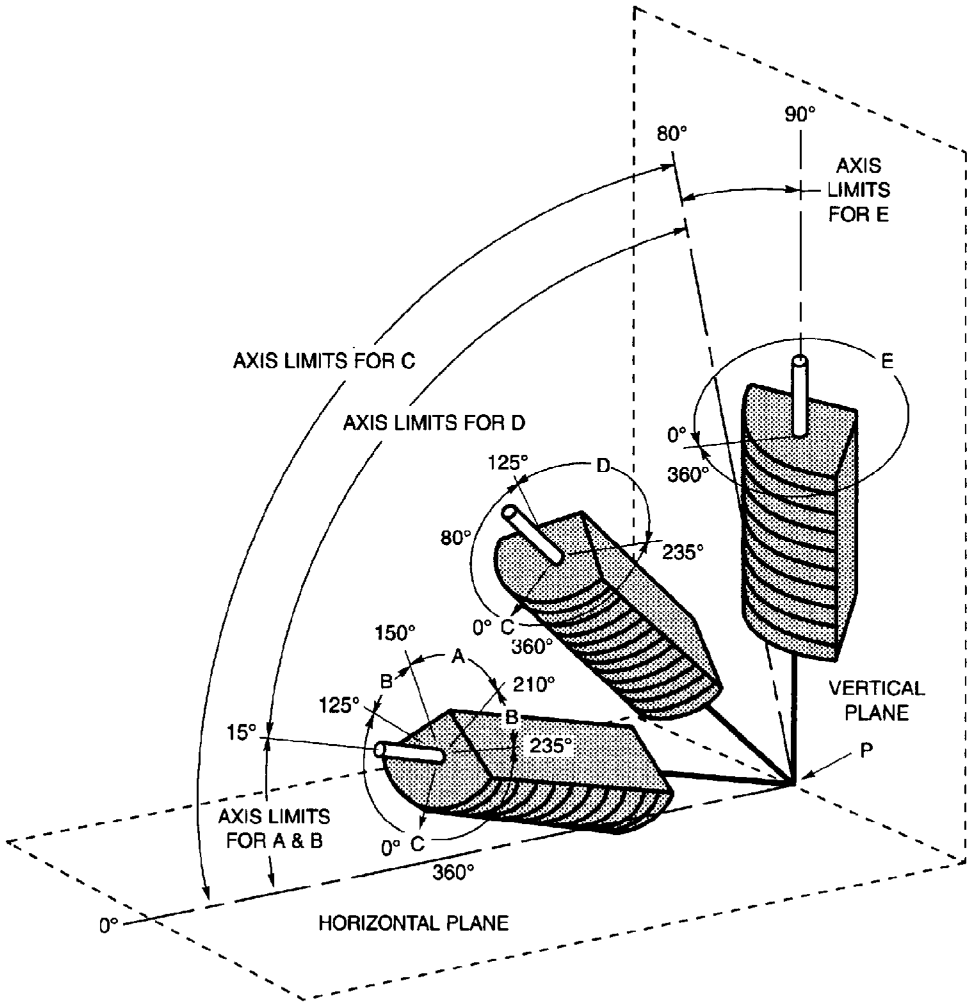


Figure 4.2—Positions of Fillet Welds (see 4.2.4)

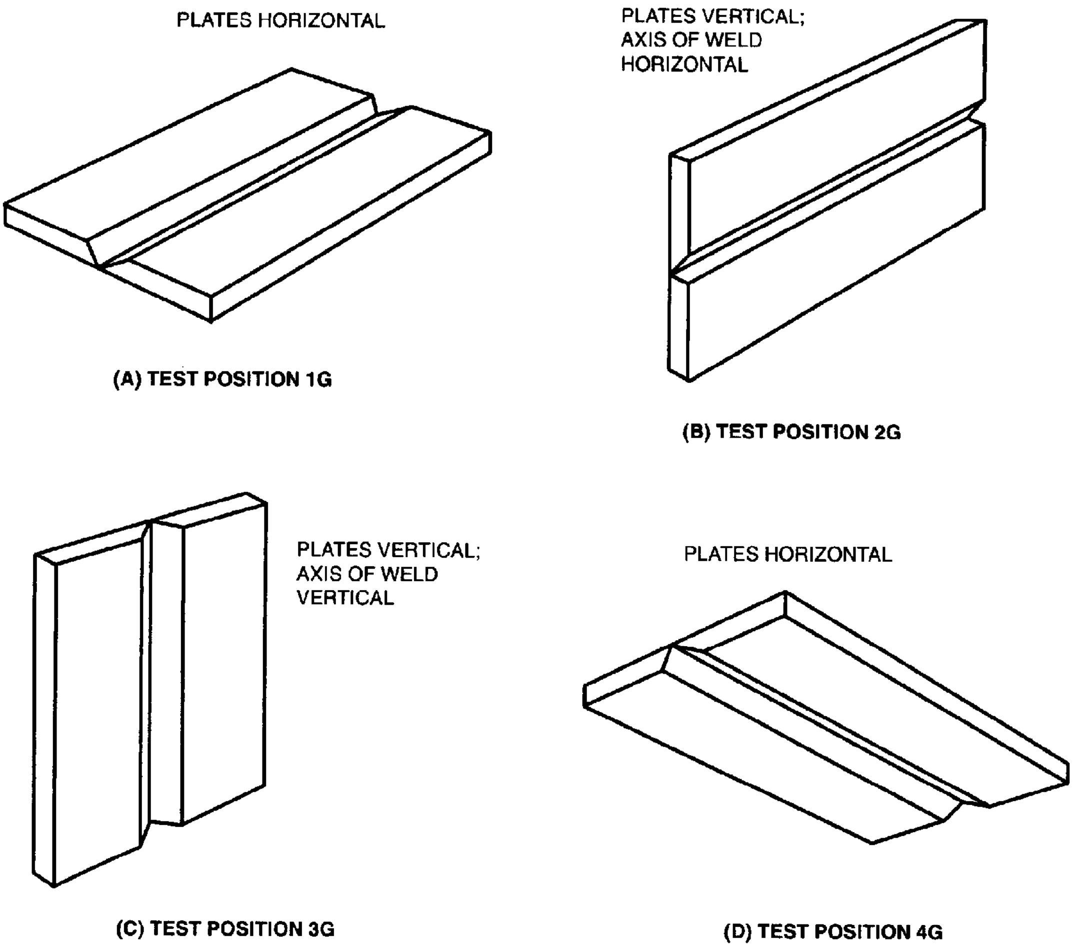


Figure 4.3—Positions of Test Plates for Groove Welds (see 4.2.4)

4.7.2 Electroslag and Electrogas Welding. See Table 4.6 for the PQR essential variable changes requiring WPS requalification for the EGW and ESW processes.

4.7.3 Base-Metal Qualification. Base metals listed in Table 3.1 that are subject to WPS qualification testing shall qualify other base metal groups in accordance with Table 4.7. Base metals not listed in Table 3.1 or Annex M shall be qualified in conformance with section 4, and have the Engineer's approval.

WPSs with steels listed in Annex M shall also qualify Table 3.1 or Annex M steels in conformance with Table 4.7. Annex M contains recommendations for matching strength filler metal and minimum preheat and interpass temperatures for ASTM A514, A517, A709 Grades 100 and 100W, ASTM A710 Grade A (class 1 and 3) steels, and ASTM A871 Grades 60 and 65.

Preheat and interpass temperatures lower than required per Table 3.2 or calculated per Annex XI shall be qualified by tests approved by the Engineer.

4.8 Methods of Testing and Acceptance Criteria for WPS Qualification

The welded test assemblies conforming to 4.8.2 shall have test specimens prepared by cutting the test plate, pipe, or tubing as shown in Figures 4.7 through 4.11, whichever is applicable. The test specimens shall be prepared for testing in conformance with Figures 4.12, 4.13, 4.14 and 4.18, as applicable.

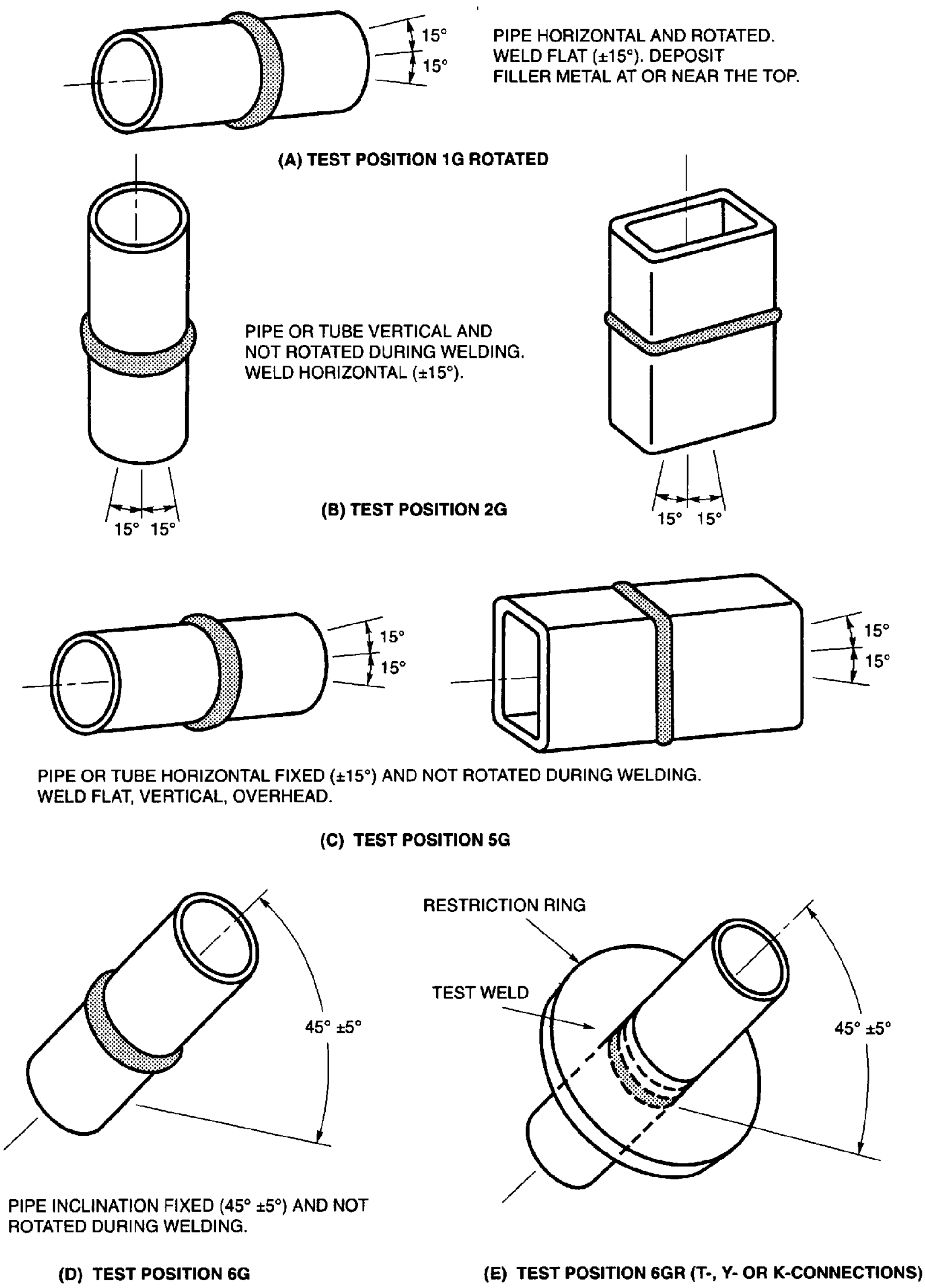


Figure 4.4—Positions of Test Pipe or Tubing for Groove Welds (see 4.2.4)

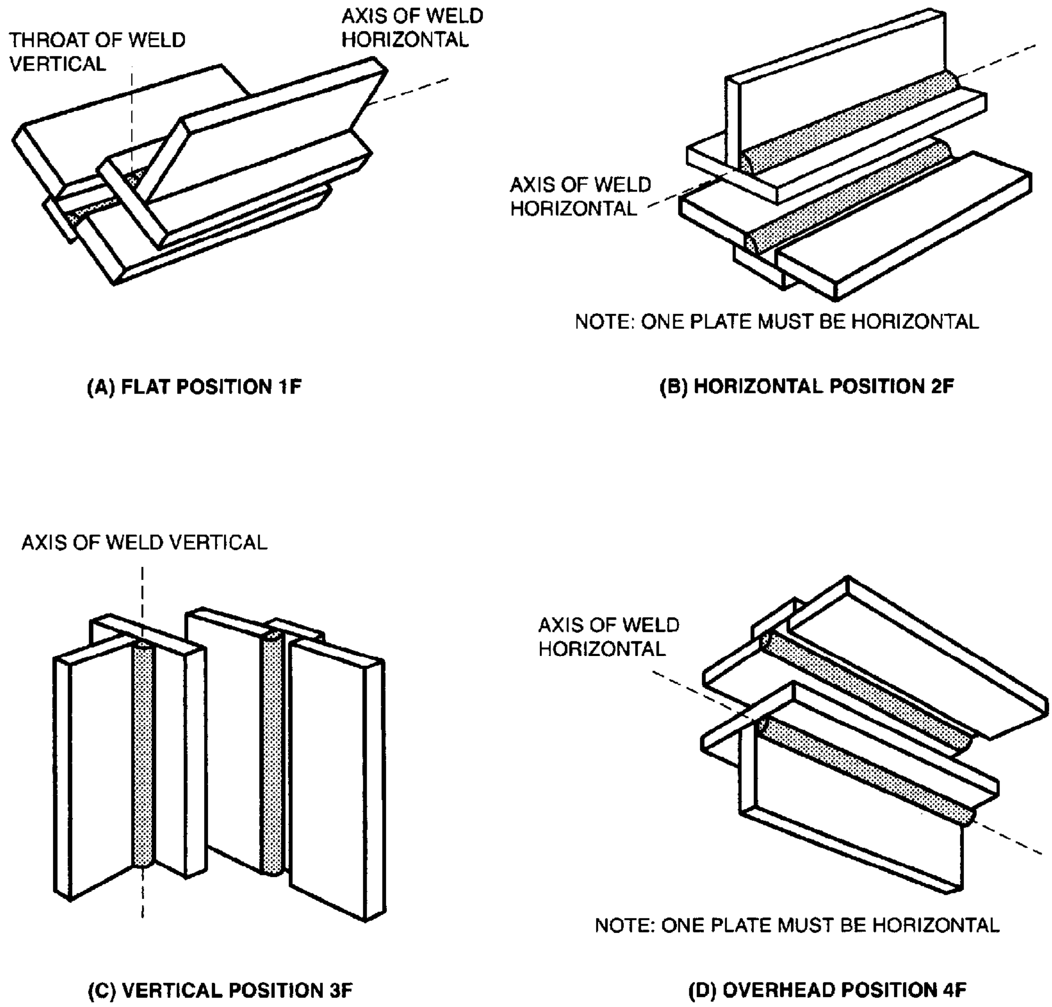


Figure 4.5—Positions of Test Plate for Fillet Welds (see 4.2.4)

4.8.1 Visual Inspection. For acceptable qualification, welds shall meet the following requirements:

(1) The weld shall be free of cracks.

(2) All craters shall be filled to the full cross section of the weld.

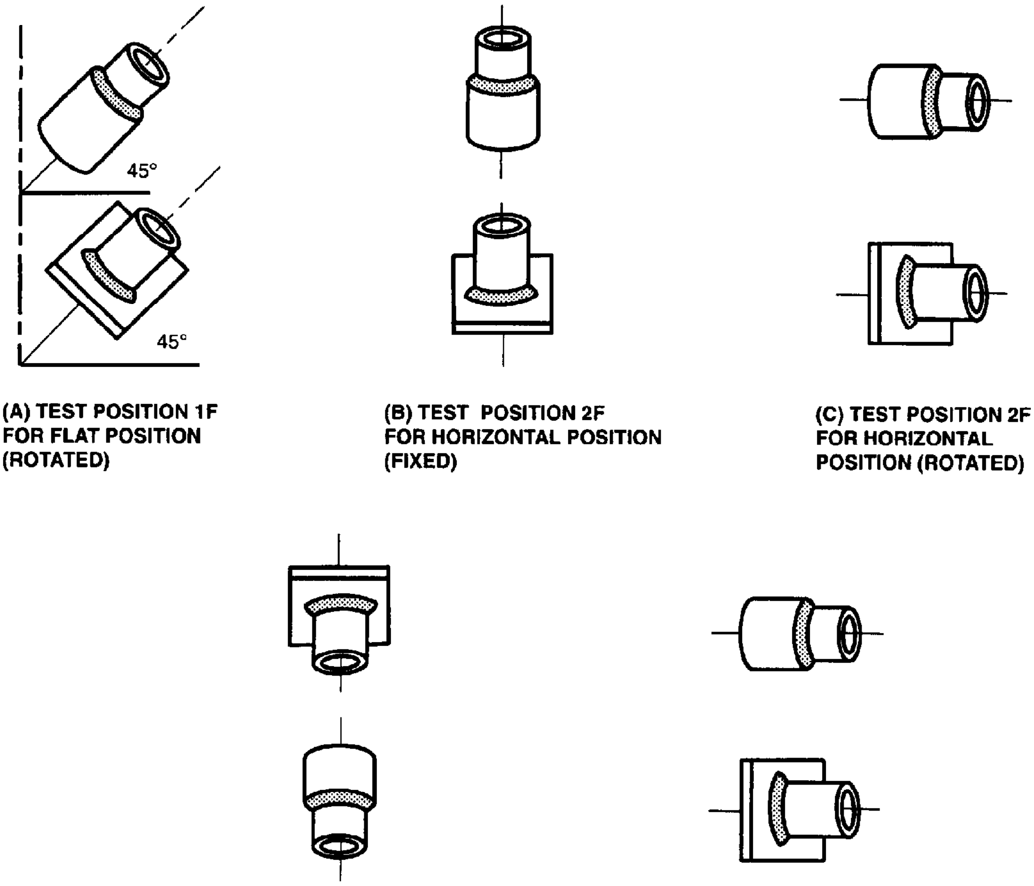
(3) The face of the weld shall be flush with the surface of the base metal, and the weld shall merge smoothly with the base metal. Undercut shall not exceed 1/32 in. (1 mm). Weld reinforcement shall not exceed 1/8 in. (3 mm).

(4) The root of the weld shall be inspected, and there shall be no evidence of cracks, incomplete fusion, or inadequate joint penetration. A concave root surface is permitted within the limits shown below, provided the total weld thickness is equal to or greater than that of the base metal.

(5) The maximum root surface concavity shall be 1/16 in. (1.6 mm) and the maximum melt-through shall be 1/8 in. (3 mm). For tubular T-, Y-, and K-connections, melt-through at the root is considered desirable and shall not be cause for rejection.

4.8.2 Nondestructive Testing. Before preparing mechanical test specimens, the qualification test plate, pipe, or tubing shall be nondestructively tested for soundness as follows:

4.8.2.1 RT or UT. Either radiographic (RT) or ultrasonic testing (UT) shall be used. The entire length of the weld in test plates, except the discard lengths at each end,



(A) TEST POSITION 1F FOR FLAT POSITION (ROTATED)

(B) TEST POSITION 2F FOR HORIZONTAL POSITION (FIXED)

(C) TEST POSITION 2F FOR HORIZONTAL POSITION (ROTATED)

(D) TEST POSITION 4F FOR OVERHEAD POSITION (FIXED)

(E) TEST POSITION 5F FOR MULTIPLE POSITION (FIXED)

Figure 4.6—Positions of Test Pipes or Tubing for Fillet Welds (see 4.2.4)

shall be examined in accordance with section 6, Part E or F. For tubulars, the full circumference of the completed weld shall be examined in conformance with section 6, Part C.

4.8.2.2 RT or UT Acceptance Criteria. For acceptable qualification, the weld, as revealed by radiographic or ultrasonic testing, shall conform to the requirements of section 6, Part C.

4.8.3 Mechanical Testing. Mechanical testing shall be as follows:

4.8.3.1 Root, Face, and Side Bend Specimens (see Figure 4.12 for root and face bends, Figure 4.13 for side bends). Each specimen shall be bent in a bend test jig that meets the requirements shown in Figures 4.15 through 4.17 or is substantially in accordance with those figures, provided the maximum bend radius is not exceeded. Any convenient means may be used to move the plunger member with relation to the die member.

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

The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and heat-affected zones shall be centered and completely within

Table 4.1
WPS Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests (see 4.3)

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
						Butt-Groove		T-, Y-, K-Groove			Butt-Groove		T-, Y-, K-Groove		
	Weld Type	Positions	Groove CJP	Groove PJP	Fillet[9]	CJP	PJP	CJP	PJP	Fillet[9]	CJP	PJP	CJP	PJP	Fillet[9]
PLATE	CJP Groove[1]	1G[2]	F	F	F	F	F			F	F	F			F
PLATE	CJP Groove[1]	2G[2]	F, H	F, H	F, H	F, H	F, H			F, H	F, H	F, H			F, H
PLATE	CJP Groove[1]	3G[2]	V	V	V	V	V			V	V	V			V
PLATE	CJP Groove[1]	4G[2]	OH	OH	OH	OH	OH			OH	OH	OH			OH
PLATE	Fillet[1]	1F			F					F					F
PLATE	Fillet[1]	2F			F, H					F, H					F, H
PLATE	Fillet[1]	3F			V					V					V
PLATE	Fillet[1]	4F			OH					OH					OH
PLATE	Plug/Slot	Qualifies Plug/Slot Welding for Only the Positions Tested													
TUBULAR	CJP Groove	1G Rotated	F	F	F	F[3]	F		F	F	F[3]	F		F	F
TUBULAR	CJP Groove	2G	F, H	F, H	F, H	(F, H)[3]	F, H		F, H	F, H	(F, H)[3]	F, H		F, H	F, H
TUBULAR	CJP Groove	5G	F, V, OH	F, V, OH	F, V, OH	(F, V, OH)[3]	F, V, OH		F, V, OH	F, V, OH	(F, V, OH)[3]	F, V, OH		F, V, OH	F, V, OH
TUBULAR	CJP Groove	(2G + 5G)	All	All	All	All[3]	All	All[5]	All[7]	All	All[3]	All	All[6]	All[7, 8]	All
TUBULAR	CJP Groove	6G	All	All	All	All[3]	All		All[7]	All	All[3]	All		All[7, 8]	All
TUBULAR	CJP Groove	6GR	All[4]	All	All	All[4]	All	All[5]	All	All	All[4]	All	All[6]	All	All
TUBULAR	Fillet	1F Rotated			F					F					F
TUBULAR	Fillet	2F			F, H					F, H					F, H
TUBULAR	Fillet	2F Rotated			F, H					F, H					F, H
TUBULAR	Fillet	4F			F, H, OH					F, H, OH					F, H, OH
TUBULAR	Fillet	5F			All					All					All

CJP—Complete Joint Penetration
PJP—Partial Joint Penetration
(R)—Restriction

Notes:
1. Qualifies for a welding axis with an essentially straight line, including welding along a line parallel to the axis of circular pipe.
2. Qualifies for circumferential welds in pipes equal to or greater than 24 in. nominal outer diameter.
3. Production butt joint details without backing or backgouging require qualification testing of the joint detail shown in Figure 4.24.
4. Limited to prequalified joint details. See 3.12 or 3.13.
5. For production joints of CJP T-, Y-, and K-connections that conform to either Figure 3.8, 3.9, or 3.10 and Table 3.6, use Figure 4.27 detail for testing. For other production joints, see 4.12.4.1.
6. For production joints of CJP T-, Y-, and K-connections that conform to Figure 3.6, and Table 3.6, use Figure 4.27 and 4.28 detail for testing, or, alternatively, test the Figure 4.27 joint and cut macroetch specimens from the corner locations shown in Figure 4.28. For other production joints, see 4.12.4.1.
7. For production joints of PJP T-, Y-, and K-connections that conform to Figure 3.5, use either the Figure 4.24 or Figure 4.25 detail for testing.
8. For matched box connections with corner radii less than twice the chord member thickness, see 3.12.4.1.
9. Fillet welds in production T-, Y-, or K-connections shall conform to Figure 3.2. WPS qualification shall conform to 4.11.

Table 4.2
WPS Qualification—Complete Joint Penetration Groove Welds: Number and Type of Test Specimens and Range of Thickness and Diameter Qualified (see 4.4) (Dimensions in Inches)

1. Tests on Plate[1, 2]

Nominal Plate Thickness (T) Tested, in.	Number of Specimens: Reduced Section Tension (see Fig. 4.14)	Number of Specimens: Root Bend (see Fig. 4.12)	Number of Specimens: Face Bend (see Fig. 4.12)	Number of Specimens: Side Bend (see Fig. 4.13)	Nominal Plate, Pipe or Tube Thickness[3, 4] Qualified, in.: Min	Nominal Plate, Pipe or Tube Thickness[3, 4] Qualified, in.: Max
1/8 ≤ T ≤ 3/8	2	2	2	—	1/8	2T
3/8 < T < 1	2	—	—	4	1/8	2T
1 and over	2	—	—	4	1/8	Unlimited

2. Tests on Pipe or Tubing[1, 7]

	Nominal Pipe Size or Diam., in.	Nominal Wall Thickness, T, in.	Number of Specimens: Reduced Section Tension (see Fig. 4.14)	Number of Specimens: Root Bend (see Fig. 4.12)	Number of Specimens: Face Bend (see Fig. 4.12)	Number of Specimens: Side Bend (see Fig. 4.13)	Nominal Diameter[5] of Pipe or Tube Size Qualified, in.	Nominal Plate, Pipe or Tube Wall Thickness[3, 4] Qualified, in.: Min	Nominal Plate, Pipe or Tube Wall Thickness[3, 4] Qualified, in.: Max
Job Size Test Pipes	< 24	1/8 ≤ T ≤ 3/8	2	2	2	—	Test diam. and over	1/8	2T
		3/8 < T < 3/4	2	—	—	4	Test diam. and over	T/2	2T
		T ≥ 3/4	2	—	—	4	Test diam. and over	3/8	Unlimited
	≥ 24	1/8 ≤ T ≤ 3/8	2	2	2	—	Test diam. and over	1/8	2T
		3/8 < T < 3/4	2	—	—	4	24 and over	T/2	2T
		T ≥ 3/4	2	—	—	4	24 and over	3/8	Unlimited
Standard Test Pipes	2 in. Sch. 80 or 3 in. Sch. 40		2	2	2	—	3/4 through 4	1/8	3/4
	6 in. Sch. 120 or 8 in. Sch. 80		2	—	—	4	4 and over	3/16	Unlimited

3. Tests on Electroslag and Electrogas Welding[1, 8]

Nominal Plate Thickness Tested	Number of Specimens: Reduced Section Tension (see Fig.4.14)	Number of Specimens: All-Weld-Metal Tension (see Fig. 4.18)	Number of Specimens: Side Bend (see Fig. 4.13)	Number of Specimens: Impact Tests	Nominal Plate Thickness Qualified: Min	Nominal Plate Thickness Qualified: Max
T	2	1	4	Note 6	0.5T	1.1T

Notes:
1. All test plate, pipe or tube welds shall be visually inspected (see 4.8.1) and subject to NDT (see 4.8.2). One test plate, pipe or tube shall be required for each qualified position.
2. See Figures 4.10 and 4.11 for test plate requirements.
3. For square groove welds that are qualified without backgouging, the maximum thickness qualified shall be limited to the test plate thickness.
4. CJP groove weld qualification on any thickness or diameter qualifies any size of fillet or PJP groove weld for any thickness.
5. Qualification with any pipe diameter qualifies all box section widths and depths.
6. If specified, impact tests shall conform to Annex III.
7. See Table 4.1 for the groove details required for qualification of tubular butt and T-, Y-, K-connection joints.
8. See Figure 4.9 for plate requirements.

Table 4.2
WPS Qualification—Complete Joint Penetration Groove Welds: Number and Type of Test Specimens and Range of Thickness and Diameter Qualified (see 4.4) (Dimensions in Millimeters)

1. Tests on Plate[1,2]

Nominal Plate Thickness (T) Tested, mm	Number of Specimens: Reduced Section Tension (see Fig. 4.14)	Root Bend (see Fig. 4.12)	Face Bend (see Fig. 4.12)	Side Bend (see Fig. 4.13)	Nominal Plate, Pipe or Tube Thickness[3,4] Qualified, mm: Min	Max
3.2 ≤ T ≤ 9.5	2	2	2	—	3.2	2T
9.5 < T < 25.4	2	—	—	4	3.2	2T
25.4 and over	2	—	—	4	3.2	Unlimited

2. Tests on Pipe or Tubing[1,7]

	Nominal Pipe Size or Diam., mm	Nominal Wall Thickness, T, mm	Number of Specimens: Reduced Section Tension (see Fig. 4.14)	Root Bend (see Fig. 4.12)	Face Bend (see Fig. 4.12)	Side Bend (see Fig. 4.13)	Nominal Diameter[5] of Pipe or Tube Size Qualified, mm	Nominal Plate, Pipe or Tube Wall Thickness[3,4] Qualified, mm: Min	Max
Job Size Test Pipes	< 610	3.2 ≤ T ≤ 9.5	2	2	2	—	Test diam. and over	3.2	2T
		9.5 < T < 19.0	2	—	—	4	Test diam. and over	T/2	2T
		T ≥ 19.0	2	—	—	4	Test diam. and over	9.5	Unlimited
	≥ 610	3.2 ≤ T ≤ 9.5	2	2	2	—	Test diam. and over	3.2	2T
		9.5 < T < 19.0	2	—	—	4	610 and over	T/2	2T
		T ≥ 19.0	2	—	—	4	610 and over	9.5	Unlimited
Standard Test Pipes	50 mm OD × 5.5 mm WT or 75 mm OD × 5.5 mm WT		2	2	2	—	19 through 100	3.2	19.0
	150 mm OD × 14.3 mm WT or 200 mm OD × 12.7 mm WT		2	—	—	4	100 and over	4.8	Unlimited

3. Tests on Electroslag and Electrogas Welding[1,8]

Nominal Plate Thickness Tested	Number of Specimens: Reduced Section Tension (see Fig. 4.14)	All-Weld-Metal Tension (see Fig. 4.18)	Side Bend (see Fig. 4.13)	Impact Tests	Nominal Plate Thickness Qualified: Min	Max
T	2	1	4	Note 6	0.5T	1.1T

Notes:
1. All test plate, pipe or tube welds shall be visually inspected (see 4.8.1) and subject to NDT (see 4.8.2). One test plate, pipe or tube shall be required for each qualified position.
2. See Figures 4.10 and 4.11 for test plate requirements.
3. For square groove welds that are qualified without backgouging, the maximum thickness qualified shall be limited to the test plate thickness.
4. CJP groove weld qualification on any thickness or diameter qualifies any size of fillet or PJP groove weld for any thickness.
5. Qualification with any pipe diameter qualifies all box section widths and depths.
6. If specified, impact tests shall conform to Annex III.
7. See Table 4.1 for the groove details required for qualification of tubular butt and T-, Y-, K-connection joints.
8. See Figure 4.9 for plate requirements.

Table 4.3
Number and Type of Test Specimens and Range of Thickness Qualified— WPS Qualification; Partial Joint Penetration Groove Welds (see 4.10)

Test Groove Depth, T in. (mm)	Number of Specimens[1,2]					Qualification Ranges[3,4]		
	Macroetch for Weld Size (E) 4.10.2 4.10.3 4.10.4	Reduced-Section Tension (see Fig. 4.14)	Root Bend (see Fig. 4.12)	Face Bend (see Fig. 4.12)	Side Bend (see Fig. 4.13)	Groove Depth	Nominal Plate, Pipe or Tubing Plate Thickness, in. (mm) Min	Max
1/8 ≤ T ≤ 3/8 (3.2 ≤ T ≤ 9.5)	3	2	2	2	—	T	1/8 (3.2)	2T
3/8 < T ≤ 1 (9.5 < T ≤ 25.4)	3	2	—	—	4	T	1/8 (3.2)	Unlimited

BASIC REQUIREMENTS

Notes:
1. One test plate, pipe or tubing per position shall be required. See Figures 4.10 or 4.11 for test plate. Use the production PJP groove detail for qualification. All plates, pipes or tubing shall be visually inspected (see 4.8.1)
2. If a partial joint penetration bevel- or J-groove weld is to be used for T-joints or double-bevel- or double-J-groove weld is to be used for corner joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate a T-joint configuration.
3. See the pipe diameter qualification requirements of Table 4.2.
4. Any PJP qualification shall also qualify any fillet weld size on any thickness.

Table 4.4
Number and Type of Test Specimens and Range of Thickness Qualified— WPS Qualification; Fillet Welds (see 4.11.1)

Test Specimen	Fillet Size	Number of Welds per WPS	Test Specimens Required[2] Macroetch 4.11.1 4.8.4	All-Weld-Metal Tension (see Figure 4.18)	Side Bend (see Figure 4.13)	Sizes Qualified Plate/Pipe Thickness[1]	Fillet Size
Plate T-test (Figure 4.19)	Single pass, max size to be used in construction	1 in each position to be used	3 faces	—	—	Unlimited	Max tested single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used	3 faces	—	—	Unlimited	Max tested multiple pass and larger
Pipe T-test[3] (Figure 4.20)	Single pass, max size to be used in construction	1 in each position to be used (see Table 4.1)	3 faces (except for 4F & 5F, 4 faces req'd)	—	—	Unlimited	Max tested single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used (see Table 4.1)	3 faces (except for 4F & 5F, 4 faces req'd)	—	—	Unlimited	Min tested multiple pass and larger
Groove test[4] (Figure 4.23)	—	1 in 1G position	—	1	2	Qualifies welding consumables to be used in T-test above	

Notes:
1. The minimum thickness qualified is 1/8 in. (3.2 mm).
2. All welded test pipes and plates shall be visually inspected per 4.8.1
3. See Table 4.2(2) for pipe diameter qualification.
4. When the welding consumables used do not conform to the prequalified provisions of section 3, and a WPS using the proposed welding consumables has not been established by the contractor in accordance with either 4.9 or 4.10.1, a complete joint penetration groove weld test plate shall be welded in accordance with 4.9.

Table 4.5
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (see 4.7.1)

Essential Variable Changes to PQR Requiring Requalification	Process[1]				
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Gas Tungsten Arc Welding (GTAW)
Filler Metal					
1) Increase in filler metal classification strength	X		X	X	
2) Change from low hydrogen to non-low-hydrogen SMAW electrode	X				
3) Change from one electrode or flux-electrode classification to any other electrode or flux-electrode classification		X (Note 2)		X	X
4) Change to an electrode or flux-electrode classification not covered in:	ANSI/AWS A5.1 or A5.5	ANSI/AWS A5.17 or A5.23	ANSI/AWS A5.18 or A5.28	ANSI/AWS A5.20 or A5.29	ANSI/AWS A5.18 or A5.28
5) Addition or deletion of filler metal					X
6) Change from cold wire feed to hot wire feed or vice versa					X
7) Addition or deletion of supplemental powdered or granular filler metal or cut wire		X			
8) Increase in the amount of supplemental powdered or granular filler metal or wire		X			
9) If the alloy content of the weld metal is largely dependent on supplemental powdered filler metal, any WPS change that results in a weld deposit with the important alloying elements not meeting the WPS chemical composition requirements		X			
Electrode					
10) Change in nominal electrode diameter by:	> 1/32 in. increase	Any increase (Note 3)	Any increase or decrease	Any increase	> 1/16 in. increase or decrease
11) Change in number of electrodes		X	X	X	
12) Change in tungsten electrode type as shown in ANSI/AWS A5.12					X
Electrical Parameters					
13) A change in the amperage for each diameter used by:	To a value not recommended by manufacturer	> 10% increase or decrease	> 10% increase or decrease	> 10% increase or decrease	> 25% increase or decrease
14) A change in type of current (ac or dc) or polarity and mode of transfer (GMAW only)		Only when using an alloy flux or quenched and tempered material	X	X	
15) A change in the voltage for each diameter used by:	To a value not recommended by the electrode manufacturer	> 7% increase or decrease	> 7% increase or decrease	> 7% increase or decrease	> 25% increase or decrease

(continued)

Table 4.5 (Continued)

Essential Variable Changes to PQR Requiring Requalification	Process[1]				
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Gas Tungsten Arc Welding (GTAW)
Electrical Parameters (cont'd)					
16) An increase or decrease in the wire feed speed for each electrode diameter (if not amperage controlled) by:		> 10%	> 10%	> 10%	
17) A change in the travel speed (unless heat input control is required) by:		> 15% increase or decrease	> 25% increase or decrease (Note 4)	> 25% increase or decrease (Note 4)	> 50% increase or decrease
18) An increase in heat input (Note 5) by:	> 10%	> 10%	> 10%	> 10%	Any (when Charpy impact tests are required)
Shielding Gas					
19) A change in shielding gas from a single gas to any other single gas or mixture of gas, or in the specified nominal percentage composition of a gas mixture, or to no gas			X	X	X
20) A change in total gas flow rate by:			≥ 25% increase; ≥ 10% decrease	≥ 20% increase; ≥ 10% decrease	≥ 50% increase; ≥ 20% decrease
21) A change to a shielding gas not covered in:			ANSI/AWS A5.18 or A5.28	ANSI/AWS A5.20 or A5.29	
SAW Parameters					
22) A change of > 10%, or 1/8 in., whichever is greater, in the longitudinal spacing of the arcs		X			
23) A change of > 10%, or 1/8 in., whichever is greater, in the lateral spacing of the arcs		X			
24) An increase or decrease of more than 10° in the angular orientation of any parallel electrode		X			
25) For machine or automatic SAW; an increase or decrease of more than 3° in the angle of the electrode		X			
26) For machine or automatic SAW, an increase or decrease of more than 5° normal to the direction of travel		X			
General					
27) For the PQR groove area, an increase or decrease > 25% in the number of passes (Note 6)	X	X	X	X	X
28) A change in position not qualified by Table 4.1	X	X	X	X	X
29) A change in diameter, or thickness, or both, not qualified by Table 4.2	X	X	X	X	X
30) A change in base metal or combination of base metals not listed on the PQR or qualified by Table 4.7	X	X	X	X	X

(continued)

Table 4.5 (Continued)

Essential Variable Changes to PQR Requiring Requalification	Process[1]				
	Shielded Metal Arc Welding (SMAW)	Submerged Arc Welding (SAW)	Gas Metal Arc Welding (GMAW)	Flux Cored Arc Welding (FCAW)	Gas Tungsten Arc Welding (GTAW)
General (cont'd)					
31) Vertical Welding: For any pass from uphill to downhill or vice versa	X		X	X	X
32) A change in groove type (e.g., single-V to double-V). Qualification of any CJP groove weld qualifies for any groove detail complying with the requirements of 3.12 or 3.13	X	X	X	X	X
33) A change in the type of groove to a square groove and vice versa	X	X	X	X	X
34) A change exceeding the tolerances of 3.12, 3.13, 3.13.4, 5.22.4.1, or 5.22.4.2 involving: a) A decrease in the groove angle b) A decrease in the root opening c) An increase in the root face	X	X	X	X	X
35) The omission, but not inclusion, of backing or backgouging	X	X	X	X	X
36) Decrease from preheat temperature (Note 7) by:	> 25°F (13.9°C)	> 25°F (13.9°C)	> 25°F (13.9°C)	> 25°F (13.9°C)	> 100°F (55°C)
37) Increase from interpass temperature (Note 7) by:					> 100°F (55°C) if Charpy's required
38) Decrease from interpass temperature (Note 7) by:	> 25°F (13.9°C)	> 25°F (13.9°C)	> 25°F (13.9°C)	> 25°F (13.9°C)	> 100°F (55°C)
39) Addition or deletion of post weld heat treatment	X	X	X	X	X

Notes:
1. An "x" indicates applicability for the process; a shaded block indicates nonapplicability.
2. A change decreasing filler metal strength level is permitted without WPS requalification.
3. For WPSs using alloy flux, any increase or decrease in the electrode diameter shall require WPS requalification.
4. Travel speed ranges for all sizes of fillet welds may be determined by the largest single pass fillet weld and the smallest multiple-pass fillet weld qualification tests.
5. These essential variables apply only when heat input control is a contract document requirement. Heat input in joules per inch shall be calculated as 60EI/V where:
   E = PQR voltage
   I = PQR amperage
   V = PQR travel speed
6. If the production weld groove area differs from that of the PQR groove area, it is permissible to change the number of PQR passes in proportion to the area without requiring WPS requalification.
7. The production welding preheat or interpass temperature may be less than the PQR preheat or interpass temperature provided that the provisions of 5.6 and Table 3.2 are met, and the base metal temperature shall not be less than the PQR temperature at the time of subsequent welding.

Table 4.6
PQR Essential Variable Changes Requiring WPS Requalification for Electroslag or Electrogas Welding (see 4.7.2)

Essential Variable Changes to PQR Requiring Requalification	Requalification[1] by WPS Test	Requalification[1] by Radiographic or Ultrasonic Test[2]
Filler Metal		
1) A "significant" change in filler metal or consumable guide metal composition	X	
Molding Shoes (fixed or movable)		
2) A change from metallic to nonmetallic or vice versa		X
3) A change from fusing to nonfusing or vice versa		X
4) A reduction in any cross-sectional dimension or area of a solid nonfusing shoe > 25%		X
5) A change in design from nonfusing solid to water cooled or vice versa	X	
Filler Metal Oscillation		
6) A change in oscillation traverse speed > 10 ipm (4.2 mm/s)		X
7) A change in oscillation traverse dwell time > 2 seconds (except as necessary to compensate for joint opening variations)		X
8) A change in oscillation traverse length which affects by more than 1/8 in. (3 mm), the proximity of filler metal to the molding shoes		X
Filler Metal Supplements		
9) A change in consumable guide metal core cross-sectional area > 30%	X	
10) A change in the flux system, i.e., cored, magnetic electrode, external, etc.	X	
11) A change in flux composition including consumable guide coating	X	
12) A change in flux burden > 30%		X
Electrode/Filler Metal Diameter		
13) Increase or decrease in electrode diameter > 1/32 in. (0.8 mm)		X
14) A change in the number of electrodes used	X	
Electrode Amperage		
15) An increase or decrease in the amperage > 20%	X	
16) A change in type of current (ac or dc) or polarity		X
Electrode Arc Voltage		
17) An increase or decrease in the voltage > 10%		X
Process Characteristics		
18) A change to a combination with any other welding process	X	
19) A change from single pass to multi-pass and vice versa	X	
20) A change from constant current to constant voltage and vice versa		X
Wire Feed Speed		
21) An increase or decrease in the wire feed speed > 40%	X	
Travel Speed		
22) An increase or decrease in the travel speed (if not an automatic function of arc length or deposition rate) > 20% (except as necessary to compensate for variation in joint opening)		X

(continued)

Table 4.6 (Continued)

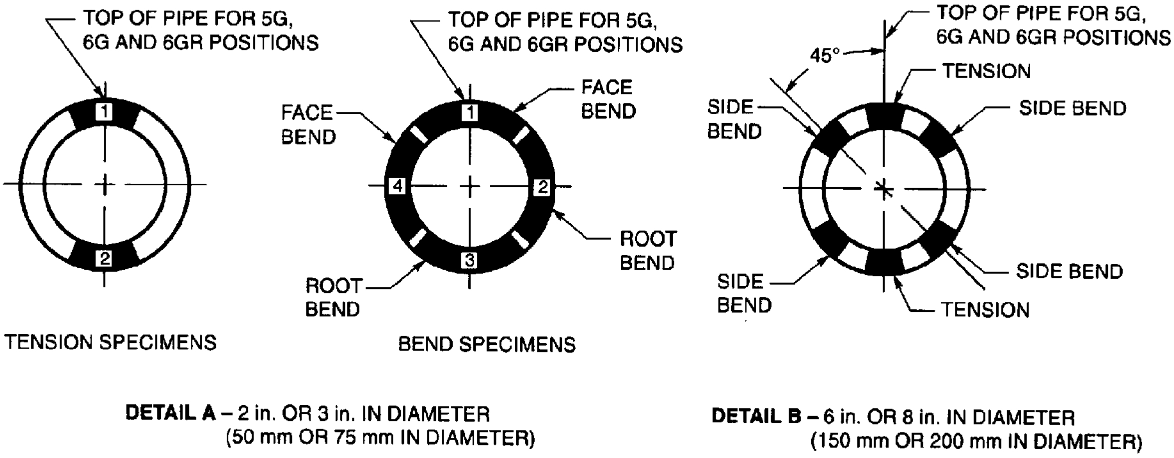
Essential Variable Changes to PQR Requiring Requalification	Requalification[1] by WPS Test	Requalification[1] by Radiographic or Ultrasonic Test[2]
Electrode Shielding (EGW only)		
23) A change in shielding gas composition of any one constituent > 5% of total flow	X	
24) An increase or decrease in the total shielding flow rate > 25%		X
Welding Position		
25) A change in vertical position by > 10°		X
Groove Type		
26) An increase in cross-sectional area (for nonsquare grooves)	X	
27) A decrease in cross-sectional area (for nonsquare grooves)		X
28) A change in PQR joint thickness, T outside limits of 0.5T–1.1T	X	
29) An increase or decrease > 1/4 in. (6 mm) in square groove root opening		X
Postweld Heat Treatment		
30) A change in postweld heat treatment	X	

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

Table 4.7
Table 3.1 and Annex M Steels Qualified by PQR Steels (see 4.7.3)

PQR Base Metal[1]	WPS Base Metal Group Combinations Permitted by PQR
Any Group I Steel to Any Group I Steel	Any Group I Steel to Any Group I Steel
Any Group II Steel to Any Group II Steel	Any Group I Steel to Any Group I Steel Any Group II Steel to Any Group I Steel Any Group II Steel to Any Group II Steel
Any Specific Group III or Annex M Steel to Any Group I Steel	The Specific PQR Group III or Annex M Steel Tested to Any Group I Steel
Any Specific Group III or Annex M Steel to Any Group II Steel	The Specific PQR Group III or Annex M Steel Tested to Any Group I or Group II Steel
Any Group III Steel to the Same or Any Other Group III Steel or Any Annex M Steel to the Same or Any Other Annex M Steel	Steels shall be of the same material specification, grade/type and minimum yield strength as the Steels listed in the PQR[2]
Any Combination of Group III and Annex M Steels	Only the Specific Combination of Steels listed in the PQR[2]
Any Unlisted Steel to Any Steel Listed in Table 3.1 or Annex M	Only the Specific Combination of Steels listed in the PQR

Notes:
1. Groups I through III are found in Table 3.1.
2. Reduction in yield strength with increased metal thickness where permitted by the steel specification.



NOTE: DUPLICATE TEST PIPES OR TUBES OR LARGER JOB SIZE PIPE MAY BE REQUIRED WHEN IMPACT TESTING IS SPECIFIED ON CONTRACT OR SPECIFICATIONS.

Figure 4.7—Location of Test Specimens on Welded Test Pipe (see 4.8)

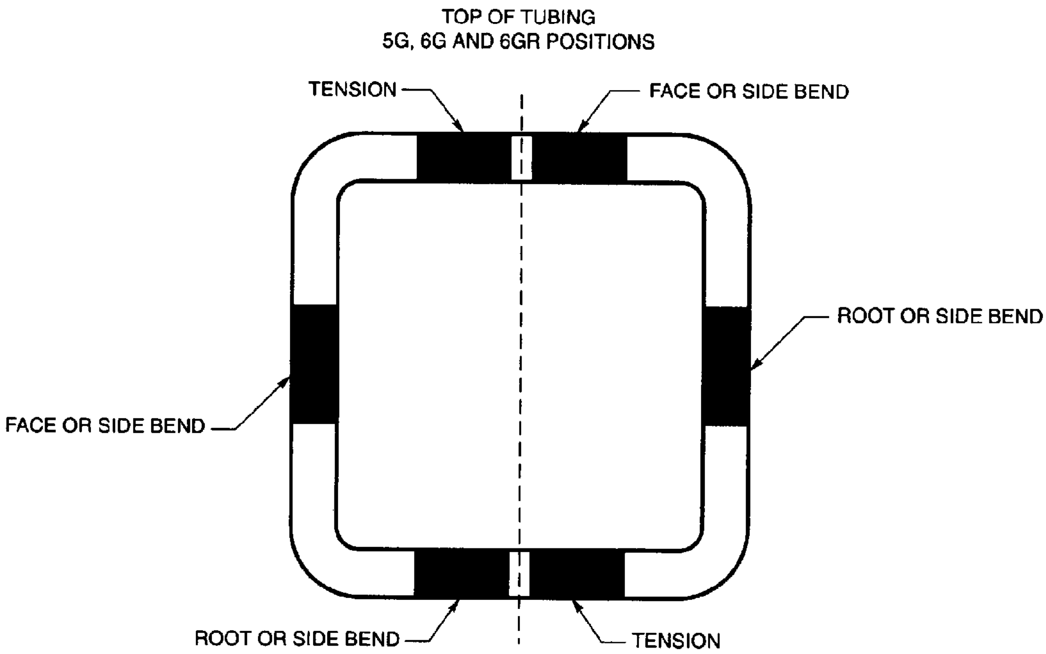
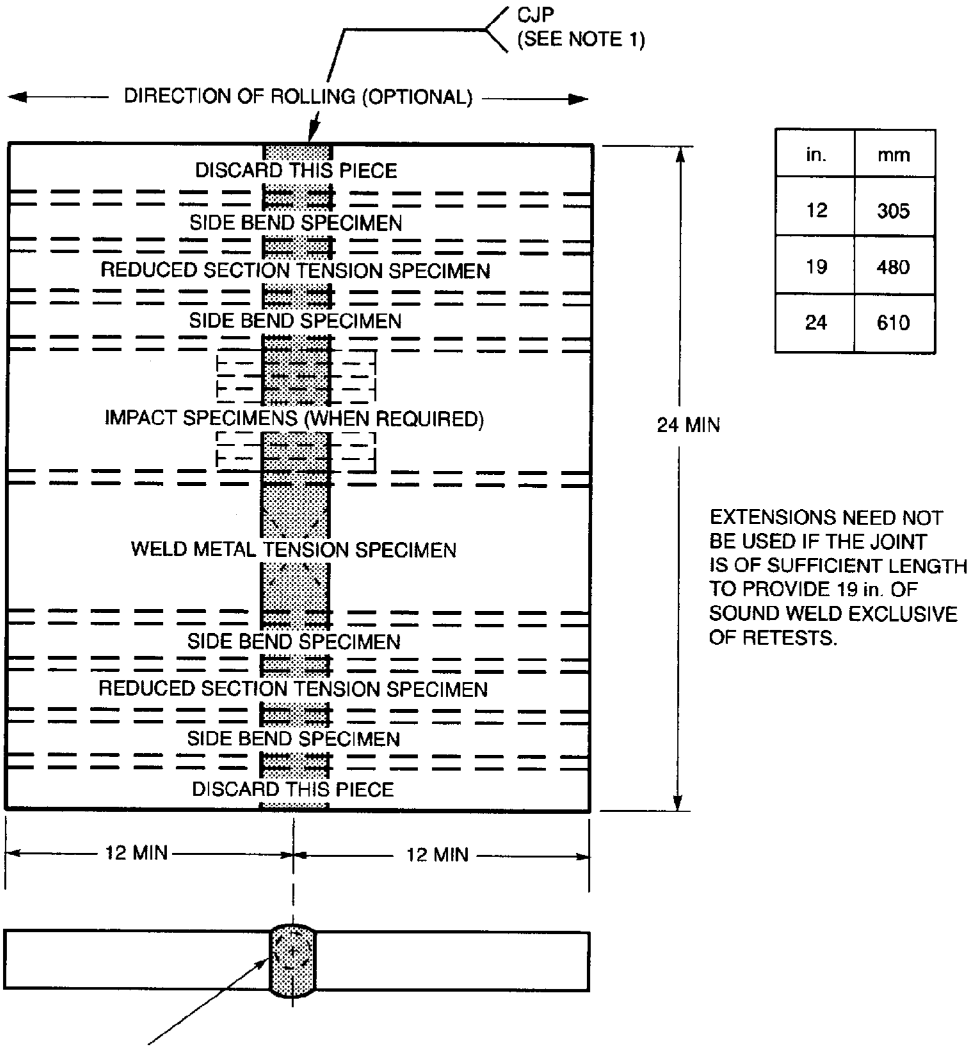


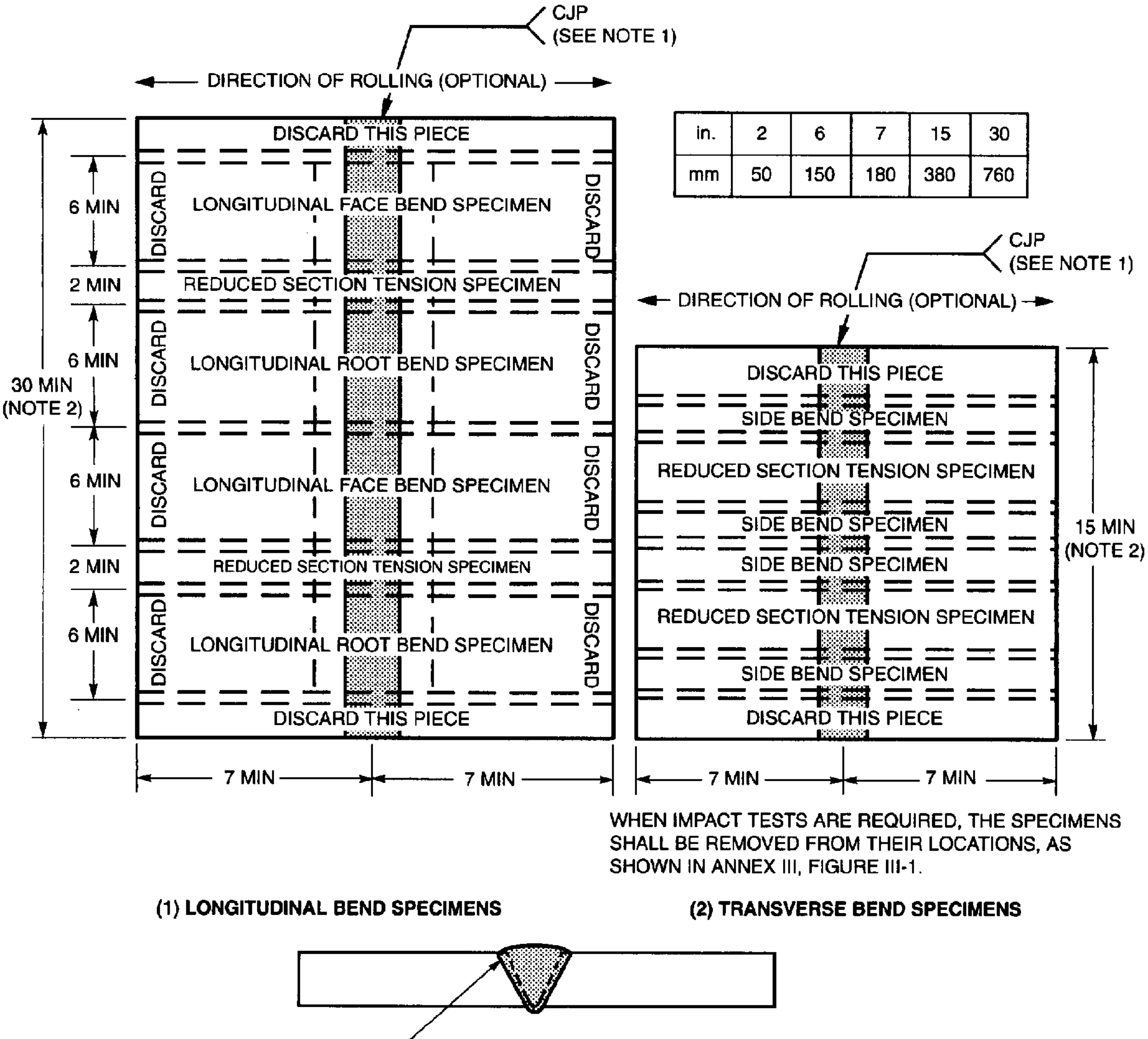
Figure 4.8—Location of Test Specimens for Welded Box Tubing (see 4.8)



in.	mm
12	305
19	480
24	610

NOTES:
1. THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE TESTED SHALL CONFORM TO THE PRODUCTION GROOVE SHAPE THAT IS BEING QUALIFIED.
2. WHEN IMPACT SPECIMENS ARE REQUIRED, SEE ANNEX III FOR REQUIREMENTS.

Figure 4.9—Location of Test Specimens on Welded Test Plates—Electroslag and Electrogas Welding—WPS Qualification (see 4.8)

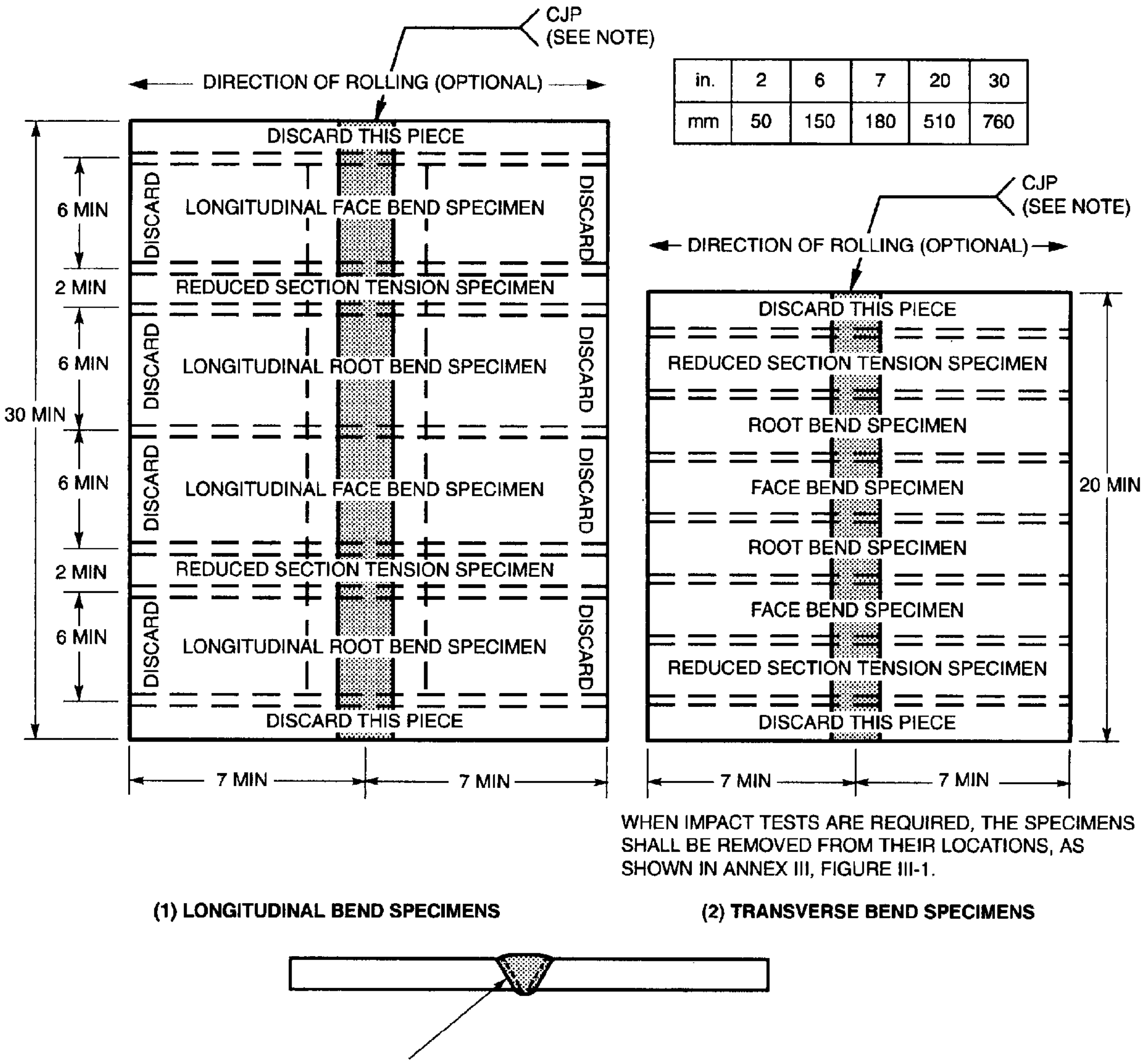


in.	2	6	7	15	30
mm	50	150	180	380	760

NOTES:
1. THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE TESTED SHALL CONFORM TO THE PRODUCTION GROOVE SHAPE THAT IS BEING QUALIFIED.
2. LONGER TEST PLATES MAY BE REQUIRED WHEN IMPACT TESTING ON CONTRACT DOCUMENTS OR IN SPECIFICATIONS. IMPACT SPECIMENS SHOULD BE REMOVED AT MID-LENGTH OF THE TEST WELD.

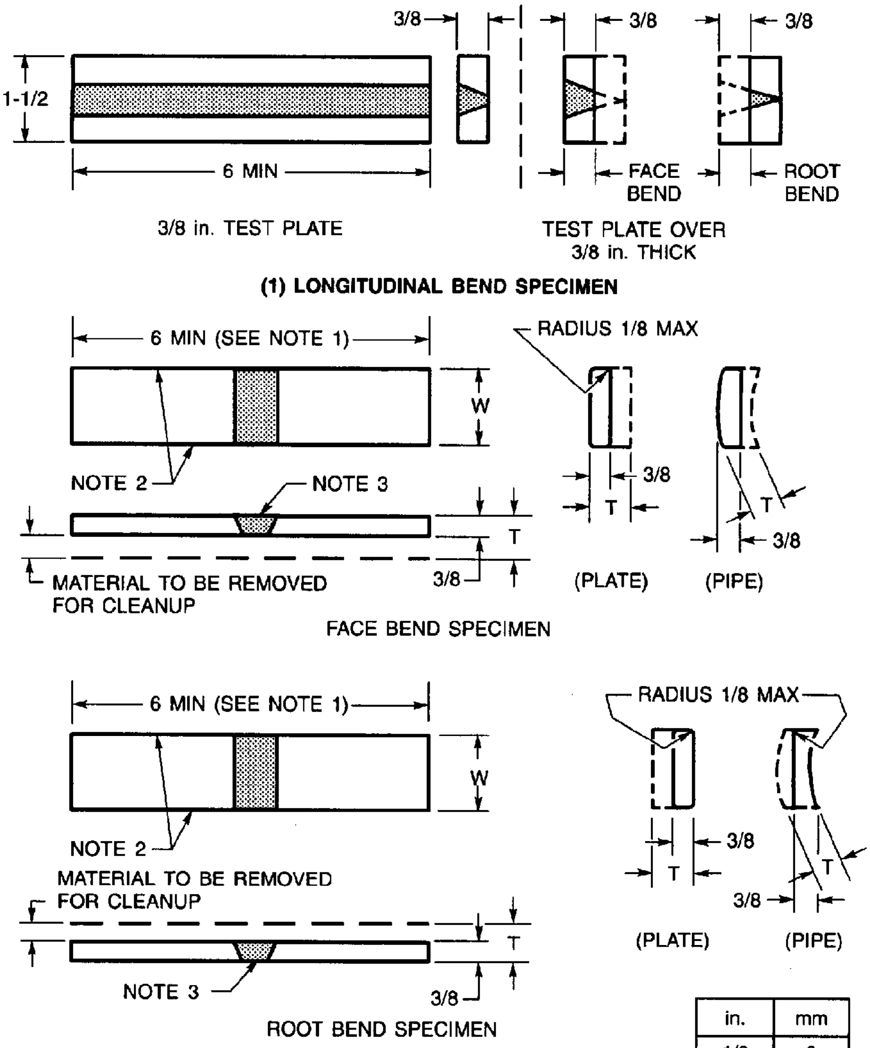
Figure 4.10—Location of Test Specimens on Welded Test Plate Over 3/8 in. (9.5 mm) Thick—WPS Qualification (see 4.8)

in.	2	6	7	20	30
mm	50	150	180	510	760



NOTE: THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE TESTED SHALL CONFORM TO THE PRODUCTION GROOVE SHAPE THAT IS BEING QUALIFIED.

Figure 4.11—Location of Test Specimens on Welded Test Plate 3/8 in. (9.5 mm) Thick and Under—WPS Qualification (see 4.8)



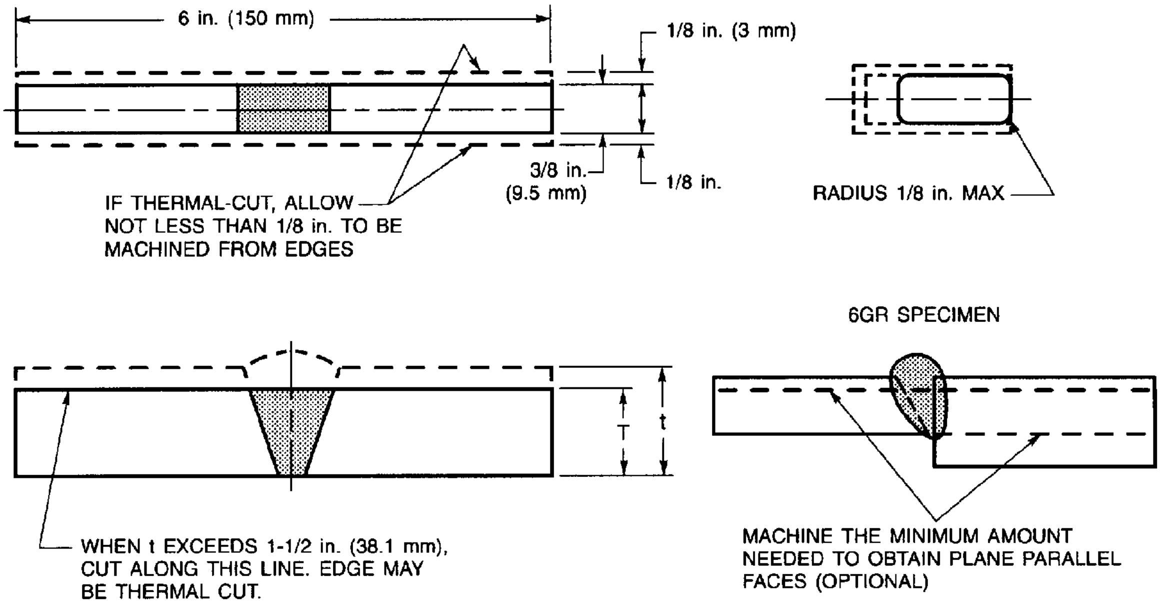
(2) TRANSVERSE BEND SPECIMEN

Dimensions	
Test weldment	Test specimen width, in. (W)
Plate	1-1/2
Test pipe or tube ≤ 4 in. (100 mm) in diameter	1
Test pipe or tube > 4 in. (100 mm) in diameter	1-1/2

in.	mm
1/8	3
3/8	10
1	25
1-1/2	38
2	50
3	75
6	150
8	200

Notes:
1. A longer specimen length may be necessary when using a wraparound type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. These edges may be thermal-cut and may or may not be machined.
3. The weld reinforcement and backing, if any, shall be removed flush with the surface of the specimen (see 5.24.4.1 and 5.24.4.2). If a recessed backing is used, this surface may be machined to a depth not exceeding the depth of the recess to remove the backing; in such a case, the thickness of the finished specimen shall be that specified above. Cut surfaces shall be smooth and parallel.
4. T = plate or pipe thickness.
5. When the thickness of the test plate is less than 3/8 in. (9.5 mm), use the nominal thickness for face and root bends.

Figure 4.12—Face and Root Bend Specimens (see 4.8.3.1)



t, in.	T, in.
3/8 to 1-1/2	t
> 1-1/2	See Note 2

t, mm	T, mm
9.5 to 38.1	t
> 38.1	See Note 2

Notes:
1. A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. For plates over 1-1/2 in. (38.1 mm) thick, cut the specimen into approximately equal strips with T between 3/4 in. (19.0 mm) and 1-1/2 in. and test each strip.
3. t = plate or pipe thickness.

Figure 4.13—Side Bend Specimens (see 4.8.3.1)

the bent portion of the specimen after testing. When using the wraparound jig, the specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation. The weld and heat-affected zones shall be completely in the bent portion of the specimen after testing. Test specimens shall be removed from the jig when the outer roll has been moved 180° from the starting point.

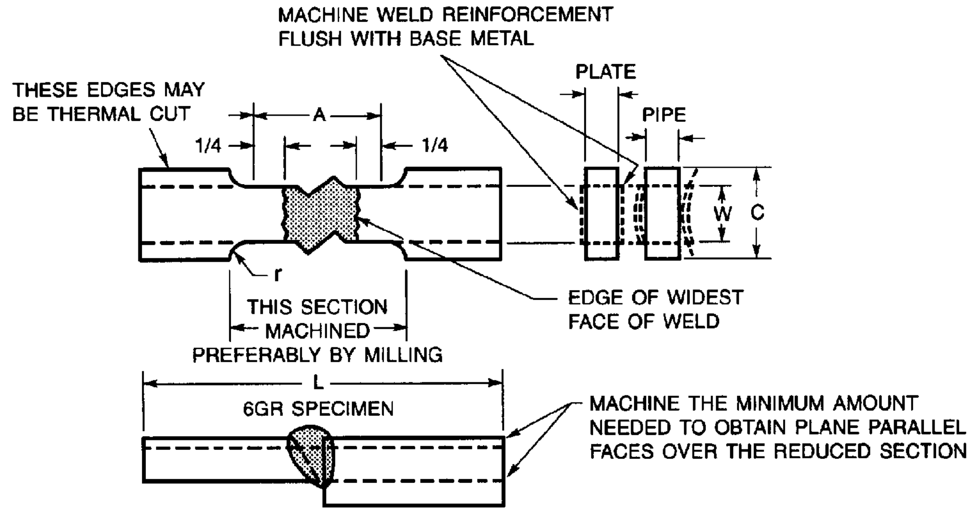
4.8.3.2 Longitudinal Bend Specimens. When material combinations differ markedly in mechanical bending properties, as between two base materials or between the weld metal and the base metal, longitudinal bend tests (face and root) may be used in lieu of the transverse face and root bend tests. The welded test assemblies conforming to 4.8.2 shall have test specimens prepared by cutting the test plate as shown in Figures 4.10 or 4.11, whichever is applicable. The test specimens for the longitudinal bend test shall be prepared for testing as shown in Figure 4.12.

4.8.3.3 Acceptance Criteria for Bend Tests. The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

(1) 1/8 in. (3 mm) measured in any direction on the surface

(2) 3/8 in. (10 mm)—the sum of the greatest dimensions of all discontinuities exceeding 1/32 in. (1 mm), but less than or equal to 1/8 in. (3 mm)

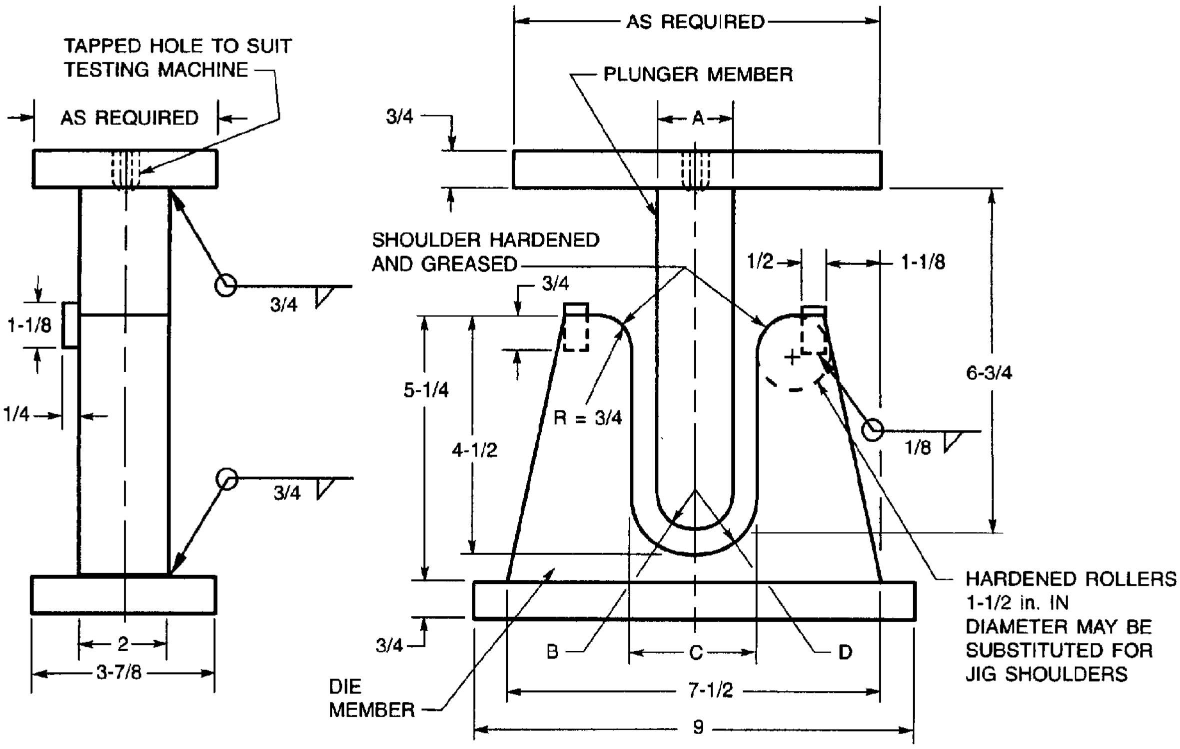
(3) 1/4 in. (6 mm)—the maximum corner crack, except when that corner crack resulted from visible slag inclusion or other fusion type discontinuities, then the 1/8 in. (3 mm) maximum shall apply



Dimensions in inches					
	Test plate			Test Pipe	
	Tp ≤ 1 in.	1 < Tp < 1-1/2 in.	Tp ≥ 1-1/2 in.	2 in. & 3 in. diameter	6 in. & 8 in. diameter or larger job size pipe
A—Length of reduced section	Widest face of weld + 1/2 in., 2-1/4 min			Widest face of weld + 1/2 in., 2-1/4 min	
L—Overall length, min (Note 2)	As required by testing equipment			As required by testing equipment	
W—Width of reduced section (Notes 3, 4)	3/4 in. min	3/4 in. min	3/4 in. min	1/2 ± 0.01	3/4 in. min
C—Width of grip section (Notes 4, 5)	W + 1/2 in. min	W + 1/2 in. min	W + 1/2 in. min	W + 1/2 in. min	W + 1/2 in. min
t—Specimen thickness (Notes 6, 7)	Tp	Tp	Tp/n (Note 7)	Maximum possible with plane parallel faces within length A	
r—Radius of fillet, min	1/2	1/2	1/2	1	1

Notes:
1. Tp = Nominal Thickness of the Plate.
2. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The ends of the reduced section shall not differ in width by more than 0.004 in. Also, there may be a gradual decrease in width from the ends to the center, but the width of either end shall not be more than 0.015 in. larger than the width at the center.
4. Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
5. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in.
6. The dimension t is the thickness of the specimen as provided for in the applicable material specifications. The minimum nominal thickness of 1-1/2 in. wide specimens shall be 3/16 in. except as permitted by the product specification.
7. For plates over 1-1/2 in. thick, specimens may be cut into approximately equal strips. Each strip shall be at least 3/4 in. thick. The test results of each strip shall meet the minimum requirements.
8. Due to limited capacity of some tensile testing machines, the specimen dimensions for Annex M steels may be as agreed upon by the Engineer and the Fabricator.

Figure 4.14—Reduced-Section Tension Specimens (see 4.8.3.4)



specified or actual base metal yield strength, psi	A in.	B in.	C in.	D in.
50 000 & under	1-1/2	3/4	2-3/8	1-3/16
over 50 000 to 90 000	2	1	2-7/8	1-7/16
90 000 & over	2-1/2	1-1/4	3-3/8	1-11/16

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

Figure 4.15—Guided Bend Test Jig (see 4.8.3)

Specimens with corner cracks exceeding 1/4 in. (6 mm) with no evidence of slag inclusions or other fusion type discontinuities shall be disregarded, and a replacement test specimen from the original weldment shall be tested.

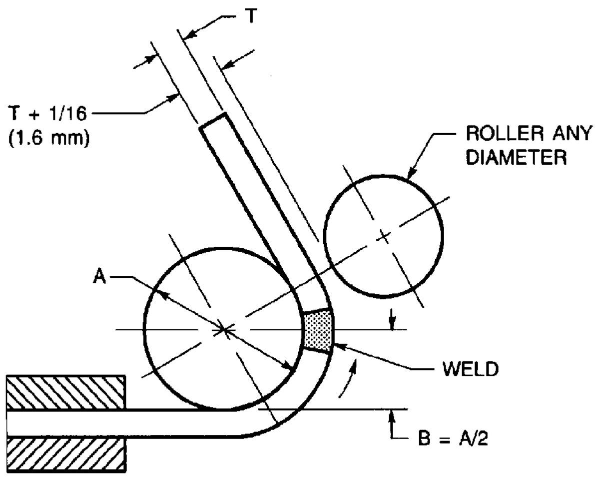
4.8.3.4 Reduced-Section Tension Specimens (See Figure 4.14). Before testing, the least width and corresponding thickness of the reduced section shall be measured. The specimen shall be ruptured under tensile load, and the maximum load shall be determined. The cross-sectional area shall be obtained by multiplying the width by the thickness. The tensile strength shall be obtained by dividing the maximum load by the cross-sectional area.

4.8.3.5 Acceptance Criteria for Reduced-Section Tension Test. The tensile strength shall be no less than the minimum of the specified tensile range of the base metal used.

4.8.3.6 All-Weld-Metal Tension Specimen (See Figure 4.18). The test specimen shall be tested in accordance with ASTM A370, *Mechanical Testing of Steel Products*.

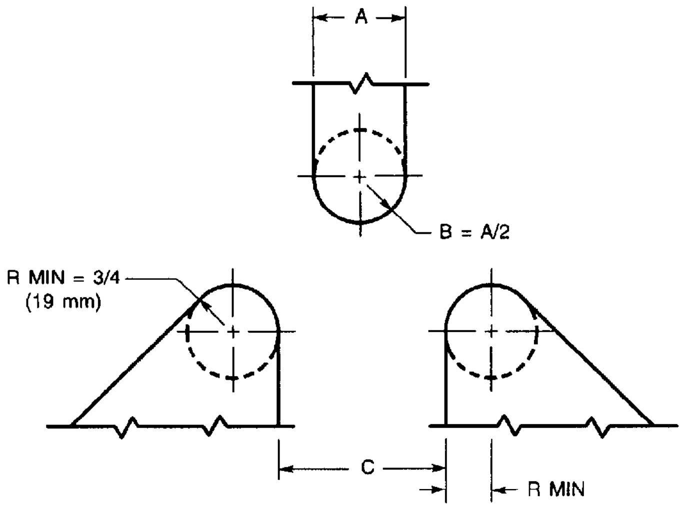
4.8.4 Macroetch Test. The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used for etching to give a clear definition of the weld.

4.8.4.1 Acceptance Criteria for Macroetch Test. For acceptable qualification, the test specimen, when inspected visually, shall conform to the following requirements:



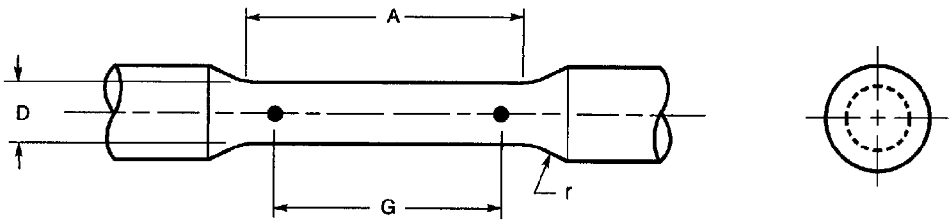
specified or actual base metal yield strength, psi (MPa)	A in.	B in.	A mm	B mm
50 000 (345) & under	1-1/2	3/4	38	19
over 50 000 to 90 000 (620)	2	1	50	25
90 000 & over	2-1/2	1-1/4	65	32

Figure 4.16—Alternative Wraparound Guided Bend Test Jig (see 4.8.3)



specified or actual base metal yield strength, psi (MPa)	A in.	B in.	C in.	A mm	B mm	C mm
50 000 (345) & under	1-1/2	3/4	2-3/8	38	19	60
over 50 000 to 90 000 (620)	2	1	2-7/8	50	25	73
90 000 & over	2-1/2	1-1/4	3-3/8	65	32	86

Figure 4.17—Alternative Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen (see 4.8.3)



Dimensions in inches			
	Standard specimen	Small-size specimens proportional to standard	
Nominal diameter	0.500 in. round	0.350 in. round	0.250 in. round
G—Gage length	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005
D—Diameter (Note 1)	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005
r—Radius of fillet, min	3/8	1/4	3/16
A—Length of reduced section (Note 2), min	2-1/4	1-3/4	1-1/4

Dimensions (metric version per ASTM E 8M)			
	Standard specimen	Small-size specimens proportional to standard	
Nominal diameter	12.5 mm round	9 mm round	6 mm round
G—Gage length	62.5 ± 0.1	45.0 ± 0.1	30.0 ± 0.1
D—Diameter (Note 1), mm	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1
r—Radius of fillet, mm, min	10	8	6
A—Length of reduced section, mm (Note 2), min	75	54	36

Notes:
1. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than one percent larger in diameter than the center (controlling dimension).
2. If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should be spaced at the indicated gage length.
3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

Figure 4.18—All-Weld-Metal Tension Specimen (see 4.8.3.6)

(1) Partial joint penetration groove welds; the actual weld size shall be equal to or greater than the specified weld size, (E).

(2) Fillet welds shall have fusion to the root of the joint, but not necessarily beyond.

(3) Minimum leg size shall meet the specified fillet weld size.

(4) The partial joint penetration groove welds and fillet welds shall have the following:

(a) no cracks

(b) thorough fusion between adjacent layers of weld metals and between weld metal and base metal

(c) weld profiles conforming to specified detail, but with none of the variations prohibited in 5.24

(d) no undercut exceeding 1/32 in. (1 mm)

4.8.5 Retest. If any one specimen of all those tested fails to meet the test requirements, two retests for that particular type of test specimen may be performed with specimens cut from the same WPS qualification material. The results of both test specimens must meet the test requirements. For material over 1 1/2 in. (38.1 mm) thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material.

4.9 Complete Joint Penetration (CJP) Groove Welds for Nontubular Connections

See Table 4.2(1) for the requirements for qualifying a WPS of a CJP weld on nontubular connections. See Figures 4.9–4.11 for the appropriate test plate.

4.9.1.1 Corner or T-Joints. Test specimens for groove welds in corner or T-joints shall be butt joints having the same groove configuration as the corner or T-joint to be used on construction, except the depth of groove need not exceed 1 in. (25 mm).

4.10 Partial Joint Penetration (PJP) Groove Welds for Nontubular Connections

4.10.1 Type and Number of Specimens to be Tested. The type and number of specimens that must be tested to qualify a WPS are shown in Table 4.3. A sample weld shall be made using the type of groove design and WPS to be used in construction, except the depth of groove need not exceed 1 in. (25 mm). For the macroetch test required below, any steel of Groups I, II, and III of Table 3.1 may be used to qualify the weld size on any steels or combination of steels in those groups. If the partial joint penetration groove weld is to be used for corner or T-joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate the T-joint configuration. The sample welds shall be tested as follows:

4.10.2 Weld Size Verification by Macroetch. For WPSs which conform in all respects to section 4, three macroetch cross-section specimens shall be prepared to demonstrate that the designated weld size (obtained from the requirements of the WPS) are met.

4.10.3 Verification of Complete Joint Penetration Groove WPS by Macroetch. When a WPS has been qualified for a complete joint penetration groove weld and is applied to the welding conditions of a partial joint penetration groove weld, three macroetch cross-section tests specimens are required to demonstrate that the designated weld size is achieved as a minimum.

4.10.4 Other WPS Verifications by Macroetch. If a WPS is not covered by either 4.10.2 or 4.10.3, or if the welding conditions do not meet a prequalified status, or if these have not been used and tested for a complete joint penetration weld in a butt joint, then a sample joint shall be prepared and the first operation is to make a macroetch test specimen to determine the weld size of the joint. Then, the excess material is machined off on the bottom side of the joint to the thickness of the weld size. Tension and bend test specimens shall be prepared and tests performed, as required for complete joint penetration groove welds (see 4.9).

4.10.5 Flare-Groove Welds. The effective weld sizes for qualified flare-groove welds are determined by the following:

(1) When required by the Engineer, test sections shall be used to verify that the effective weld size is consistently obtained.

(2) For a given set of WPS conditions, if the contractor has demonstrated consistent production of larger effective weld sizes than those shown in Table 2.1, the contractor may establish such larger effective weld sizes by qualification.

(3) Qualification required by (2) shall consist of sectioning the radiused member, normal to its axis, at midlength and ends of the weld. Such sectioning shall be made on a number of combinations of material sizes representative of the range used by the contractor in construction or as required by the Engineer.

4.11 Fillet Weld Qualification Requirements for Tubular and Nontubular Connections

4.11.1 Type and Number of Specimens. The type and number of specimens that must be tested to qualify a fillet weld WPS are shown in Table 4.4.

4.11.2 Fillet Weld Test. A fillet welded T-joint, as shown in Figure 4.19 for plate or Figure 4.20 for pipe (Detail A or Detail B), shall be made for each WPS and position to be used in construction. One test weld shall be the maximum size single-pass fillet weld and one test weld shall be the minimum size multiple-pass fillet weld used in construction. These two fillet weld tests may be combined in a single test weldment or assembly. The weldment shall be cut perpendicular to the direction of welding at locations shown in Figure 4.19 or Figure 4.20 as applicable. Specimens representing one face of each cut shall constitute a macroetch test specimen and shall be tested in accordance with 4.8.4.

4.11.3 Consumables Verification Test. If both the proposed welding consumable and the proposed WPS for welding the fillet weld test plate or test pipe prescribed in 4.11.2 are neither prequalified nor otherwise qualified by section 4, that is:

(1) If the welding consumables used do not conform to the prequalified provisions of section 3, and also

(2) If the WPS using the proposed consumable has not been established by the contractor in accordance with either 4.9 or 4.10, then a complete joint penetration groove weld test plate shall be welded to qualify the proposed combination.

The test plate shall be welded as follows:

(A) The test plate shall have the groove configuration shown in Figure 4.21 (Figure 4.22 for SAW), with steel backing.

(B) The plate shall be welded in the 1G (flat) position.

(C) The plate length shall be adequate to provide the test specimens required and oriented as shown in Figure 4.23.

(D) The welding test conditions of current, voltage, travel speed, and gas flow shall approximate those to be used in making production fillet welds as closely as practical.

These conditions establish the WPS from which, when production fillet welds are made, changes in essential variables will be measured in conformance with 4.7.

The test plate shall be tested as follows:

(a) Two side bend (Figure 4.13) specimens and one all-weld-metal tension (Figure 4.18) test specimen shall be removed from the test plate, as shown in Figure 4.23.

(b) The bend test specimens shall be tested in conformance with 4.8.3.1. Those test results shall conform to the requirements of 4.8.3.3.

(c) The tension test specimen shall be tested in conformance with 4.8.3.6. The test result shall determine the strength level for the welding consumable, which shall conform to the requirements of Table 2.3 or the base metal strength level being welded.

4.12 Complete Joint Penetration (CJP) Groove Welds for Tubular Connections

CJP groove welds shall be classified as follows:

(1) CJP butt joints with backing or backgouging (see 4.12.1).

(2) CJP butt joints without backing welded from one side only (see 4.12.2).

(3) T-, Y-, K-connections with backing or backgouging [see 4.12.3].

(4) T-,Y-, K-connections without backing welded from one side only [see 4.12.4].

4.12.1 Complete Joint Penetration (CJP) Butt Joints with Backing or Backgouging. A WPS with backing or backgouging shall be qualified using the detail shown in Figure 4.24 (with backgouging) or Figure 4.25 (with backing).

4.12.2 Complete Joint Penetration (CJP) Butt Joints without Backing Welded from One Side Only. A WPS without backing welded from one side only shall be qualified using the joint detail shown in Figure 4.24.

4.12.3 T-, Y-, or K-Connections with Backing or Backgouging. A WPS for tubular T-,Y-, or K-connections with backing or backgouging shall be qualified using:

(1) the appropriate nominal pipe OD selected from Table 4.2(2), and

(2) the joint detail of Figure 4.25, or

(3) for nominal pipe ODs equal to or greater than 24 in. (610 mm), a plate qualification in conformance with 4.9 using the joint detail of Figure 4.25.

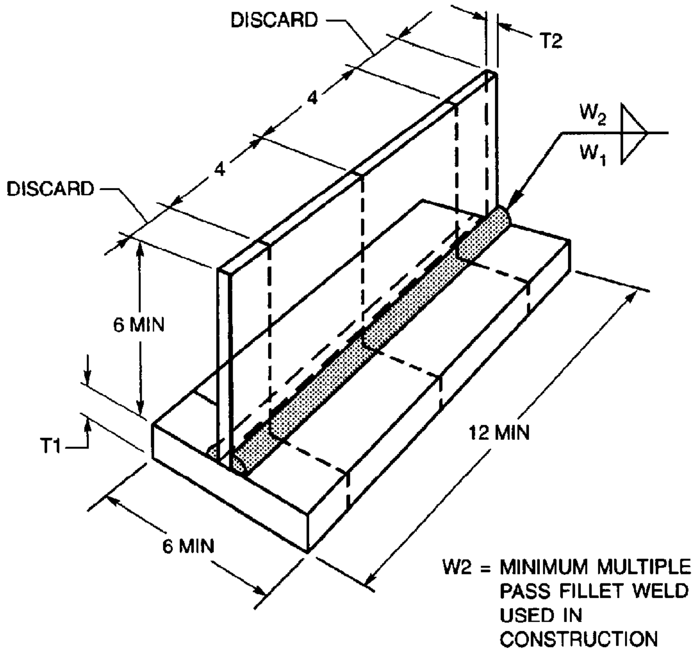
4.12.4 T-, Y-, or K-Connections without Backing Welded from One Side Only. A WPS that conforms to the prequalified requirements of section 3 shall be exempt from qualification testing. When qualification is required, the requirements are as follows:

4.12.4.1 WPSs without Prequalified Status. For a WPS whose essential variables are outside the prequalified range, qualification for complete joint penetration tubular groove welds shall require the following:

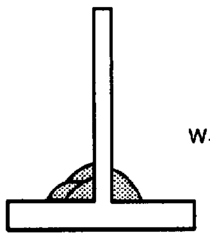
(1) Qualification in conformance with Figure 4.27 for pipes or Figure 4.27 and Figure 4.28 for box tubes.

(2) A Sample Joint or Tubular Mock-up. The sample joint or tubular mock-up shall provide at least one macroetch test section for each of the following conditions:

(a) The groove combining the greatest groove depth with the smallest groove angle, or combination of grooves to be used: test with welding position vertical.



in.	mm
4	100
6	150
12	305



MACROETCH TEST SPECIMEN

INCHES			MILLIMETERS		
Weld size	T1 min*	T2 min*	Weld size	T1 min*	T2 min*
3/16	1/2	3/16	5	12.7	4.8
1/4	3/4	1/4	6	19.0	6.4
5/16	1	5/16	8	25.4	8.0
3/8	1	3/8	10	25.4	9.5
1/2	1	1/2	13	25.4	12.7
5/8	1	5/8	16	25.4	15.9
3/4	1	3/4	19	25.4	19.0
> 3/4	1	1	> 19	25.4	25.4

*Note: Where the maximum plate thickness used in production is less than the value shown in the table, the maximum thickness of the production pieces may be substituted for T1 and T2.

Figure 4.19—Fillet Weld Soundness Tests for WPS Qualification (see 4.11.2)

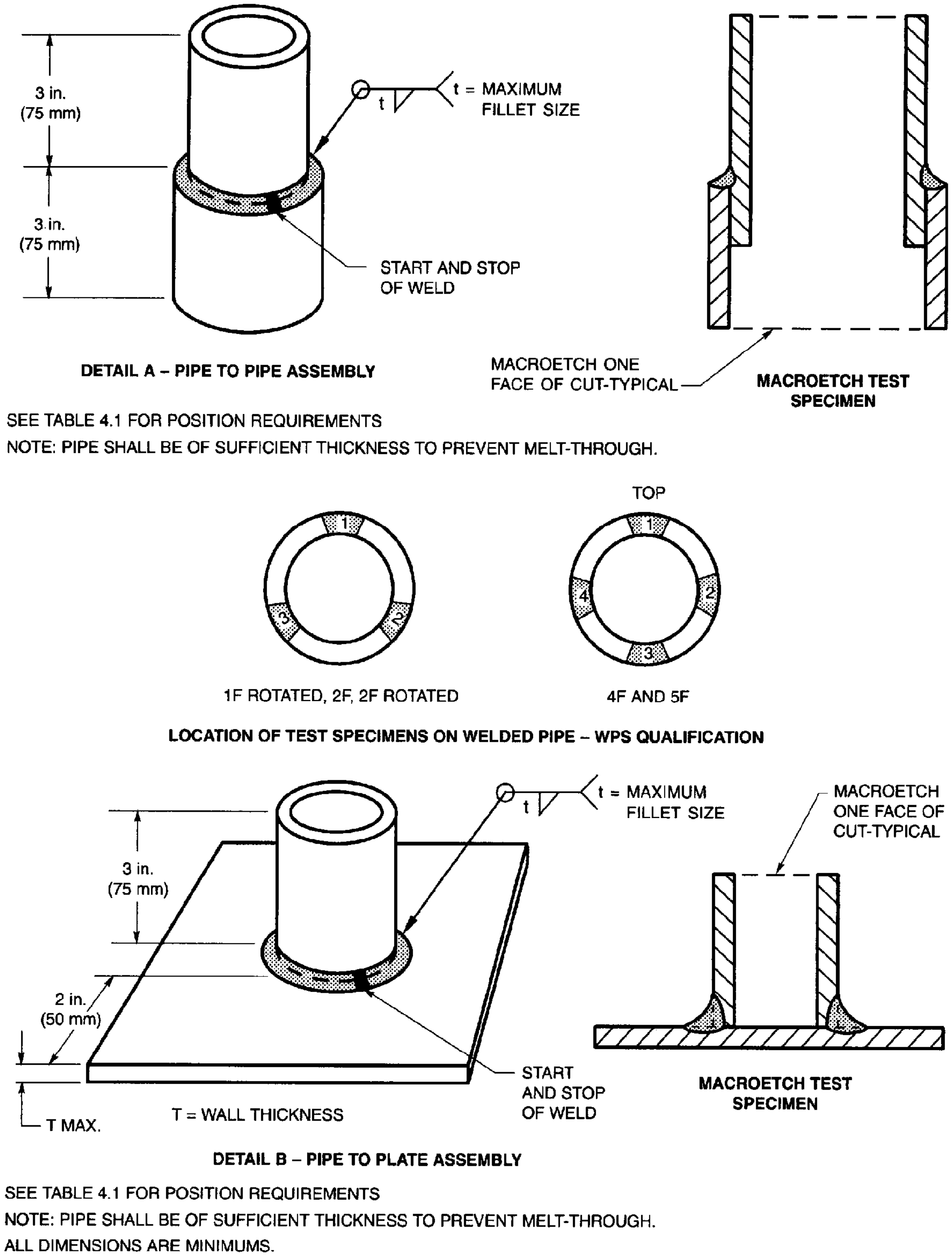
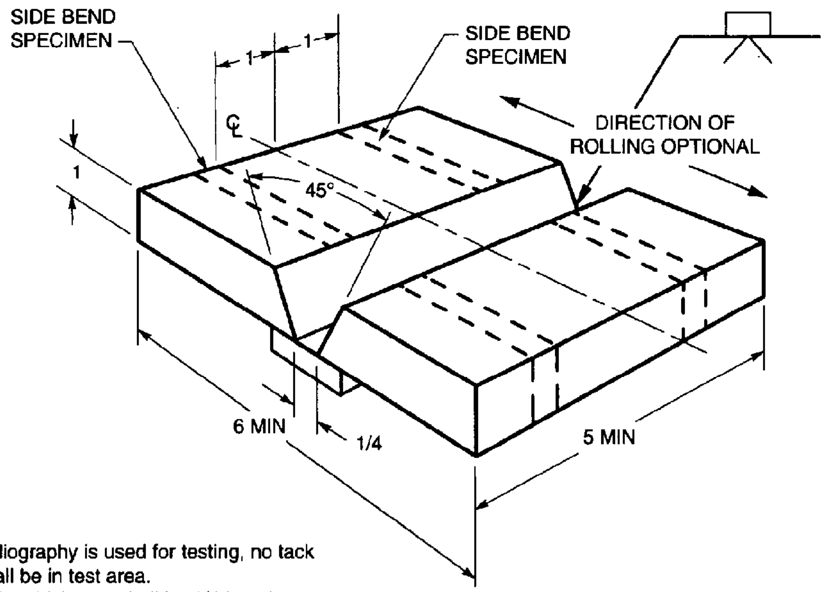


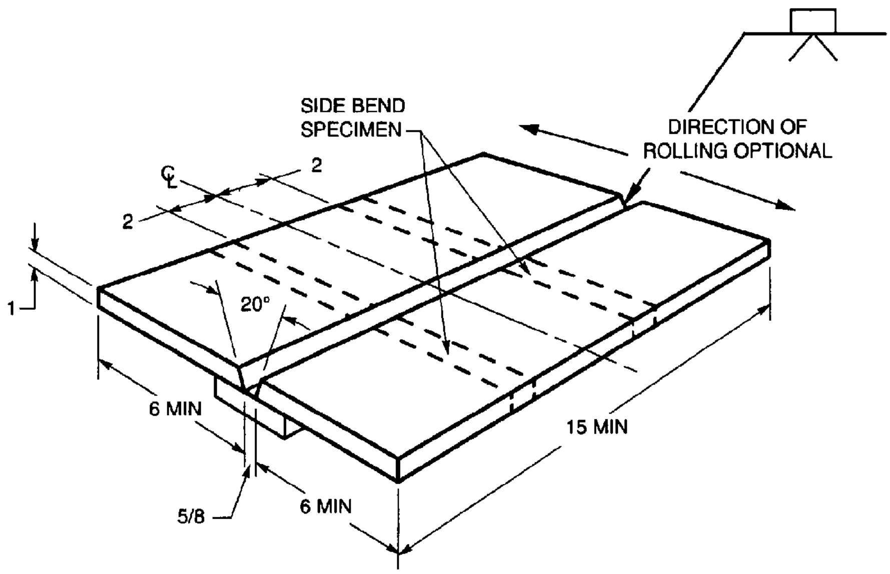
Figure 4.20—Pipe Fillet Weld Soundness Test—WPS Qualification (see 4.11.2)



in.	mm
1/4	6
3/8	10
1	25
3	75
5	125
6	150

Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. min to 3/8 in. max; backing width shall be 3 in. min when not removed for radiography, otherwise 1 in. min.

Figure 4.21—Test Plate for Unlimited Thickness—Welder Qualification (see 4.23.1)



in.	mm
1/2	13
5/8	16
1	25
1-1/2	38
2	50
3	75
6	150
15	380

Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The joint configuration of a qualified WPS may be used in lieu of the groove configuration shown here.
3. The backing thickness shall be 3/8 in. min to 1/2 in. max; backing width shall be 3 in. min when not removed for radiography, otherwise 1-1/2 in. min.

Figure 4.22—Test Plate for Unlimited Thickness—Welding Operator Qualification (see 4.23.2)

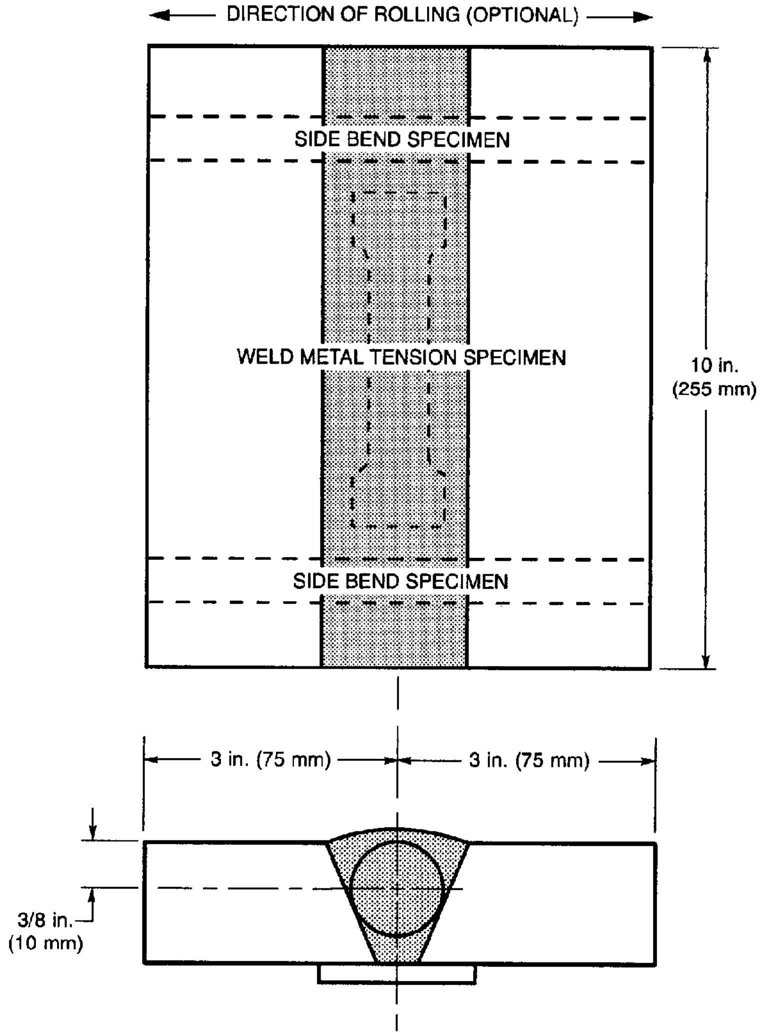


Figure 4.23—Location of Test Specimen on Welded Test Plate 1 in. (25.4 mm) Thick—Consumables Verification for Fillet Weld WPS Qualification (see 4.11.3)

(b) The narrowest root opening to be used with a 37.5° groove angle: one test welded in the flat position and one test welded in the overhead position.

(c) The widest root opening to be used with a 37.5° groove angle: one test to be welded in the flat position and one test to be welded in the overhead position.

(d) for matched box connections only, the minimum groove angle, corner dimension and corner radius to be used in combination: one test in horizontal position.

(3) The macroetch test specimens required in (1) and (2) above shall be examined for discontinuities and shall have:

(a) No cracks

(b) Thorough fusion between adjacent layers of weld metal and between weld metal and base metal

(c) Weld details conforming to the specified detail but with none of the variations prohibited in 5.24.

(d) No undercut exceeding the values permitted in 6.9.

(e) For porosity 1/32 in. (1 mm) or larger, accumulated porosity shall not exceed 1/4 in. (6 mm)

(f) No accumulated slag, the sum of the greatest dimension of which shall not exceed 1/4 in. (6 mm)

Those specimens not conforming to (a) through (f) shall be considered unacceptable; (b) through (f) not applicable to backup weld.

4.12.4.2 Complete Joint Penetration Groove Welds in a T-, Y-, or K-Connection WPS with Dihedral Angles Less than 30°. The sample joint described

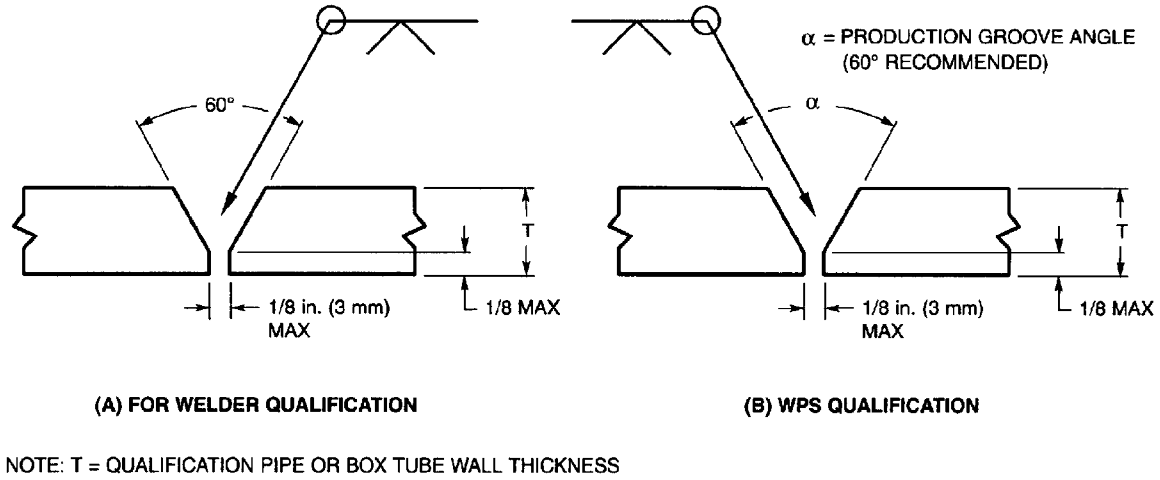


Figure 4.24—Tubular Butt Joint—Welder or WPS Qualification—without Backing (see 4.12.1, 4.12.2, and 4.26)

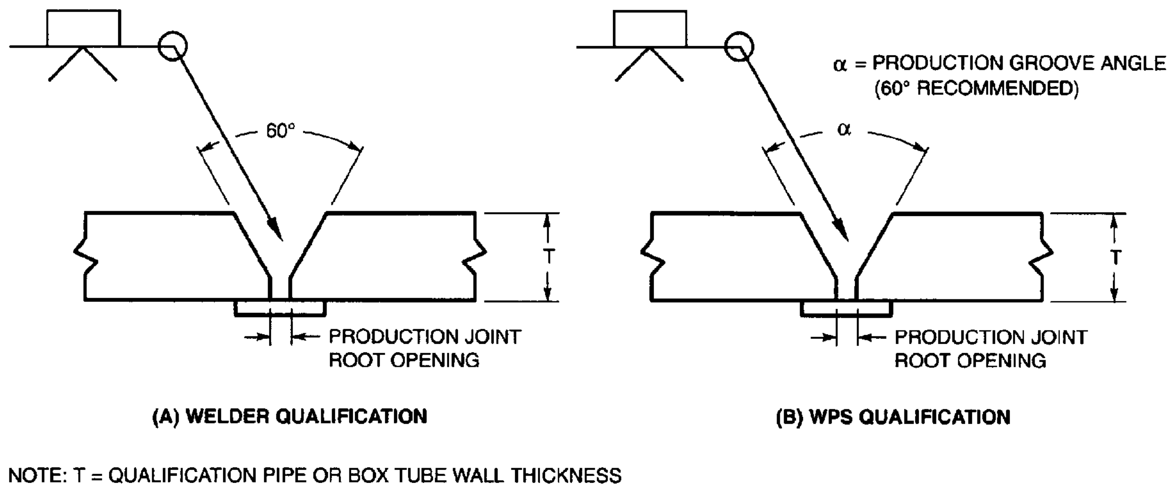


Figure 4.25—Tubular Butt Joint—Welder or WPS Qualification—with Backing (see 4.12.1, 4.12.3, and 4.26)

in 4.12.4.1 (2) [a] shall be required. Three macroetch test sections shall be cut from the test specimens, and shall conform to the requirements of 4.12.4.1(3), and shall show the required theoretical weld (with due allowance for backup welds to be discounted, as shown in Details C and D of Figures 3.8–3.10.) [See Figure 4.26 for test joint details.]

4.12.4.3 Complete Joint Penetration Groove Welds in a T-, Y-, or K-Connection WPS Using GMAW-S. For T-, Y-, and K-connections, where gas metal arc welding (short circuiting transfer) is used, qualification in conformance with section 4 shall be required prior to welding the standard joint configurations detailed in 3.13.4. The joint tested shall incorporate a 37.5° single bevel groove, offset root and restriction ring as shown in Figure 4.27.

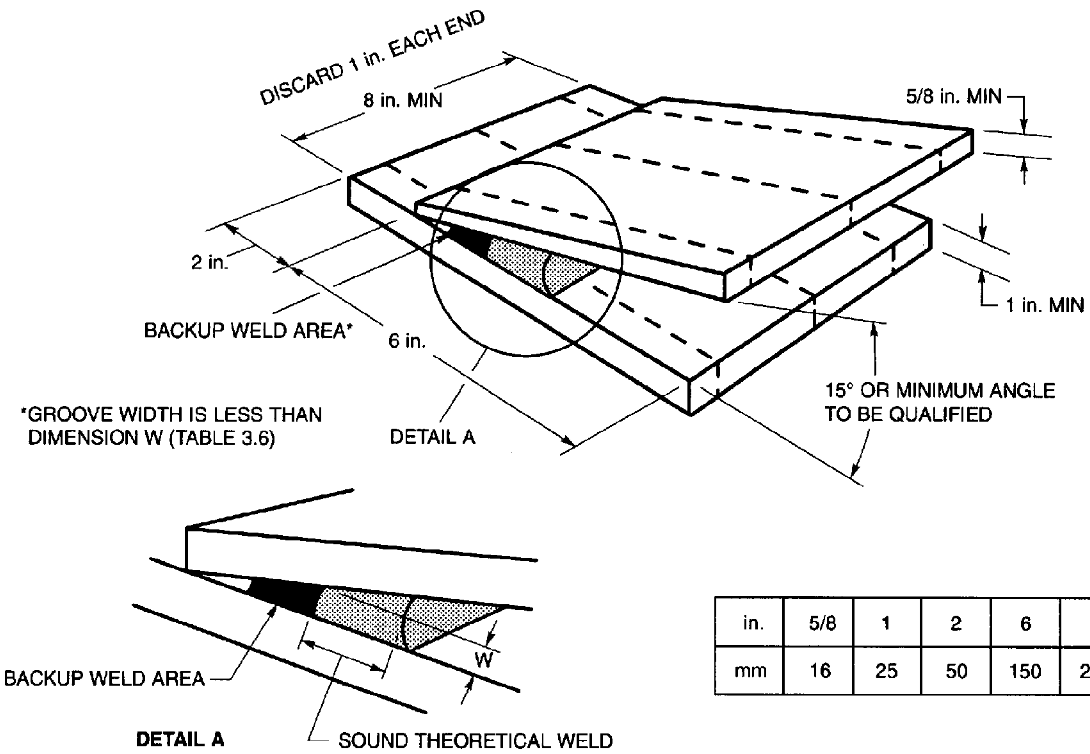
4.12.4.4 Weldments Requiring Notch Toughness. WPSs for butt joints (longitudinal or circumferential seams) within 0.5D of attached branch members, in tubular connection joint-cans requiring Charpy testing under 2.42.2.2, shall be required to demonstrate weld metal Charpy V-notch absorbed energy of 20 ft·lb (27 J) at the LAST, (Lowest Anticipated Service Temperature), or at 0°F (–18°C), whichever is lower. If AWS specifications for the welding materials to be used do not encompass this requirement, or if production welding is outside the range covered by prior testing, e.g., tests per AWS filler metal specifications, then weld metal Charpy tests shall be made during WPS qualification, as described in Annex III.

4.13 PJP Tubular T-, Y-, or K-Connections and Butt Joints

When PJP groove welds are specified, in T-, Y-, or K-connections or butt welds, qualification shall be in conformance with Table 4.3.

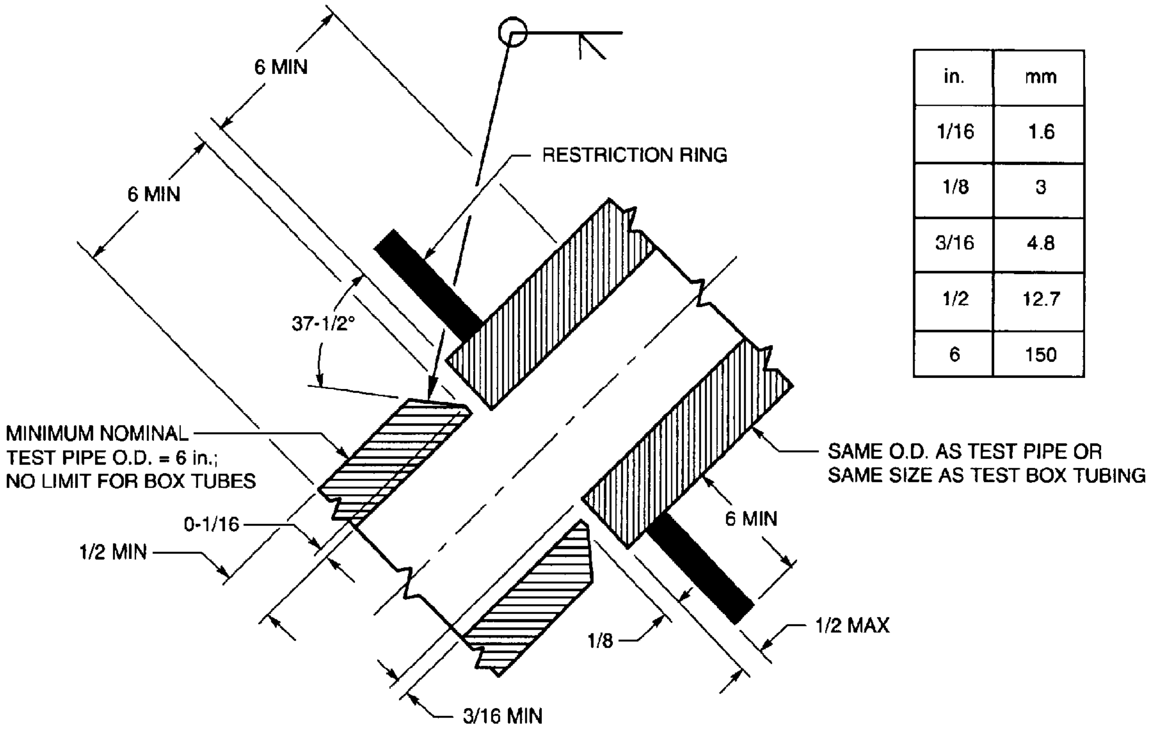
4.14 Plug and Slot Welds for Tubular and Nontubular Connections

When plug and slot groove welds are specified, WPS qualification shall be in conformance with 4.29.



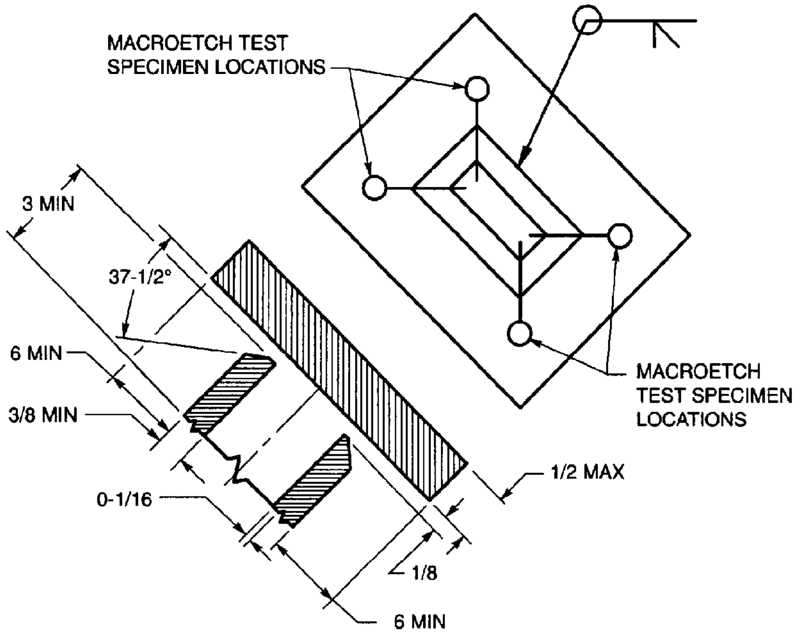
in.	5/8	1	2	6	8
mm	16	25	50	150	200

Figure 4.26—Acute Angle Heel Test (Restraints not Shown) (see 4.12.4.2)



in.	mm
1/16	1.6
1/8	3
3/16	4.8
1/2	12.7
6	150

Figure 4.27—Test Joint for T-, Y-, and K-Connections without Backing on Pipe or Box Tubing—Welder and WPS Qualification (see 4.12.4.1 and 4.26)



in.	mm
1/16	1.6
1/8	3
3/8	10
1/2	13
3	75
6	150

Figure 4.28—Corner Macroetch Test Joint for T-, Y-, and K-Connections without Backing on Box Tubing for Complete Joint Penetration—Welder and WPS Qualification (see 4.12.4.1 and 4.26)

4.15 Welding Processes Requiring Qualification

4.15.1 ESW, EGW, GTAW, and GMAW-S. Electroslag (ESW), electrogas (EGW), gas tungsten arc welding (GTAW) and gas metal arc welding (short circuiting) [GMAW-S] welding may be used, provided the WPSs are qualified in conformance with the requirements of section 4. See Annex A for GMAW-S. Note that the essential variable limitations in Table 4.5 for GMAW also apply to GMAW-S.

4.15.2 Other Welding Processes. Other welding processes not covered by 3.2.1 or 4.15.1 may be used, provided the WPSs are qualified by applicable tests as prescribed in section 4 and approved by the Engineer. In conjunction with the tests, the WPSs and limitation of essential variables applicable to the specific welding process shall be established by the contractor developing the WPS. The range of essential variables shall be based on documented evidence of experience with the process, or a series of tests shall be conducted to establish the limit of essential variables. Any change in essential variables outside the range so established shall require requalification.

4.16 WPS Requirement (GTAW)

Prior to use, the contractor shall prepare a WPS(s) and qualify each WPS according to the requirements of section 4.

4.17 WPS Requirements (ESW/EGW)

Prior to use, the contractor shall prepare and qualify each WPS for each process to be used according to the requirements in section 4. The WPS shall include the joint details, filler metal type and diameter, amperage, voltage (type and polarity), speed of vertical travel if not an automatic function of arc length or deposition rate, oscillation (traverse speed, length, and dwell time), type of shielding including flow rate and dew point of gas or type of flux, type of molding shoe, postweld heat treatment if used, and other pertinent information.

4.17.1 Previous Qualification. With the Engineer's approval, properly documented evidence of previous qualification of the WPSs to be employed may be accepted.

4.17.2 All-Weld-Metal Tension Test Requirements. Prior to use, the contractor shall demonstrate by the test prescribed in section 4, that each combination of shielding and filler metal will produce weld metal having the mechanical properties specified in the latest edition of ANSI/AWS A5.25, *Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding* or the latest edition of ANSI/AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes for Electrogas Welding*, as applicable, when welded in conformance with the WPS.

Part C
Performance Qualification

4.18 General

The performance qualification tests required by this code are specifically devised tests to determine a welder's, welding operator's, or tack welder's ability to produce sound welds. The qualification tests are not intended to be used as guides for welding or tack welding during actual construction. The latter shall be performed in accordance with a WPS.

4.18.1 Production Welding Positions Qualified

4.18.1.1 Welders. The production welding positions that a welder is qualified for shall be in conformance with Table 4.8.

4.18.1.2 Welding Operators. Qualification of a welding operator on plate in the 1G (flat), or 2G (horizontal) position shall qualify the welding operator for welding pipe or tubing over 24 in. (610 mm) in diameter or plate for the position qualified, except that qualification in the 1G position also qualifies for fillet welding in the 1F and 2F positions, and qualification in the 2G position also qualifies for groove welding in the 1G position and for fillet welding in the 1F and 2F positions.

4.18.1.3 Tack Welders. A tack welder shall be qualified by one test plate in each position in which the tack welding is to be performed.

4.18.2 Production Thicknesses and Diameters Qualified

4.18.2.1 Welders or Welding Operators. The range of production welding thicknesses and diameters that a welder or welding operator is qualified for shall be in conformance with Table 4.9.

4.18.2.2 Tack Welders. Tack welder qualification shall qualify for thicknesses greater than or equal to 1/8 in., and all diameters.

4.18.3 Welder and Welding Operator Qualification Through WPS Qualification. A welder or welding operator may also be qualified by welding a satisfactory WPS qualification test plate, pipe or tubing that meets

Table 4.8
Welder Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests (see 4.18.1.1)

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
						Butt-Groove		T-, Y-, K-Groove			Butt-Groove		T-, Y-, K-Groove		
	Weld Type	Positions[2]	Groove CJP	Groove PJP	Fillet	CJP	PJP	CJP	PJP	Fillet	CJP	PJP	CJP	PJP	Fillet
PLATE	Groove[3]	1G 2G 3G 4G 3G + 4G	F F, H F, H, V F, OH All	F F, H F, H, V F, OH All	F, H F, H F, H, V F, H, OH All Note 9	F F, H F, H, V F, OH All Note 4	F F, H F, H, V F, OH All Note 4		F F, H F, H, V F, OH All Notes 4,6	F, H F, H F, H, V F, H, OH All Note 9	F F, H F, H, V F, OH All Note 5	F F, H F, H, V F, OH All		F F, H F, H, V F, OH All Note 6	F, H F, H F, H, V F, H, OH All Note 9
PLATE	Fillet	1F 2F 3F 4F 3F + 4F			F F, H F, H, V F, H, OH All Note 9					F F, H F, H, V F, H, OH All Note 9					F F, H F, H, V F, H, OH All Note 9
PLATE	Plug	Qualifies Plug and Slot Welding For Only The Positions Tested													
TUBULAR	Groove[3] (Pipe or Box)	1G Rotated 2G 5G 6G 2G + 5G Note 10	F F, H F, V, OH All All	F F, H F, V, OH All All	F, H F, H F, V, OH All All Note 9	F F, H F, V, OH All All Note 7	F F, H F, V, OH All All Note 7		F F, H F, V, OH All All Notes 6,7	F, H F, H F, V, OH All All Note 9	F F, H F, V, OH All All	F F, H F, V, OH All All		F F, H F, V, OH All All Note 6	F, H F, H F, V, OH All All Note 9
TUBULAR	Groove[3] (Pipe or Box)	6GR (Fig. 4.27)	All	All	All Note 9	All Notes 5,7	All Note 7	All Notes 6,7	All Notes 6,7	All Note 9	All Note 5	All		All Note 6	All Note 9
TUBULAR	Groove[3] (Pipe or Box)	6GR (Fig. 4.27 & 4.28)	All	All	All Note 9	All Notes 5,7	All Note 7	All Notes 6,7	All Notes 6,7	All Note 9	All Note 5	All	All Notes 6,8	All Note 6	All Note 9
TUBULAR	Pipe Fillet	1F Rotated 2F 2F Rotated 4F 5F			F F, H F, H F, H, OH All Note 9					F F, H F, H F, H, OH All Note 9					F F, H F, H F, H, OH All Note 9

CJP—Complete Joint Penetration; PJP—Partial Joint Penetration; (R)—Restriction

Notes (Notes shown at the bottom of a column box apply to all entries.):
1. Not applicable for welding operator qualification (see Table 4.10).
2. See Figures 4.3, 4.4, 4.5, and 4.6.
3. Groove Weld qualification also qualifies plug and slot welds for the test positions indicated.
4. Only qualified for pipe over 24 in. (610 mm) in diameter with backing, backgouging, or both.
5. Not qualified for joints welded from one side without backing, or welded from two sides without backgouging.
6. Not qualified for welds having groove angles less than 30° (see 4.12.4.2).
7. Qualification using box tubing (Figure 4.27) also qualifies welding pipe over 24 in. (610 mm) in diameter.
8. Pipe or box tubing is required for the 6GR qualification (Figure 4.27). If box tubing is used per Figure 4.27, the macroetch test may be performed on the corners of the test specimen (similar to Figure 4.28).
9. See 4.25 and 4.28 for dihedral angle restrictions for plate joints and tubular T-, Y-, K-connections.
10. Qualification for welding production joints without backing or backgouging requires using the Figure 4.24 joint detail. For welding production joints with backing or backgouging, either the Figure 4.24 or Figure 4.25 joint detail can be used for qualification.

Table 4.9
Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in inches) (see 4.18.2.1)

(1) Test on Plate		Number of Specimens[1]				Qualified Dimensions	
Production Groove or Plug Welds						Nominal Plate, Pipe or Tube Thickness Qualified, in.	
Type of Test Weld (Applicable Figures)	Nominal Thickness of Test Plate (T) in.	Face Bend[2] (Fig. 4.12)	Root Bend[2] (Fig. 4.12)	Side Bend[2] (Fig. 4.13)	Macro-etch	Min	Max
Groove (Fig. 4.30 or 4.31)	3/8	1	1	—	—	1/8	3/4 max[3]
Groove (Fig. 4.30 or 4.31)	3/8 < T < 1	—	—	2	—	1/8	2T max[3]
Groove (Fig. 4.21, 4.22, or 4.29)	1 or over	—	—	2	—	1/8	Unlimited[3]
Plug (Fig. 4.37)	3/8	—	—	—	2	1/8	Unlimited

Production Fillet Welds (T-joint and Skewed)			Number of Specimens[1]				Qualified Dimensions			
							Nominal Plate Thickness Qualified, in.		Dihedral Angles Qualified[7]	
Type of Test Weld (Applicable Figures)	Nominal Test Plate Thickness, T, in.	Fillet Weld Break	Macro-etch	Side Bend[2]	Root Bend[2]	Face Bend[2]	Min	Max	Min	Max
Groove (Fig. 4.30 or 4.31)	3/8	—	—	—	1	1	1/8	Unlimited	30°	Unlimited
Groove (Fig. 4.30 or 4.31)	3/8 < T < 1	—	—	2	—	—	1/8	Unlimited	30°	Unlimited
Groove (Fig. 4.21, 4.22, or 4.29)	≥ 1	—	—	2	—	—	1/8	Unlimited	30°	Unlimited
Fillet Option 1 (Fig. 4.36)	1/2	1	1	—	—	—	1/8	Unlimited	60°	135°
Fillet Option 2 (Fig. 4.32)	3/8	—	—	—	2	—	1/8	Unlimited	60°	135°
Fillet Option 3 (Fig. 4.20) [Any diam. pipe]	> 1/8	—	1	—	—	—	1/8	Unlimited	30°	Unlimited

(2) Tests on Pipe or Tubing[5]			Number of Specimens[1]						Nominal Pipe or Tube Size Qualified, in.		Nominal Plate, Pipe or Tube Wall Thickness[3] Qualified, in.	
Production CJP Groove Butt Joints			1G and 2G Positions Only			5G, 6G and 6GR Positions Only						
Type of Test Weld	Nominal Size of Test Pipe, in.	Nominal Test Thickness, in.	Face Bend[2]	Root Bend[2]	Side Bend[2]	Face Bend[2]	Root Bend[2]	Side Bend[2]	Min	Max	Min	Max
Groove	≤ 4	Unlimited	1	1	—	2	2	—	3/4	4	1/8	3/4
Groove	> 4	< 3/8	1	1	—	2	2	—	Note 4	Unlimited	1/8	3/4
Groove	> 4	≥ 3/8	—	—	2	—	—	4	Note 4	Unlimited	3/16	Unlimited

(continued)

Table 4.9 (Continued)

(2) Test on Pipe or Tubing[5] (cont'd)

Production T-, Y-, or K-Connection CJP Groove Welds			Number of Specimens[1]		Qualified Dimensions					
					Nominal Pipe or Tube Size Qualified, in.		Nominal Wall or Plate Thickness[3] Qualified, in.		Dihedral Angles Qualified[7]	
Type of Test Weld	Nominal Size of Test Pipe, in.	Nominal Test Thickness, in.	Side Bend[2]	Macro-etch	Min	Max	Min	Max	Min	Max
Pipe Groove	≥ 6 O.D.	≥ 1/2	4	—	4	Unlimited	3/16	Unlimited	30°	Unlimited
Box Groove	Unlimited	≥ 1/2	4	4	Unlimited (Box only)	Unlimited (Box Only)	3/16	Unlimited	30°	Unlimited

Production T-, Y-, or K-Connection Fillet Welds			Number of Specimens[1]				Qualified Dimensions					
							Nominal Pipe or Tube Size Qualified, in.		Nominal Wall or Plate Thickness Qualified		Dihedral Angles Qualified[7]	
Type of Test Weld	Nominal Size of Test Pipe, D	Nominal Test Thickness, in.	Fillet Weld Break	Macro-etch	Root Bend[2]	Face Bend[2]	Min	Max	Min	Max	Min	Max
5G position (Groove)	Unlimited	≥ 1/8	—	—	2	2	Note 4	Unlimited	1/8 (Note 3)	Unlimited (Note 3)	30°	Unlimited
Option 1—Fillet (Fig. 4.36)[6]	—	≥ 1/2	1	1	—	—	24	Unlimited	1/8	Unlimited	60°	Unlimited
Option 2—Fillet (Fig. 4.32)[6]	—	3/8	—	—	2	—	24	Unlimited	1/8	Unlimited	60°	Unlimited
Option 3—Fillet (Fig. 4.20)	Unlimited	≥ 1/8	—	1	—	—	D	Unlimited	1/8	Unlimited	30°	Unlimited

(3) Tests on Electroslag and Electrogas Welding

Production Plate Groove Welds		Number of Specimens[1]	Nominal Plate Thickness Qualified, in.	
Type of Test Weld	Nominal Plate Thickness Tested, T, in.	Side Bend[2] (see Fig. 4.13)	Min	Max
Groove (Fig. 4.35)	< 1-1/2	2	1/8	T
	1-1/2	2	1/8	Unlimited

Notes:
1. All welds shall be visually inspected (see 4.30.1). One test pipe, plate or tubing is required for each position tested, unless otherwise noted.
2. Radiographic examination of the test plate, pipe or tubing may be made in lieu of the bend tests (see 4.19.1.1).
3. Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
4. The minimum pipe size qualified shall be 1/2 the test diameter or 4 in., whichever is greater.
5. See Table 4.8 for appropriate groove details.
6. Two plates required, each subject to the test specimen requirements described. One plate shall be welded in the 3F position and the other in the 4F position.
7. For dihedral angles < 30°, see 4.26.1.

Table 4.9
Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in millimeters) (see 4.18.2.1)

(1) Test on Plate		Number of Specimens[1]				Qualified Dimensions	
Production Groove or Plug Welds						Nominal Plate, Pipe or Tube Thickness Qualified, mm	
Type of Test Weld (Applicable Figures)	Nominal Thickness of Test Plate, T, mm	Face Bend[2] (Fig. 4.12)	Root Bend[2] (Fig. 4.12)	Side Bend[2] (Fig. 4.13)	Macro-etch	Min	Max
Groove (Fig. 4.30 or 4.31)	9.5	1	1	—	—	3.2	19.0 max[3]
Groove (Fig. 4.30 or 4.31)	9.5 < T < 25.4	—	—	2	—	3.2	2T max[3]
Groove (Fig. 4.21, 4.22, or 4.29)	25.4 or over	—	—	2	—	3.2	Unlimited[3]
Plug (Fig. 4.37)	9.5	—	—	—	2	3.2	Unlimited

Production Fillet Welds (T-joint and Skewed)		Number of Specimens[1]					Qualified Dimensions			
							Nominal Plate Thickness Qualified, mm		Dihedral Angles Qualified[7]	
Type of Test Weld (Applicable Figures)	Nominal Test Plate Thickness, T, mm	Fillet Weld Break	Macro-etch	Side Bend[2]	Root Bend[2]	Face Bend[2]	Min	Max	Min	Max
Groove (Fig. 4.30 or 4.31)	9.5	—	—	—	1	1	3.2	Unlimited	30°	Unlimited
Groove (Fig. 4.30 or 4.31)	9.5 < T < 25.4	—	—	2	—	—	3.2	Unlimited	30°	Unlimited
Groove (Fig. 4.21, 4.22, or 4.29)	≥ 25.4	—	—	2	—	—	3.2	Unlimited	30°	Unlimited
Fillet Option 1 (Fig. 4.36)	12.7	1	1	—	—	—	3.2	Unlimited	60°	135°
Fillet Option 2 (Fig. 4.32)	9.5	—	—	—	2	—	3.2	Unlimited	60°	135°
Fillet Option 3 (Fig. 4.20) [Any diam. pipe]	> 3.2	—	1	—	—	—	3.2	Unlimited	30°	Unlimited

(2) Tests on Pipe or Tubing[5]			Number of Specimens[1]						Nominal Pipe or Tube Size Qualified, mm		Nominal Plate, Pipe or Tube Wall Thickness[3] Qualified, mm	
Production CJP Groove Butt Joints			1G and 2G Positions Only			5G, 6G and 6GR Positions Only						
Type of Test Weld	Nominal Size of Test Pipe, mm	Nominal Test Thickness, mm	Face Bend[2]	Root Bend[2]	Side Bend[2]	Face Bend[2]	Root Bend[2]	Side Bend[2]	Min	Max	Min	Max
Groove	≤ 100	Unlimited	1	1	—	2	2	—	19	100	3.2	19.0
Groove	> 100	< 9.5	1	1	—	2	2	—	Note 4	Unlimited	3.2	19.0
Groove	> 100	≥ 9.5	—	—	2	—	—	4	Note 4	Unlimited	4.8	Unlimited

(continued)

Table 4.9 (Continued)

(2) Test on Pipe or Tubing[5] (cont'd)

Production T-, Y-, or K-Connection CJP Groove Welds			Number of Specimens[1]		Qualified Dimensions					
					Nominal Pipe or Tube Size Qualified, mm		Nominal Wall or Plate Thickness[3] Qualified, mm		Dihedral Angles Qualified[7]	
Type of Test Weld	Nominal Size of Test Pipe, mm	Nominal Test Thickness, mm	Side Bend[2]	Macro-etch	Min	Max	Min	Max	Min	Max
Pipe Groove	≥ 150 O.D.	≥ 12.7	4	—	100	Unlimited	4.8	Unlimited	30°	Unlimited
Box Groove	Unlimited	≥ 12.7	4	4	Unlimited (Box only)	Unlimited (Box Only)	4.8	Unlimited	30°	Unlimited

Production T-, Y-, or K-Connection Fillet Welds			Number of Specimens[1]				Qualified Dimensions					
							Nominal Pipe or Tube Size Qualified, mm		Nominal Wall or Plate Thickness Qualified, mm		Dihedral Angles Qualified[7]	
Type of Test Weld	Nominal Size of Test Pipe, D	Nominal Test Thickness, mm	Fillet Weld Break	Macro-etch	Root Bend[2]	Face Bend[2]	Min	Max	Min	Max	Min	Max
5G position (Groove)	Unlimited	≥ 3.2	—	—	2	2	Note 4	Unlimited	3.2 (Note 3)	Unlimited (Note 3)	30°	Unlimited
Option 1—Fillet (Fig. 4.36)[6]	—	≥ 12.7	1	1	—	—	610	Unlimited	3.2	Unlimited	60°	Unlimited
Option 2—Fillet (Fig. 4.32)[6]	—	9.5	—	—	2	—	610	Unlimited	3.2	Unlimited	60°	Unlimited
Option 3—Fillet (Fig. 4.20)	Unlimited	≥ 3.2	—	1	—	—	D	Unlimited	3.2	Unlimited	30°	Unlimited

(3) Tests on Electroslag and Electrogas Welding

Production Plate Groove Welds		Number of Specimens[1]	Nominal Plate Thickness Qualified, mm	
Type of Test Weld	Nominal Plate Thickness Tested, T, mm	Side Bend[2] (see Fig. 4.13)	Min	Max
Groove (Fig. 4.35)	< 38.1	2	3.2	T
	38.1	2	3.2	Unlimited

Notes:
1. All welds shall be visually inspected (see 4.30.1). One test pipe, plate or tubing is required for each position tested, unless otherwise noted.
2. Radiographic examination of the test plate, pipe or tubing may be made in lieu of the bend tests (see 4.19.1.1).
3. Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
4. The minimum pipe size qualified shall be 1/2 the test diameter or 100 mm, whichever is greater.
5. See Table 4.8 for appropriate groove details.
6. Two plates required, each subject to the test specimen requirements described. One plate shall be welded in the 3F position and the other in the 4F position.
7. For dihedral angles < 30°, see 4.26.1.

the requirements of 4.8. The welder or welding operator is thereby qualified in conformance with 4.18.1 and 4.18.2.

4.19 Type of Qualification Tests Required

4.19.1 Welders and Welding Operators. The type and number of qualification tests required for welders or welding operators shall conform to Table 4.9. Details on the individual NDT and mechanical test requirements are found in the following subsections:

(1) Visual Inspection (see 4.8.1) [Use WPS requirements]

(2) Face, root and side bend (see 4.8.3.1) [Use WPS requirements]

(3) Macroetch (see 4.30.2)

(4) Fillet Weld Break (see 4.30.4)

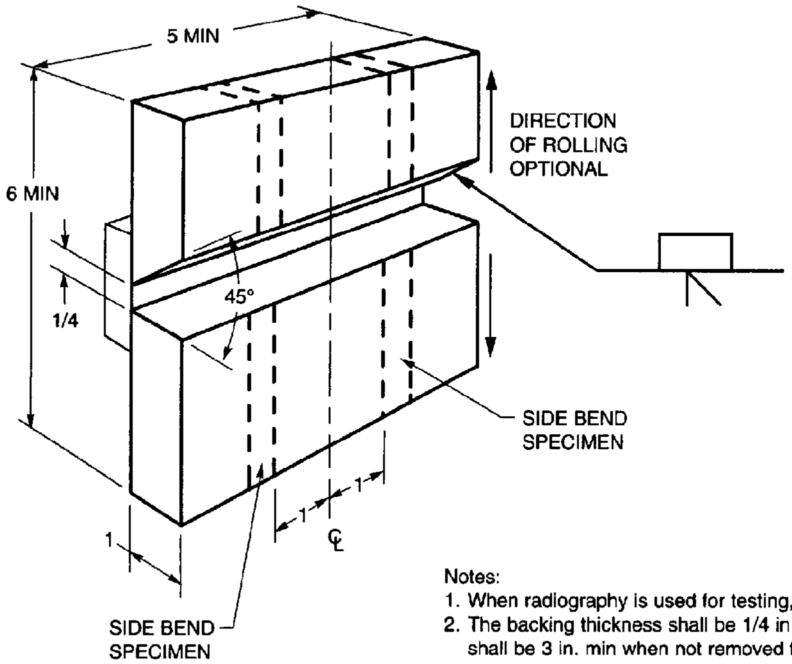
4.19.1.1 Substitution of RT for Guided Bend Tests. Except for joints welded by GMAW-S, radiographic examination of a welder or welding operator qualification test plate or test pipe may be made in lieu of guided bend tests prescribed in Part C. See 4.30.3 for RT requirements.

In lieu of mechanical or RT testing of the qualification test assemblies, a welding operator may be qualified by radiography of the initial 15 in. (380 mm) of a production groove weld. The material thickness range qualified shall be that shown in Table 4.9.

4.19.1.2 Guided Bend Tests. Mechanical test specimens shall be prepared by cutting the test plate, pipe, or tubing as shown in Figures 4.21, 4.29, 4.30, 4.31, 4.32, and 4.33 for welder qualification or Figures 4.22, 4.32 or 4.35 for welding operator qualification, whichever is applicable. These specimens shall be approximately rectangular in cross section, and be prepared for testing in conformance with Figures 4.12, 4.13, 4.14, or 4.18, whichever is applicable.

4.19.2 Tack Welders. The tack welder shall make a 1/4 in. (6 mm) maximum size tack weld approximately 2 in. (50 mm) long on the fillet-weld-break specimen as shown in Figure 4.38.

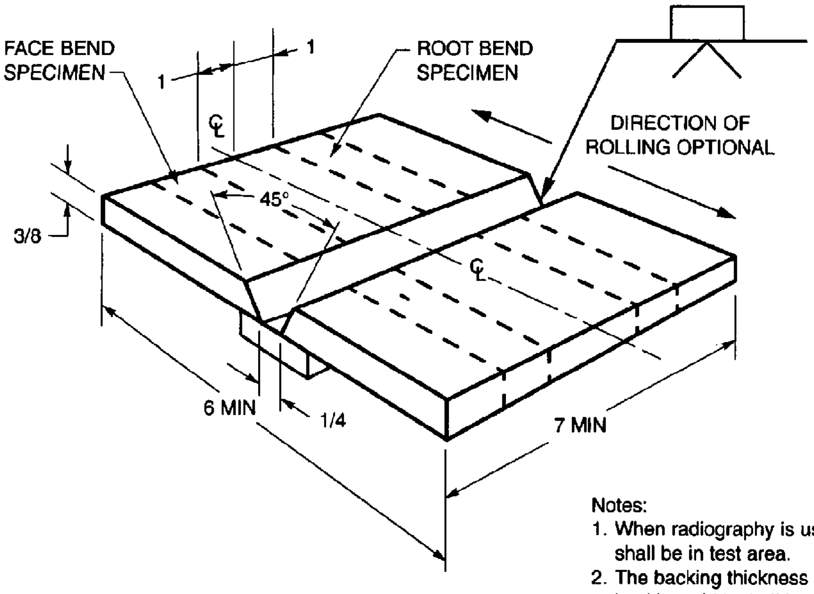
4.19.2.1 Extent of Qualification. A tack welder who passes the fillet weld break test shall be qualified to tack weld all types of joints (except complete joint



in.	mm
1/4	6
3/8	10
1	25
3	75
5	125
6	150

Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. min to 3/8 in. max; backing width shall be 3 in. min when not removed for radiography, otherwise 1 in. min.

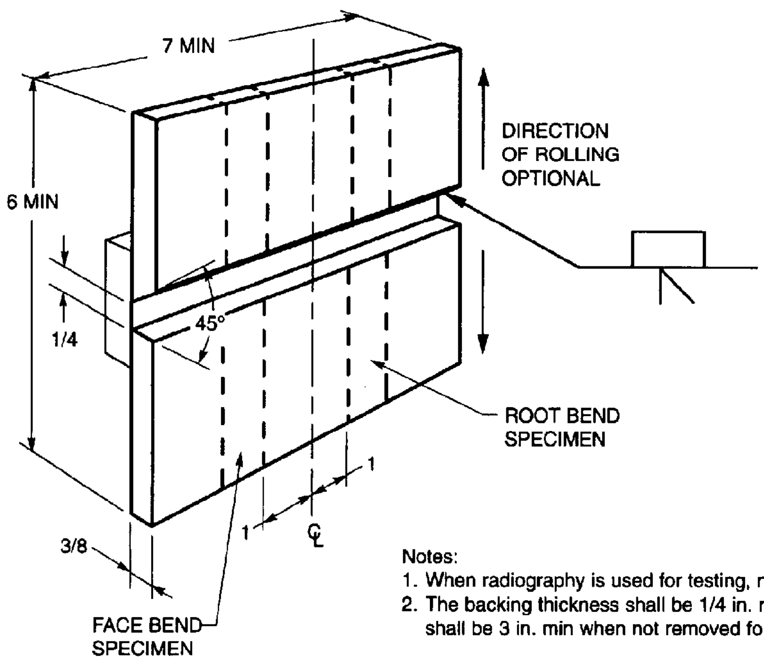
Figure 4.29—Optional Test Plate for Unlimited Thickness—Horizontal Position—Welder Qualification (see 4.23.1)



in.	mm
1/4	6
3/8	10
1	25
3	75
6	150
7	180

Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. min to 3/8 in. max; backing width shall be 3 in. min when not removed for radiography, otherwise 1 in. min.

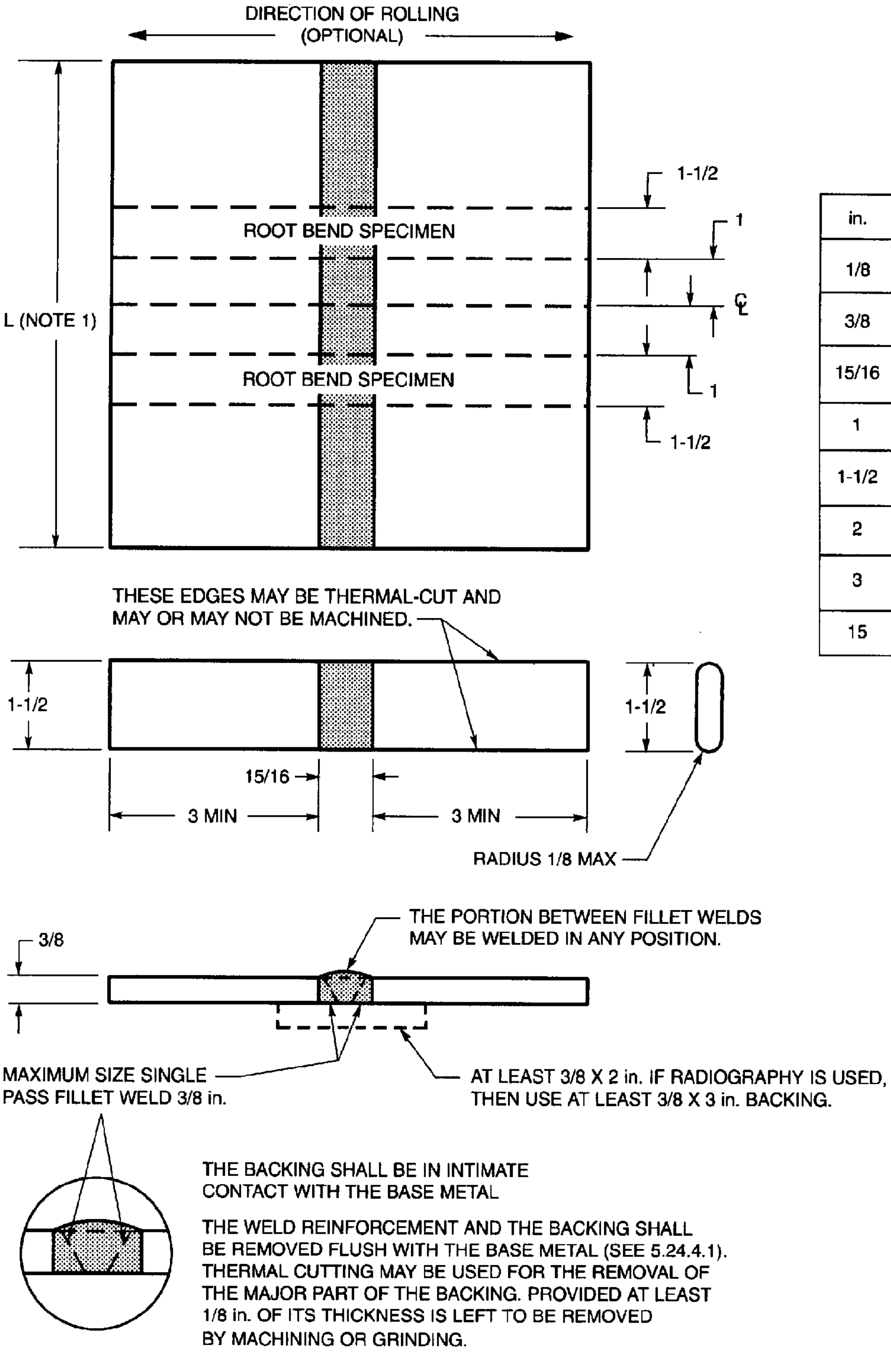
Figure 4.30—Test Plate for Limited Thickness—All Positions—Welder Qualification (see 4.23.1)



in.	mm
1/4	6
3/8	10
1	25
3	75
6	150
7	180

Notes:
1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in. min to 3/8 in. max; backing width shall be 3 in. min when not removed for radiography, otherwise 1 in. min.

Figure 4.31—Optional Test Plate for Limited Thickness—Horizontal Position—Welder Qualification (see 4.23.1)



in.	mm
1/8	3
3/8	10
15/16	24
1	25
1-1/2	38
2	50
3	75
15	380

NOTE 1: L = 7 MIN (WELDER), L = 15 MIN (WELDING OPERATOR).

Figure 4.32—Fillet Weld Root Bend Test Plate—Welder or Welding Operator Qualification—Option 2 (see 4.28 or 4.25)

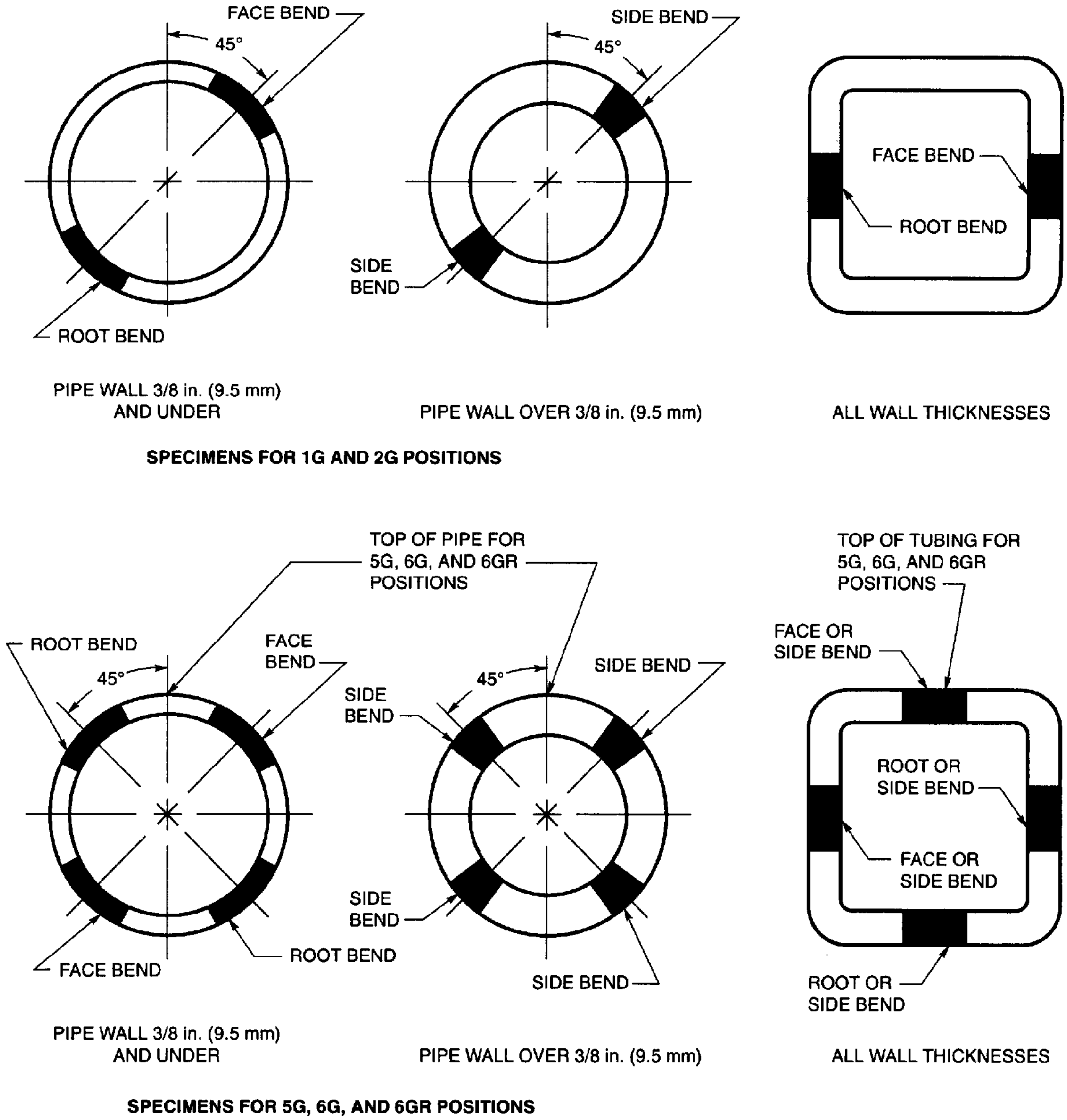


Figure 4.33—Location of Test Specimens on Welded Test Pipe and Box Tubing—Welder Qualification (see 4.19.1.2)

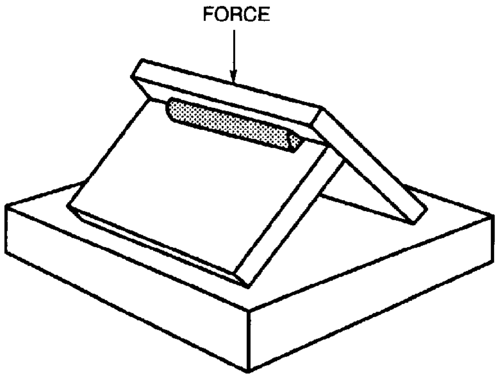
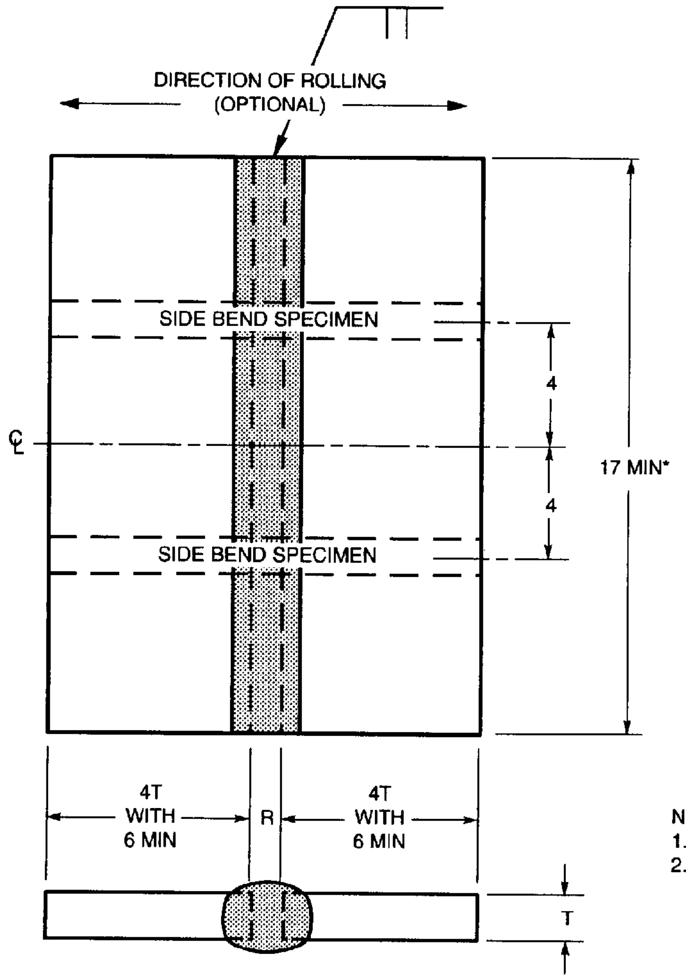


Figure 4.34—Method of Rupturing Specimen— Tack Welder Qualification (See 4.31)

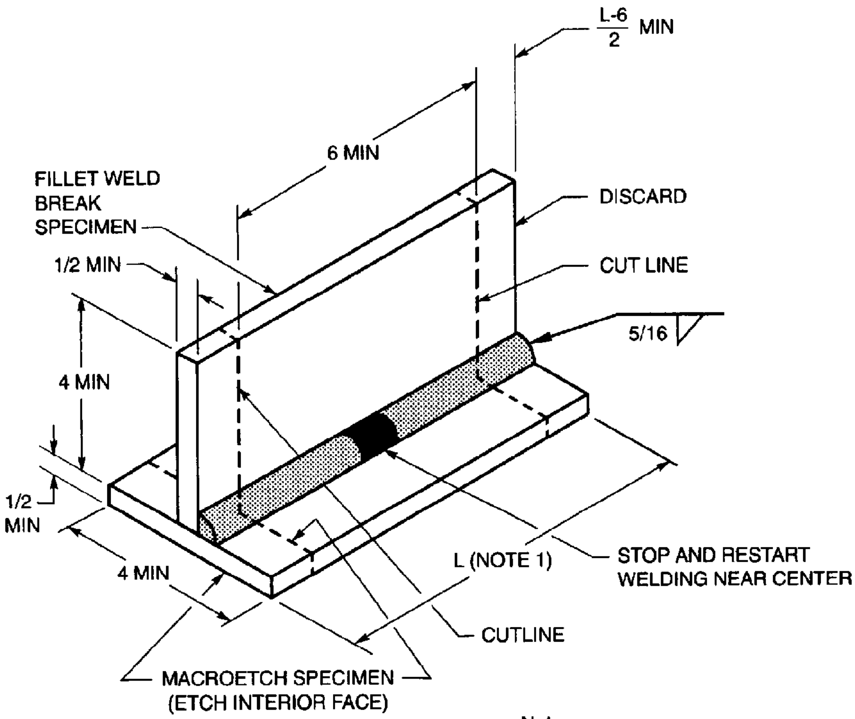


in.	mm
1-1/2	38
4	100
6	150
17	430

Notes:
1. Root opening "R" established by WPS.
2. T = maximum to be welded in construction but need not exceed 1-1/2 in.

*Extensions need not be used if joint is of sufficient length to provide 17 in. of sound weld.

Figure 4.35—Butt Joint for Welding Operator Qualification— Electroslag and Electrogas Welding (see 4.23.2)



in.	mm
5/16	8
1/2	13
4	100
6	150
15	380

Notes:
1. L = 8 min. (welder), 15 min. (welding operator).
2. Either end may be used for the required macroetch specimen. The other end may be discarded.

Figure 4.36—Fillet Weld Break and Macroetch Test Plate—Welder or Welding Operator Qualification—Option 1 (see 4.28 or 4.25)

penetration groove welds, welded from one side without backing; e.g., butt joints and T-, Y-, and K-connections) for the process and in the position in which the tack welder is qualified. Tack welds in the foregoing exception shall be performed by welders fully qualified for the process and in the position in which the welding is to be done.

4.20 Weld Types for Welder and Welding Operator Performance Qualification

For the purpose of welder and welding operator qualification, weld types shall be classified as follows:

(1) CJP Groove Welds for Nontubular Connections (see 4.23)

(2) PJP Groove Welds for Nontubular Connections (see 4.24)

(3) Fillet Welds for Nontubular Connections (see 4.25)

(4) CJP Groove Welds for Tubular Connections (see 4.26)

(5) PJP Groove Welds for Tubular Connections (see 4.27)

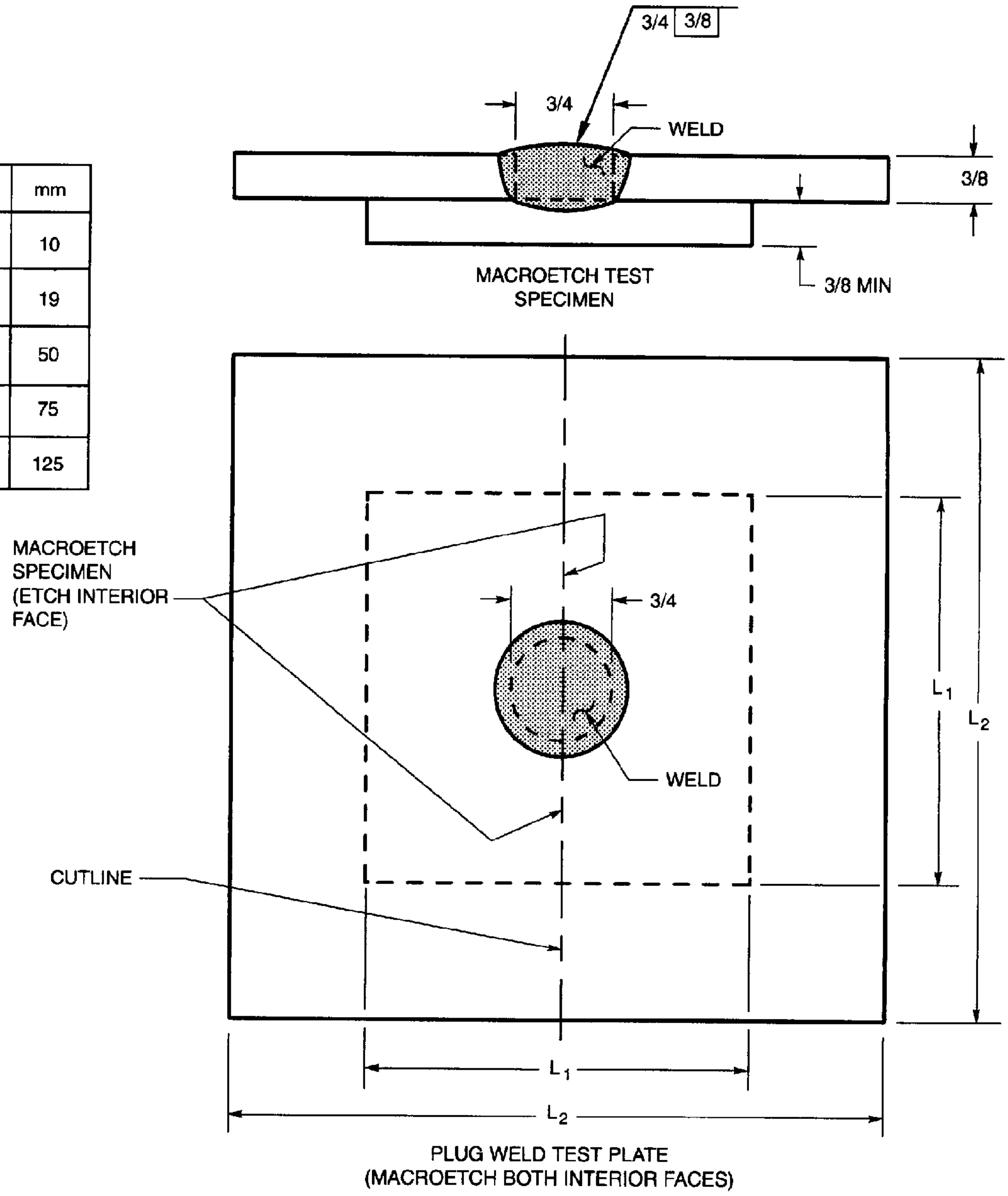
(6) Fillet Welds for Tubular Connections (see 4.28)

(7) Plug and Slot Welds for Tubular and Nontubular Connections (see 4.29)

4.21 Preparation of Performance Qualification Forms

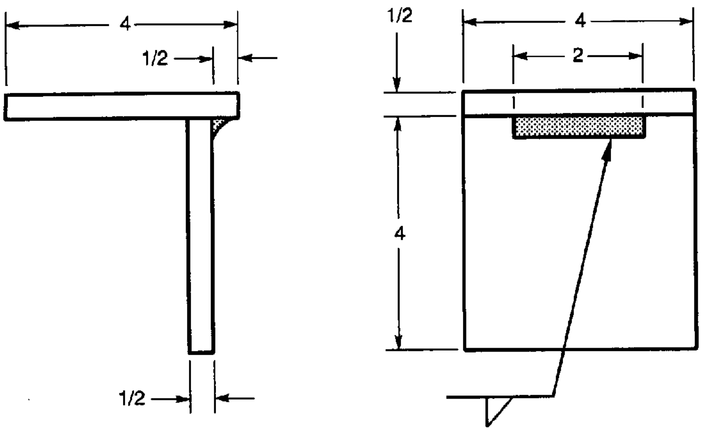
The welding personnel shall follow a WPS applicable to the qualification test required. All of the WPS essential variable limitations of 4.7 shall apply, in addition to the performance essential variables of 4.22. The Welding Performance Qualification Record (WPQR) shall serve as written verification and shall list all of the essential variables of Table 4.10. Suggested forms are found in Annex E.

in.	mm
3/8	10
3/4	19
2	50
3	75
5	125



NOTE 1: L_1 = 2 MIN (WELDER), 3 MIN (WELDING OPERATOR),
L_2 = 3 MIN (WELDER), 5 MIN (WELDING OPERATOR).

Figure 4.37—Plug Weld Macroetch Test Plate—Welding Operator or Welder Qualification (see 4.29)



in.	mm
1/2	13
2	50
4	100

Figure 4.38—Fillet Weld Break Specimen—Tack Welder Qualification (see 4.19.2)

4.22 Essential Variables

Changes beyond the limitation of essential variables for welders, welding operators, or tack welders shown in Table 4.10 shall require requalification.

4.23 CJP Groove Welds for Nontubular Connections

See Table 4.8 for the position requirements for welder or welding operator qualification on nontubular connections. Note that qualification on joints with backing qualifies for welding production joints that are backgouged and welded from the second side.

4.23.1 Welder Qualification Plates. The following figure numbers apply to the position and thickness requirements for welders.

(1) Figure 4.21—All Positions—Unlimited Thickness

(2) Figure 4.29—Horizontal Position—Unlimited Thickness

(3) Figure 4.30—All Positions—Limited Thickness

(4) Figure 4.31—Horizontal Position—Limited Thickness

4.23.2 Welding Operator Qualification Plates for ESW/EGW. The qualification test plate for a welding operator not using electrogas welding (EGW) or electroslag welding (ESW) or plug welding shall conform to Figure 4.22. This will qualify a welding operator for groove and fillet welding in material of unlimited thickness for the process and position tested.

The qualification test for an ESW or EGW welding operator shall consist of welding a joint of the maximum thickness of material to be used in construction, but the thickness of the material of the test weld need not exceed 1-1/2 in. (38 mm) [see Figure 4.35.] If a 1-1/2 in. thick test weld is made, no test need be made for a lesser thickness. The test shall qualify the welding operator for groove and fillet welds in material of unlimited thickness for this process and test position.

4.24 PJP Groove Welds for Nontubular Connections

Qualification for CJP groove welds qualifies for all PJP groove welds.

4.25 Fillet Welds for Nontubular Connections

Qualification of CJP groove welds qualifies for fillet welds. However, where only fillet weld qualification is required, see Table 4.9.

4.26 CJP Groove Welds for Tubular Connections

Welder or welding operator qualification tests shall use the following details:

(1) CJP groove butt joints with backing or backgouging in pipe. Use Figure 4.25

(2) CJP groove butt joints without backing or backgouging. Use Figure 4.24

(3) CJP groove butt joints or T-,Y-, and K-connections with backing in box tubing. Use Figure 4.25 in pipe (any diameter), plate or box tubing.

Table 4.10
Welding Personnel Performance Essential Variable Changes Requiring Requalification (see 4.22)

Essential Variable Changes to WPQR[2] Requiring Requalification	Welding Personnel[1] Welders	Welding Operators (Note 6 and 7)	Tack Welders
(1) To a process not qualified (GMAW-S is considered a separate process)	X	X	X
(2) To an SMAW electrode with an F-number (see Table 4.11) higher than the WPQR electrode F-number	X		X
(3) To an electrode and shielding medium combination not approved by an AWS A5 document	X	X	X
(4) To a position not qualified	X (Note 3)	X	X
(5) To a diameter or thickness not qualified	X (Note 4)	X (Note 4)	
(6) To a vertical welding progression not qualified (uphill or downhill)	X		
(7) The omission of backing (if used in the WPQR test)	X	X	
(8) To multiple electrodes (if a single electrode was used in the WPQR test) but not vice versa		X (Note 5)	

Notes:
1. An "x" indicates applicability for the welding for the welding personnel; a shaded area indicates nonapplicability.
2. WPQR = Welding Performance Qualification Record.
3. See Table 4.8 for positions qualified by welder WPQR.
4. See Table 4.9 for ranges of diameters or thicknesses qualified.
5. Not for ESW or EGW.
6. Welders qualified for GMAW, FCAW or GTAW shall be considered as qualified welding operators in the same process(es), subject to the welder essential variable limitations and provided the welders receive training and demonstrate their ability to make satisfactory production welds.
7. A groove weld qualifies a slot weld for the WPQR position and the thickness ranges as shown in Table 4.9.

Table 4.11
Electrode Classification Groups (see Table 4.10)

Group Designation	AWS Electrode Classification*
F4	EXX15, EXX16, EXX18, EXX15-X, EXX16-X, EXX16-X, EXX18-X
F3	EXX10, EXX11, EXX10-X, EXX11-X
F2	EXX12, EXX13, EXX14, EXX13-X
F1	EXX20, EXX24, EXX27, EXX28, EXX20-X, EXX27-X

*The letters "XX" used in the classification designation in this table stand for the various strength levels (60, 70, 80, 90, 100, 110, and 120) of electrodes.

(4) CJP groove T-, Y-, and K-Connections welded from one side with backing in pipe. Use Figure 4.25 in pipe of the appropriate diameter.

(5) CJP groove T-,Y-, and K-connections welded from one side without backing in pipe. Use Figure 4.27.

(6) CJP groove T-,Y-, and K-connection welded from one side without backing or backgouging in box tubing. The options are the following:

(a) Figure 4.27 in pipe (any diameter) or box tubing plus Figure 4.28 in box tubing.

(b) Figure 4.27 in box tubing with macroetch specimens removed from the locations shown in Figure 4.28.

See Table 4.9 for the production ranges of diameter and thickness qualified by the test assembly diameters and thicknesses.

4.26.1 Other Joint Details or WPSs. For joint details, WPSs, or assumed depth of sound welds that are more difficult than those described herein, a test described in 4.12.4.2 shall be performed by each welder in addition to the 6GR tests (Figure 4.27 or 4.28). The test position shall be vertical.

4.27 PJP Groove Welds for Tubular Connections

Qualification for CJP groove welds on tubular connections qualifies for all PJP groove welds.

4.28 Fillet Welds for Tubular Connections

See Table 4.9 for fillet weld qualification requirements.

4.29 Plug and Slot Welds for Tubular and Nontubular Connections

Qualification for CJP groove welds on tubular or nontubular connections qualifies for all plug and slot welds.

See Table 4.8 for plug and slot weld qualification only. The joint shall consist of a 3/4 in. (19 mm) diameter hole in a 3/8 in. (9.5 mm) thick plate with a 3/8 in. minimum thickness backing plate. (See Figure 4.37.)

4.30 Methods of Testing and Acceptance Criteria for Welder and Welding Operator Qualification

4.30.1 Visual Inspection. See 4.8.1 for acceptance criteria.

4.30.2 Macroetch Test. The test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used for etching to give a clear definition of the weld.

4.30.2.1 Plug and Fillet Weld Macroetch Tests. The plug weld macroetch tests shall be cut from the test joints per:

(1) Welder Qualification—Figure 4.37

(2) Welding Operator Qualification—Figure 4.37

The fillet weld macroetch tests shall be cut from the test joints per:

(a) Welder Qualification—Figure 4.36

(b) Welding Operator Qualification—Figure 4.36

The face of the macroetch shall be smooth for etching.

4.30.2.2 Macroetch Test for T-,Y-, and K-Connections. The corner macroetch test joint for T-, Y-, and K-connections on box tubing in Figure 4.28 shall have four macroetch test specimens cut from the weld corners at the locations shown in Figure 4.28. One face from each corner specimen shall be smooth for etching. If the welder tested on a 6GR coupon (Figure 4.27) using box tubing, the four required corner macroetch test specimens may be cut from the corners of the 6GR coupon in a manner similar to Figure 4.28. One face from each corner specimen shall be smooth for etching.

4.30.2.3 Macroetch Test Acceptance Criteria. For acceptable qualification, the test specimen, when inspected visually, shall conform to the following requirements:

(1) Fillet welds shall have fusion to the root of the joint but not necessarily beyond.

(2) Minimum leg size shall meet the specified fillet weld size.

(3) Fillet welds and the corner macroetch test joint for T-, Y-, and K-connections on box tubing, Figure 4.28, shall have:

(a) No cracks

(b) Thorough fusion between adjacent layers of weld metals and between weld metal and base metal

(c) Weld profiles conforming to intended detail, but with none of the variations prohibited in 5.24

(d) No undercut exceeding 1/32 in. (1 mm)

(e) For porosity 1/32 in. (1 mm) or larger, accumulated porosity not exceeding 1/4 in. (6 mm)

(f) No accumulated slag, the sum of the greatest dimensions of which shall not exceed 1/4 in. (4 mm)

(4) Plug welds shall have:

(a) No cracks

(b) Thorough fusion to backing and to sides of the hole

(c) No visible slag in excess of 1/4 in. (6 mm) total accumulated length

4.30.3 Radiographic Test. If RT is used in lieu of the prescribed bend tests, the weld reinforcement need not to be ground or otherwise smoothed for inspection unless its surface irregularities or juncture with the base metal would cause objectionable weld discontinuities to be obscured in the radiograph. If the backing is removed for radiography, the root shall be ground flush (see 5.24.4.1) with the base metal.

The radiographic procedure and technique shall be in accordance with the requirements of Part E, section 6. For welder qualification, exclude 1-1/4 in. (32 mm) at each end of the weld from evaluation in the plate test; for welding operator qualification exclude 3 in. (75 mm) at each end of the test plate length. Welded test pipe or tubing 4 in. (100 mm) in diameter or larger shall be examined for a minimum of one-half of the weld perimeter selected to include a sample of all positions welded. (For example, a test pipe or tube welded in the 5G, 6G, or 6GR position shall be radiographed from the top centerline to the bottom centerline on either side.) Welded test pipe or tubing less than 4 in. in diameter shall require 100% radiography.

4.30.3.1 Radiographic Test Acceptance Criteria. For acceptable qualification, the weld, as revealed by the radiograph, shall conform to the requirements of 6.12.2, except that 6.12.2.2 shall not apply.

4.30.4 Fillet Weld Break Test. The entire length of the fillet weld shall be examined visually, and then a 6 in. (150 mm) long specimen (see Figure 4.36) or a quarter-section of the pipe fillet weld assembly shall be loaded in such a way that the root of the weld is in tension. At least one welding start and stop shall be located within the test specimen. The load shall be increased or repeated until the specimen fractures or bends flat upon itself.

4.30.4.1 Acceptance Criteria for Fillet Weld Break Test. To pass the visual examination prior to the break test, the weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and undercut in excess of the requirements of 6.9. There shall be no porosity visible on the weld surface.

The broken specimen shall pass if:

(1) The specimen bends flat upon itself, or

(2) The fillet weld, if fractured, has a fracture surface showing complete fusion to the root of the joint with no inclusion or porosity larger than 3/32 in. (2 mm) in greatest dimension, and

(3) The sum of the greatest dimensions of all inclusions and porosity shall not exceed 3/8 in. (10 mm) in the 6 in. (150 mm) long specimen.

4.30.5 Root, Face, and Side Bend Specimens. See 4.8.3.3 for acceptance criteria.

4.31 Method of Testing and Acceptance Criteria for Tack Welder Qualification

A force shall be applied to the specimen as shown in Figure 4.34 until rupture occurs. The force may be applied by any convenient means. The surface of the weld and of the fracture shall be examined visually for defects.

4.31.1 Visual Acceptance Criteria. The tack weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and undercut exceeding 1/32 in. (1 mm). There shall be no porosity visible on the surface of the tack weld.

4.31.2 Destructive Testing Acceptance Criteria. The fractured surface of the tack weld shall show fusion to the root, but not necessarily beyond, and shall exhibit no incomplete fusion to the base metals or any inclusion or porosity larger than 3/32 in. (2 mm) in greatest dimension.

4.32 Retest

When a welder, welding operator or tack welder either fails a qualification test, or if there is specific reason to question their welding abilities or period of effectiveness has lapsed, the following shall apply:

4.32.1 Welder and Welding Operator Retest Requirements

4.32.1.1 Immediate Retest. An immediate retest may be made consisting of two welds of each type and position that the welder or welding operator failed. All retest specimens shall meet all of the specified requirements.

4.32.1.2 Retest After Further Training or Practice. A retest may be made, provided there is evidence that the welder or welding operator has had further training or practice. A complete retest of the types and positions failed or in question shall be made.

4.32.1.3 Retest After Lapse of Qualification Period of Effectiveness. When a welder's or welding operator's qualification period of effectiveness has lapsed, a requalification test shall be required. Welders have the option of using a test thickness of 3/8 in. to qualify any production welding thickness greater than or equal to 1/8 in.

4.32.1.4 Exception — Failure of a Requalification Retest. No immediate retest shall be permitted after failure of a requalification retest. A retest shall be permitted only after further training and practice per 4.32.1.2.

4.32.2 Tack Welder Retest Requirements

4.32.2.1 Retest without Additional Training. In case of failure to pass the test requirements, the tack welder may make one retest without additional training.

4.32.2.2 Retest After Further Training or Practice. A retest may be made, provided the tack welder has had further training or practice. A complete retest shall be required.

5. Fabrication

5.1 Scope

All applicable provisions of this section shall be observed in the fabrication and erection of welded assemblies and structures produced by any process acceptable under this code. (See 3.2 and 4.15.)

5.2 Base Metal

5.2.1 Specified Base Metal. The contract documents shall designate the specification and classification of base metal to be used. When welding is involved in the structure, approved base metals, listed in Table 3.1 or Annex M, should be used wherever possible.

5.2.2 Base Metal for Weld Tabs, Backing, and Spacers

5.2.2.1 Weld Tabs. Weld tabs used in welding shall conform to the following requirements:

(1) When used in welding with an approved steel listed in Table 3.1 or Annex M, they may be any of the steels listed in Table 3.1 or Annex M.

(2) When used in welding with a steel qualified in accordance with 4.7.3 they may be:

(a) The steel qualified, or

(b) Any steel listed in Table 3.1 or Annex M

5.2.2.2 Backing. Steel for backing shall conform to the requirements of 5.2.2.1, except that 100 ksi (690 MPa) minimum yield strength steel as backing shall be used only with 100 ksi minimum yield strength steels.

5.2.2.3 Spacers. Spacers used shall be of the same material as the base metal.

5.3 Welding Consumables and Electrode Requirements

5.3.1 General

5.3.1.1 Certification for Electrodes or Electrode-Flux Combinations. When requested by the Engineer, the contractor or fabricator shall furnish certification that the electrode or electrode-flux combination will meet the requirements of the classification.

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

5.3.1.3 Shielding Gas. A gas or gas mixture used for shielding shall be of a welding grade and have a dew point of −40°F (−40°C) or lower. When requested by the Engineer, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture will meet the dew point requirements. When mixed at the welding site, suitable meters shall be used for proportioning the gases. Percentage of gases shall conform to the requirements of the WPS.

5.3.1.4 Storage. Welding consumables that have been removed from the original package shall be protected and stored so that the welding properties are not affected.

5.3.1.5 Condition. Electrodes shall be dry and in suitable condition for use.

5.3.2 SMAW Electrodes. Electrodes for SMAW shall conform to the requirements of the latest edition of ANSI/AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding Electrodes*, or to the requirements of ANSI/AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

5.3.2.1 Low-Hydrogen Electrode Storage Conditions. All electrodes having low hydrogen coverings conforming to ANSI/AWS A5.1 and ANSI/AWS A5.5 shall be purchased in hermetically sealed containers or shall be baked by the user in accordance with 5.3.2.4 prior to use. Immediately after opening the hermetically sealed container, electrodes shall be stored in ovens held at a temperature of at least 250°F (120°C). Electrodes shall be rebaked no more than once. Electrodes that have been wet shall not be used.

5.3.2.2 Approved Atmospheric Time Periods. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere shall not exceed the values shown in column A, Table 5.1, for the specific electrode classification with optional supplemental designators, where applicable. Electrodes exposed to the atmosphere for periods less than those permitted by column A, Table 5.1 may be returned to a holding oven maintained at 250°F (120°C) min; after a minimum hold period of four hours at 250°F min. the electrodes may be reissued.

5.3.2.3 Alternative Atmospheric Exposure Time Periods Established by Tests. The alternative exposure time values shown in column B in Table 5.1 may be used provided testing establishes the maximum allowable time. The testing shall be performed in conformance with ANSI/AWS A5.5, subsection 3.10, for each electrode classification and each electrode manufacturer. Such tests shall establish that the maximum moisture content values of ANSI/AWS A5.5 (Table 9) are not exceeded. Additionally, E70XX or E70XX-X (ANSI/AWS A5.1 or A5.5) low-hydrogen electrode coverings shall be limited to a maximum moisture content not exceeding 0.4% by weight. These electrodes shall not be used at relative humidity-temperature combinations that exceed either the relative humidity or moisture content in the air that prevailed during the testing program.

For proper application of this provision, see Annex VIII for the temperature-moisture content chart and its examples. The chart shown in Annex VIII, or any standard psychometric chart, shall be used in the determination of temperature-relative humidity limits.

Table 5.1
Permissible Atmospheric Exposure of Low-Hydrogen Electrodes (see 5.3.2.2 and 5.3.2.3)

Electrode	Column A (hours)	Column B (hours)
A5.1		
E70XX	4 max	
E70XXR	9 max	Over 4 to 10 max
E70XXHZR	9 max	
E7018M	9 max	
A5.5		
E70XX-X	4 max	Over 4 to 10 max
E80XX-X	2 max	Over 2 to 10 max
E90XX-X	1 max	Over 1 to 5 max
E100XX-X	1/2 max	Over 1/2 to 4 max
E110XX-X	1/2 max	Over 1/2 to 4 max

Notes:
1. Column A: Electrodes exposed to atmosphere for longer periods than shown shall be redried before use.
2. Column B: Electrodes exposed to atmosphere for longer periods than those established by testing shall be redried before use.
3. Entire table: Electrodes shall be issued and held in quivers, or other small open containers. Heated containers are not mandatory.
4. The optional supplemental designator, R, designates a low-hydrogen electrode which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level permitted in ANSI/AWS A5.1-91, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*.

5.3.2.4 Baking Electrodes. Electrodes exposed to the atmosphere for periods greater than those permitted in Table 5.1 shall be baked as follows:

(1) All electrodes having low-hydrogen coverings conforming to ANSI/AWS A5.1 shall be baked for at least two hours between 500°F (260°C) and 800°F (430°C), or

(2) All electrodes having low-hydrogen coverings conforming to ANSI/AWS A5.5 shall be baked for at least one hour at temperatures between 700°F (370°C) and 800°F (430°C).

All electrodes shall be placed in a suitable oven at a temperature not exceeding one half the final baking temperature for a minimum of one half hour prior to increasing the oven temperature to the final baking temperature. Final baking time shall start after the oven reaches final baking temperature.

5.3.2.5 Electrode Restrictions for ASTM A514 or A517 Steels. When used for welding ASTM A514 or A517 steels, electrodes of any classification lower than E100XX-X, except for E7018M and E70XXH4R, shall be baked at least one hour at temperatures between 700 and 800°F (370 and 430°C) before being used, whether furnished in hermetically sealed containers or otherwise.

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

5.3.3.1 Electrode-Flux Combination Requirements. The bare electrodes and flux used in combination for SAW of steels shall conform to the requirements in the latest edition of ANSI/AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, or to the requirements of the latest edition of ANSI/AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*.

5.3.3.2 Condition of Flux. Flux used for SAW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 500°F (260° C) for one hour before use. Flux shall be placed in the dispensing system immediately upon opening a package, or if used from an opened package, the top one inch shall be discarded. Flux that has been wet shall not be used.

5.3.3.3 Flux Reclamation. SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, catch pans, sweeping, or other means. The welding fabricator shall have a system for collecting unmelted flux, adding new flux, and welding with the mixture of these two, such that the flux composition and particle size distribution at the weld puddle are relatively constant.

5.3.3.4 Recrushed Slag. Recrushed slag may be used provided it has its own marking, using the recrusher's name and trade designation. In addition, each dry batch or dry blend (lot) of flux, as defined in ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*, shall be tested in conformance with Schedule I of ANSI/AWS A5.01 and classified by the contractor or recrusher per ANSI/AWS A5.17 or A5.23, as applicable.

5.3.4 GMAW/FCAW Electrodes. The electrodes and shielding for gas metal arc welding (GMAW) or flux cored arc welding (FCAW) for producing weld metal with minimum specified yield strengths of 60 000 psi (415 MPa) or less, shall conform to the requirements of the latest edition of ANSI/AWS A5.18, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*, or ANSI/AWS A5.20, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, as applicable.

5.3.4.1 Low-Alloy Electrodes for GMAW. The electrodes and shielding for GMAW for producing weld metal with a minimum specified yield strength greater than 60 000 psi (415 MPa) shall conform with the latest edition of ANSI/AWS A5.28, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*.

5.3.4.2 Low-Alloy Electrodes for FCAW. The electrodes and shielding gas for FCAW for producing weld metal with a minimum specified yield strength greater than 60 000 psi (415 MPa) shall conform to the latest edition of ANSI/ AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*.

5.3.5 GTAW

5.3.5.1 Tungsten Electrodes. Welding current shall be compatible with the diameter and type or classification of electrode. Tungsten electrodes shall be in accordance with ANSI/AWS A5.12, *Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting*.

5.3.5.2 Filler Metal. The filler metal shall conform to all the requirements of the latest edition of ANSI/AWS A5.18 or ANSI/AWS A5.28 and ANSI/AWS A5.30, *Specification for Consumable Inserts*, as appropriate.

5.4 Electroslag and Electrogas Welding Processes

5.4.1 Process Limitations. The electroslag and electrogas welding processes shall not be used for welding quenched and tempered steel nor for welding cyclically loaded structural members subject to tensile stresses or reversal of stress.

5.4.2 Condition of Electrodes and Guide Tubes. Electrodes and consumable guide tubes shall be dry, clean, and in suitable condition for use.

5.4.3 Condition of Flux. Flux used for electroslag welding shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from packages damaged in transit or in handling shall be discarded or shall be dried at a minimum temperature of 250° F (120° C) for one hour before use. Flux that has been wet shall not be used.

5.4.4 Weld Starts and Stops. Welds shall be started in such a manner as to permit sufficient heat buildup for complete fusion of the weld metal to the groove faces of the joint. Welds which have been stopped at any point in the weld joint for a sufficient amount of time for the slag or weld pool to begin to solidify may be restarted and completed, provided the completed weld is examined by ultrasonic testing for a minimum of 6 in. (150 mm) on either side of the restart and, unless prohibited by joint geometry, also confirmed by radiographic testing. All such restart locations shall be recorded and reported to the Engineer.

5.4.5 Preheating. Because of the high-heat input characteristic of these processes, preheating is not normally required. However, no welding shall be performed when the temperature of the base metal at the point of welding is below 32°F (0°C).

5.4.6 Repairs. Welds having discontinuities prohibited by section 6, Part C shall be repaired as permitted by 5.26 utilizing a qualified welding process, or the entire weld shall be removed and replaced.

5.4.7 Weathering Steel Requirements. For electroslag and electrogas welding of exposed, bare, unpainted applications of ASTM A588 steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode-flux combination shall be in accordance with 4.17.2, and the filler metal chemical composition shall conform to Table 3.3.

5.5 WPS Variables

The welding variables shall be in conformance with a written WPS. (See Annex E, Form E1, as an example.) Each pass will have complete fusion with the adjacent base metal, and such that there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in the roots of joints under restraint.

5.6 Preheat and Interpass Temperatures

Base metal shall be preheated, if required, to a temperature not less than the minimum value listed on the WPS. (See 3.5 for prequalified WPS limitations and Table 4.5 for qualified WPS essential variable limitations.) For combinations of base metals, the minimum preheat shall be based on the highest minimum preheat.

This preheat and all subsequent minimum interpass temperatures shall be maintained during the welding operation for a distance at least equal to the thickness of the thickest welded part (but not less than 3 in. [75 mm]) in all directions from the point of welding.

Minimum interpass temperature requirements shall be considered equal to the preheat requirements, unless otherwise indicated on the WPS.

The preheat and interpass temperature shall be checked just prior to initiating the arc for each pass.

5.7 Heat Input Control for Quenched and Tempered Steels

When quenched and tempered steels are welded, the heat input shall be restricted in conjunction with the maximum preheat and interpass temperatures required. Such considerations shall include the additional heat input produced in simultaneous welding on the two sides of a common member. The preceding limitations shall be in conformance with the producer's recommendations. Oxygen gouging of quenched and tempered steel is not permitted.

5.8 Stress-Relief Heat Treatment

Where required by the contract drawings or specifications, welded assemblies shall be stress relieved by heat treating. Final machining after stress relieving shall be considered when needed to maintain dimensional tolerances.

5.8.1 Requirements. The stress-relief treatment shall conform to the following requirements:

(1) The temperature of the furnace shall not exceed 600°F (315°C) at the time the welded assembly is placed in it.

(2) Above 600°F, the rate of heating shall not be more than 400°F (200°C) per hour divided by the maximum metal thickness of the thicker part, in inches, but in no case more than 400°F per hour. During the heating period, variations in temperature throughout the portion of the part being heated shall be no greater than 250°F (140°C) within any 15 ft (4.6 m) interval of length. The rates of heating and cooling need not be less than 100°F (55°C) per hour. However, in all cases, consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

(3) After a maximum temperature of 1100°F (590°C) is reached on quenched and tempered steels, or a mean temperature range between 1100 and 1200°F (650°C) is reached on other steels, the temperature of the assembly shall be held within the specified limits for a time not less than specified in Table 5.2, based on weld thickness. When the specified stress relief is for dimensional stability, the holding time shall be not less than specified in Table 5.2, based on the thickness of the thicker part. During the holding period there shall be no difference greater than 150°F (84°C) between the highest and lowest temperature throughout the portion of the assembly being heated.

(4) Above 600°F, cooling shall be done in a closed furnace or cooling chamber at a rate no greater than 500°F (260°C) per hour divided by the maximum metal thickness of the thicker part in inches, but in no case more than 500°F per hour. From 600°F, the assembly may be cooled in still air.

Table 5.2
Minimum Holding Time (see 5.8.1)

1/4 in. (6.4 mm) or Less	Over 1/4 in. (6.4 mm) Through 2 in. (50.8 mm)	Over 2 in. (50.8 mm)
15 min	1 hr/in.	2 hrs plus 15 min for each additional in. over 2 in. (50.8 mm)

5.8.2 Alternative PWHT. Alternatively, when it is impractical to postweld heat treat (PWHT) to the temperature limitations stated in 5.8.1, welded assemblies may be stress-relieved at lower temperatures for longer periods of time, as given in Table 5.3.

5.8.3 Steels Not Recommended for PWHT. Stress relieving of weldments of A514, A517, A709 Grades 100 and 100W, and A710 steels is not generally recommended. Stress relieving may be necessary for those applications where weldments must retain dimensional stability during machining or where stress corrosion may be involved, neither condition being unique to weldments involving A514, A517, A709 Grades 100 and 100W, and A710 steels. However, the results of notch toughness tests have shown that PWHT may actually impair weld metal and heat-affected zone toughness, and intergranular cracking may sometimes occur in the grain-coarsened region of the weld heat-affected zone.

5.9 Backing, Backing Gas, or Inserts

Complete joint penetration groove welds may be made with or without the use of backing gas, backing or consumable inserts, or may have the root of the initial weld gouged, chipped, or otherwise removed to sound metal before welding is started on the second side.

5.10 Backing

Roots of groove or fillet welds may be backed by copper, flux, glass tape, ceramic, iron powder, or similar materials to prevent melting through. They may also be sealed by means of root passes deposited with low-hydrogen electrodes if SMAW is used, or by other arc welding processes. Steel backing shall conform to the following requirements:

Table 5.3
Alternate Stress-Relief Heat Treatment (see 5.8.2)

Decrease in Temperature below Minimum Specified Temperature, ΔF	ΔC	Minimum Holding Time at Decreased Temperature, Hours per Inch (25.4 mm) of Thickness
50	28	2
100	56	4
150	84	10
200	112	20

5.10.1 Fusion. Groove welds made with the use of steel backing shall have the weld metal thoroughly fused with the backing.

5.10.2 Full-Length Backing. Steel backing shall be made continuous for the full length of the weld. All joints in the steel backing shall be complete joint penetration welded butt joints meeting all the requirements of section 5 of this code.

5.10.3 Backing Thickness. The suggested minimum nominal thickness of backing bars, provided that the backing shall be of sufficient thickness to prevent melt-through, is shown in the following table:

Process	Thickness, min in.	mm
GTAW	1/8	3.2
SMAW	3/16	4.8
GMAW	1/4	6.4
FCAW-S	1/4	6.4
FCAW-G	3/8	9.5
SAW	3/8	9.5

Note: Commercially available steel backing for pipe and tubing is acceptable, provided there is no evidence of melting on exposed interior surfaces.

5.10.4 Cyclically Loaded Nontubular Connections. For cyclically loaded structures, steel backing of welds that are transverse to the direction of computed stress shall be removed, and the joints shall be ground or finished smooth. Steel backing of welds that are parallel to the direction of stress or are not subject to computed stress need not be removed, unless so specified by the Engineer.

5.10.4.1 Externally Attached Backing. Where the steel backing of longitudinal welds in cyclically loaded structures is externally attached to the base metal by welding, such welding shall be continuous for the length of the backing.

5.10.5 Statically Loaded Connections. Steel backing for welds in statically loaded structures (tubular and nontubular) need not be welded full length and need not be removed unless specified by the Engineer.

5.11 Welding and Cutting Equipment

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

5.12 Welding Environment

5.12.1 Maximum Wind Velocity. GMAW, GTAW, EGW, or FCAW-G shall not be done in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of five miles per hour (eight kilometers per hour).

5.12.2 Minimum Ambient Temperature. Welding shall not be done

(1) when the ambient temperature is lower than 0°F (−18°C)

(2) when surfaces are wet or exposed to rain, snow, or

(3) high wind velocities, or

(4) when welding personnel are exposed to inclement conditions.

Note: Zero°F does not mean the ambient environmental temperature, but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0°F, but a heated structure or shelter around the area being welded could maintain the temperature adjacent to the weldment at 0°F or higher.

5.13 Compliance with Design

The sizes and lengths of welds shall be no less than those specified by design requirements and detail drawings, except as permitted in Table 6.1. The location of welds shall not be changed without approval of the Engineer.

5.14 Minimum Fillet Weld Sizes

The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 5.8. In both cases the minimum size applies if it is sufficient to satisfy design requirements.

5.15 Preparation of Base Metal

Surfaces on which weld metal is to be deposited shall be smooth, uniform, and free from fins, tears, cracks, and other discontinuities which would adversely affect the quality or strength of the weld. Surfaces to be welded, and surfaces adjacent to a weld, shall also be free from loose or thick scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that can withstand vigorous wire brushing, a thin rust-inhibitive coating, or antispatter compound may remain with the following exception: for girders in cyclically loaded structures, all mill scale shall be removed from the surfaces on which flange-to-web welds are to be made.

5.15.1 Mill-Induced Discontinuities. The limits of acceptability and the repair of visually observed cut surface discontinuities shall be in accordance with Table 5.4, in which the length of discontinuity is the visible long dimension on the cut surface of material and the depth is the distance that the discontinuity extends into the material from the cut surface. All welded repairs shall be in accordance with this code. Removal of the discontinuity

Table 5.4
Limits on Acceptability and Repair of Mill Induced Laminar Discontinuities in Cut Surfaces (see 5.15.1)

Description of Discontinuity	Repair Required
Any discontinuity 1 in. (25 mm) in length or less	None, need not be explored.
Any discontinuity over 1 in. (25 mm) in length and 1/8 in. (3 mm) maximum depth	None, but the depth should be explored.*
Any discontinuity over 1 in. (25 mm) in length with depth over 1/8 in. (3 mm) but not greater than 1/4 in. (6 mm)	Remove, need not weld.
Any discontinuity over 1 in. (25 mm) in length with depth over 1/4 in. (6 mm) but not greater than 1 in.	Completely remove and weld.
Any discontinuity over 1 in. (25 mm) in length with depth greater than 1 in.	See 5.15.1.1.

*A spot check of 10% of the discontinuities on the cut surface in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 in. (3 mm), then all of the discontinuities over 1 in. (25 mm) in length remaining on that cut surface shall be explored by grinding to determine depth. If none of the discontinuities explored in the 10% spot check have a depth exceeding 1/8 in. (3 mm), then the remainder of the discontinuities on that cut surface need not be explored.

may be done from either surface of the base metal. The aggregate length of welding shall not exceed 20% of the length of the plate surface being repaired except with approval of the Engineer.

5.15.1.1 Acceptance Criteria. For discontinuities greater than 1 in. (25 mm) in length and depth discovered on cut surfaces, the following procedures shall be observed.

(1) Where discontinuities such as W, X, or Y in Figure 5.1 are observed prior to completing the joint, the size and shape of the discontinuity shall be determined by ultrasonic testing. The area of the discontinuity shall be determined as the area of total loss of back reflection, when tested in accordance with the procedure of ASTM A435, *Specification for Straight Beam Ultrasonic Examination of Steel Plates.*[1]

(2) For acceptance of W, X, or Y discontinuities, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4% of the cut material area (length times width) with the following exception: if the length of the discontinuity, or the aggregate width of discontinuities on any transverse section, as measured perpendicular to the cut material length, exceeds 20% of the cut material width, the 4% cut material area shall be reduced by the percentage amount of the width exceeding 20%. (For example, if a discontinuity is 30% of the cut material width, the area of discontinuity cannot exceed 3.6% of the cut material area.) The discontinuity on the cut surface of the cut material shall be removed to a depth of 1 in. (25 mm) beyond its intersection with the surface by chipping, gouging, or grinding, and blocked off by welding with a low-hydrogen process in layers not exceeding 1/8 in. (3 mm) in thickness for at least the first four layers.

(3) If a discontinuity Z, not exceeding the allowable area in 5.15.1.1(2), is discovered after the joint has been completed and is determined to be 1 in. (25 mm) or more away from the face of the weld, as measured on the cut base-metal surface, no repair of the discontinuity is required. If the discontinuity Z is less than 1 in. away from the face of the weld, it shall be removed to a distance of 1 in. from the fusion zone of the weld by chipping, gouging, or grinding. It shall then be blocked off by welding with a low- hydrogen process in layers not exceeding 1/8 in. (3 mm) in thickness for at least the first four layers.

(4) If the area of the discontinuity W, X, Y, or Z exceeds the allowable in 5.15.1.1 (2), the cut material or subcomponent shall be rejected and replaced, or repaired at the discretion of the Engineer.

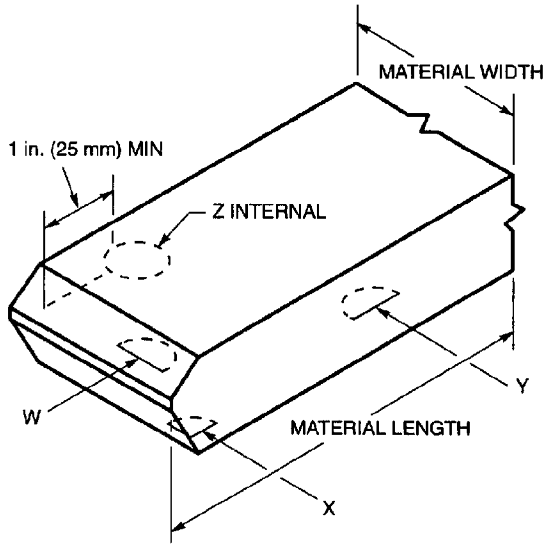


Figure 5.1—Edge Discontinuities in Cut Material (see 5.15.1.1)

1. ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

5.15.1.2 Repair. In the repair and determination of limits of mill induced discontinuities visually observed on cut surfaces, the amount of metal removed shall be the minimum necessary to remove the discontinuity or to determine that the limits of Table 5.4 are not exceeded. However, if weld repair is required, sufficient base metal shall be removed to provide access for welding. Cut surfaces may exist at any angle with respect to the rolling direction. All welded repairs of discontinuities shall be made by:

(1) Suitably preparing the repair area

(2) Welding with an approved low-hydrogen process and observing the applicable provisions of this code

(3) Grinding the completed weld smooth and flush (see 5.24.4.1) with the adjacent surface to produce a workmanlike finish.

Note: The requirements of 5.15.1.2 may not be adequate in cases of tensile load applied through the thickness of the material.

5.15.2 Joint Preparation. Machining, thermal cutting, gouging, chipping, or grinding may be used for joint preparation, or the removal of unacceptable work or metal, except that oxygen gouging shall not be used on steels that are ordered as quenched and tempered or normalized.

5.15.3 Material Trimming. For cyclically loaded structures, material thicker than specified in the following list shall be trimmed if and as required to produce a satisfactory welding edge wherever a weld is to carry calculated stress:

(1) Sheared material thicker than 1/2 in. (12.7 mm)

(2) Rolled edges of plates (other than universal mill plates) thicker than 3/8 in.(9.5 mm)

(3) Toes of angles or rolled shapes (other than wide flange sections) thicker than 5/8 in. (15.9 mm)

(4) Universal mill plates or edges of flanges of wide flange sections thicker than 1 in. (25.4 mm)

(5) The preparation for butt joints shall conform to the requirements of the detail drawings

5.15.4 Thermal Cutting Processes. Electric arc cutting and gouging processes and oxyfuel gas cutting processes are recognized under this code for use in preparing, cutting, or trimming materials. The use of these processes shall conform to the applicable requirements of section 5.

5.15.4.1 Other Processes. Other thermal cutting processes may be used under this code, provided the Contractor demonstrates to the Engineer an ability to successfully use the process.

5.15.4.2 Profile Accuracy. Steel and weld metal may be thermally cut, provided a smooth and regular surface free from cracks and notches is secured, and provided that an accurate profile is secured by the use of a mechanical guide. For cyclically loaded structures, freehand thermal cutting shall be done only where approved by the Engineer.

5.15.4.3 Roughness Requirements. In thermal cutting, the equipment shall be so adjusted and manipulated as to avoid cutting beyond (inside) the prescribed lines. The roughness of all thermal cut surfaces shall be no greater than that defined by the American National Standards Institute surface roughness value of 1000 μin. (25 μm) for material up to 4 in. (102 mm) thick and 2000 μin. (50 μm) for material 4 in. to 8 in. (203 mm) thick, with the following exception: the ends of members not subject to calculated stress at the ends shall not exceed a surface roughness value of 2000 μin. ANS/ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)* is the reference standard. AWS *Surface Roughness Guide for Oxygen Cutting* (AWS C4.1-77) may be used as a guide for evaluating surface roughness of these edges. For materials up to and including 4 in. (102 mm) thick, use Sample No. 3, and for materials over 4 in. up to 8 in. (203 mm) thick, use Sample No. 2.

5.15.4.4 Gouge or Notch Limitations. Roughness exceeding these values and notches or gouges not more than 3/16 in. (5 mm) deep on other wise satisfactory surfaces shall be removed by machining or grinding. Notches or gouges exceeding 3/16 in. deep may be repaired by grinding if the nominal cross-sectional area is not reduced by more than 2%. Ground or machined surfaces shall be fared to the original surface with a slope not exceeding one in ten. Cut surfaces and adjacent edges shall be left free of slag. In thermal-cut surfaces, occasional notches or gouges may, with approval of the Engineer, be repaired by welding.

5.16 Reentrant Corners

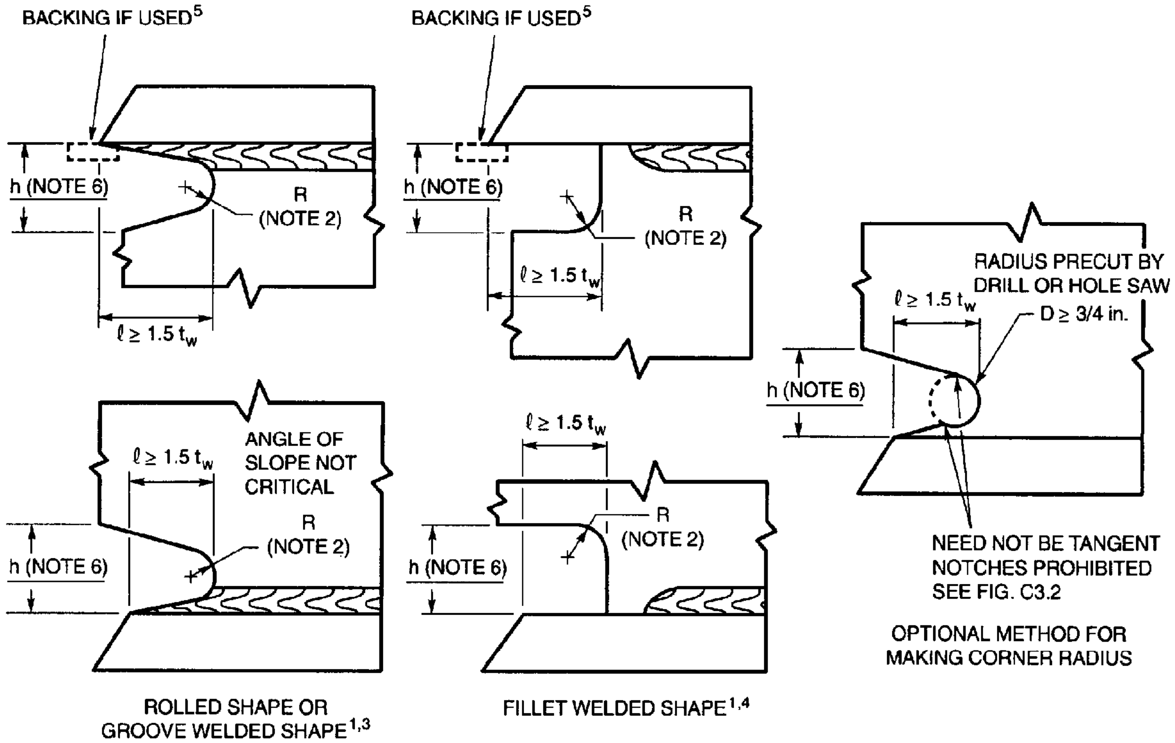
Reentrant corners of cut material shall be formed to provide a gradual transition with a radius of not less than 1 in. (25 mm). Adjacent surfaces shall meet without offset or cutting past the point of tangency. The reentrant corners may be formed by thermal cutting, followed by grinding, if necessary, to meet the surface requirements of 5.15.4.3.

5.17 Beam Copes and Weld Access Holes

Radii of beam copes and weld access holes shall provide a smooth transition free of notches or cutting past the points of tangency between adjacent surfaces and shall meet the surface requirements of 5.15.4.3.

5.17.1 Weld Access Hole Dimensions. All weld access holes required to facilitate welding operations shall have a length (ℓ) from the toe of the weld preparation not less than 1-1/2 times the thickness of the material in which the hole is made. The height (h) of the access hole shall be adequate for deposition of sound weld metal in the adjacent plates and provide clearance for weld tabs for the weld in the material in which the hole is made, but not less than the thickness of the material. In hot rolled shapes and built-up shapes, all beam copes and weld access holes shall be shaped free of notches or sharp reentrant corners except that when fillet web-to-flange welds are used in built-up shapes, access holes are permitted to terminate perpendicular to the flange. Fillet welds shall not be returned through weld access holes. See Figure 5.2.

5.17.2 Group 4 and 5 Shapes. For ASTM A6 Group 4 and 5 shapes and built-up shapes with web material thickness greater than 1-1/2 in. (38.1 mm), the thermally cut surfaces of beam copes and weld access holes shall be ground to bright metal and inspected by either magnetic particle or dye penetrant methods. If the curved transition portion of weld access holes and beam copes are formed by predrilled or sawed holes, that portion of the access hole or cope need not be ground. Weld access holes and beam copes in other shapes need not be ground nor dye penetrant or magnetic-particle inspected.



Notes:
1. For ASTM A6 Group 4 and 5 shapes and welded built-up shapes with web thickness more than 1-1/2 in. (38.1 mm), preheat to 150°F (66°C) prior to thermal cutting, grind and inspect thermally cut edges of access hole using magnetic particle or dye penetration methods prior to making web and flange splice groove welds.
2. Radius shall provide smooth notch-free transition; R ≥ 3/8 in. (9 mm) [Typical 1/2 in. (13 mm)].
3. Access opening made after welding web to flange.
4. Access opening made before welding web to flange. Weld not returned through opening.
5. These are typical details for joints welded from one side against steel backing. Alternative joint designs should be considered.
6. h_{min} = 3/4 in. or t_w (web thickness), whichever is greater.

Figure 5.2—Weld Access Hole Geometry (see 5.17.1)

5.18 Temporary and Tack Welds

5.18.1 Temporary Welds. Temporary welds shall be subject to the same welding procedure requirements as the final welds. These shall be removed, when required by the Engineer. When they are removed, the surface shall be made flush with the original surface.

For cyclically loaded nontubular connections, there shall be no temporary welds in tension zones of members made of quenched and tempered steel except at locations more than 1/6 of the depth of the web from tension flanges of beams or girders; temporary welds at other locations shall be shown on shop drawings.

5.18.2 General Requirements for Tack Welds. Tack welds shall be subject to the same quality requirements as the final welds, with the following exceptions:

(1) Preheat is not mandatory for single-pass tack welds which are remelted and incorporated into continuous submerged arc welds.

(2) Discontinuities, such as undercut, unfilled craters, and porosity need not be removed before the final submerged arc welding.

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

5.18.2.2 Additional Requirements for Tack Welds Incorporated in SAW Welds. Tack welds in the form of fillet welds 3/8 in. (10 mm) or smaller, or in the roots of joints requiring specific root penetration shall not produce objectionable changes in the appearance of the weld surface or result in decreased penetration. Tack welds not conforming to the preceding requirements shall be removed or reduced in size by any suitable means before welding. Tack welds in the root of a joint with steel backing less than 5/16 in. (8 mm) thick shall be removed or made continuous for the full length of the joint using SMAW with low-hydrogen electrodes, GMAW, or FCAW-G.

5.18.2.3 Nonincorporated Tack Welds. Tack welds not incorporated into final welds shall be removed, except that, for statically loaded structures, they need not be removed unless required by the Engineer.

5.19 Camber in Built-Up Members

5.19.1 Camber. Edges of built-up beam and girder webs shall be cut to the prescribed camber with suitable allowance for shrinkage due to cutting and welding. However, moderate variation from the specified camber tolerance may be corrected by a careful application of heat.

5.19.2 Correction. Corrections of errors in camber of quenched and tempered steel shall be given prior approval by the Engineer.

5.20 Splices in Cyclically Loaded Structures

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 general specifications shall apply.

5.21 Control of Distortion and Shrinkage

5.21.1 Procedure and Sequence. In assembling and joining parts of a structure or of built-up members and in welding reinforcing parts to members, the procedure and sequence shall be such as will minimize distortion and shrinkage.

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

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

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

5.21.5 Minimized Restraint. In assemblies, joints expected to have significant shrinkage should usually be welded before joints expected to have lesser shrinkage. They should also be welded with as little restraint as possible.

5.21.6 Subassembly Splices. All welded shop splices in each component part of a cover-plated beam or built-up member shall be made before the component part is welded to other component parts of the member. Long girders or girder sections may be made by welding subassemblies, each made in accordance with 5.21.6. When making these subassembly splices, whether in the shop or field, the welding sequence should be reasonably balanced between the web and flange welds as well as about the major and minor axes of the member.

5.21.7 Temperature Limitations. In making welds under conditions of severe external shrinkage restraint, once the welding has started, the joint shall not be allowed to cool below the minimum specified preheat until the joint has been completed or sufficient weld has been deposited to ensure freedom from cracking.

5.22 Tolerance of Joint Dimensions

5.22.1 Fillet Weld Assembly. The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening shall not exceed 3/16 in. (5 mm) except in cases involving either shapes or plates 3 in. (76.2 mm) or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in. (8 mm) is acceptable, provided suitable backing is used. Backing may be of flux, glass tape, iron powder, or similar materials, or welds using a low-hydrogen process compatible with the filler metal deposited. If the separation is greater than 1/16 in. (1.6 mm), the leg of the fillet weld shall be increased by the amount of the root opening, or the contractor shall demonstrate that the required effective throat has been obtained.

5.22.1.1 Faying Surface. The separation between faying surfaces of plug and slot welds, and of butt joints landing on a backing, shall not exceed 1/16 in. (1.6 mm). Where irregularities in rolled shapes occur after straightening do not permit contact within the above limits, the procedure necessary to bring the material within these limits shall be subject to the approval of the Engineer. The use of filler plates is prohibited except as specified on the drawings or as specially approved by the Engineer and made in accordance with 2.13.

5.22.2 Partial Joint Penetration Groove Weld Assembly. The parts to be joined by partial joint penetration groove welds parallel to the length of the member shall be brought into as close contact as practicable. The root opening between parts shall not exceed 3/16 in. (5 mm) except in cases involving rolled shapes or plates 3 in. (76.2 mm) or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in. (8 mm) is acceptable, provided suitable backing is used and the final weld meets the requirements for weld size. Tolerances for bearing joints shall be in accordance with the applicable contract specifications.

5.22.3 Butt Joint Alignment. Parts to be joined at butt joints shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10% of the thickness of the thinner part joined, but in no case more than 1/8 in. (3 mm), shall be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 1/2 in. (13 mm) in 12 in. (305 mm). Measurement of offset shall be based upon the centerline of parts unless otherwise shown on the drawings.

5.22.3.1 Girth Weld Alignment (Tubular). Abutting parts to be joined by girth welds shall be carefully aligned. No two girth welds shall be located closer than one pipe diameter or 3 ft (0.9 mm), whichever is less. There shall be no more than two girth welds in any 10 ft (3 m) interval of pipe, except as may be agreed upon by the owner and contractor. Radial offset of abutting edges of girth seams shall not exceed 0.2t (where t is the thickness of the thinner member) and the maximum allowable shall be 1/4 in. (6 mm), provided that any offset exceeding 1/8 in. (3 mm) is welded from both sides. However, with the approval of the Engineer, one localized area per girth seam may be offset up to 0.3t with a maximum of 3/8 in. (10 mm), provided the localized area is under 8t in length. Filler metal shall be added to this region to provide a 4 to 1 transition and may be added in conjunction with making the weld. Offsets in excess of this shall be corrected as provided in 5.22.3. Longitudinal weld seams of adjoining sections shall be staggered a minimum of 90°, unless closer spacing is agreed upon by the owner and fabricator.

5.22.4 Groove Dimensions

5.22.4.1 Nontubular Cross-Sectional Variations. With the exclusion of electroslag and electrogas welding, and with the exception of 5.22.4.3 for root openings in excess of those permitted in Figure 5.3, the dimensions of the cross section of the groove welded joints which vary from those shown on the detail drawings by more than these tolerances shall be referred to the Engineer for approval or correction.

5.22.4.2 Tubular Cross-Sectional Variations. Variation in cross section dimension of groove welded joints, from those shown on the detailed drawings, shall be in accordance with 5.22.4.1 except

(1) Tolerances for T-, Y-, and K-connections are included in the ranges given in 3.13.4.

(2) The tolerances shown in Table 5.5 apply to complete joint penetration tubular groove welds in butt joints, made from one side only, without backing.

5.22.4.3 Correction. Root openings greater than those permitted in 5.22.4.1, but not greater than twice the thickness of the thinner part or 3/4 in. (19 mm), whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding.

5.22.4.4 Engineer's Approval. Root openings greater than permitted by 5.22.4.3 may be corrected by welding only with the approval of the Engineer.

5.22.5 Gouged Grooves. Grooves produced by gouging shall be in substantial conformance with groove profile dimensions as specified in Figure 3.3 and 3.4 and provisions of 3.12.3 and 3.13.1. Suitable access to the root shall be maintained.

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

5.23 Dimensional Tolerance of Welded Structural Members

The dimensions of welded structural members shall conform to the tolerances of (1) the general specifications governing the work, and (2) the special dimensional tolerances in 5.23.1 to 5.23.11.3. (Note that a tubular column is interpreted as a compression tubular member.)

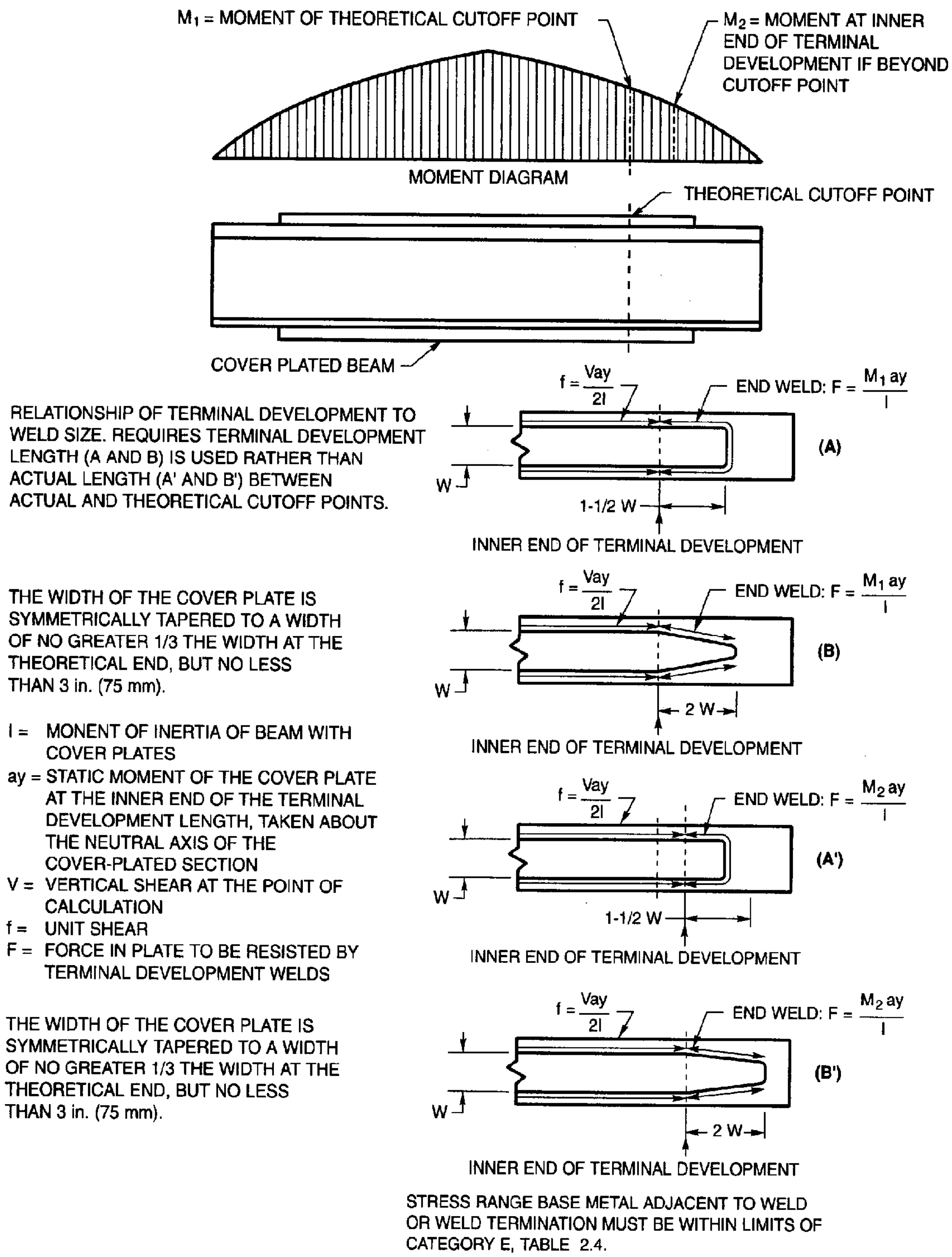


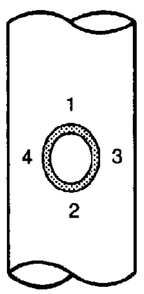
Figure C2.18—Relationship of Terminal Development to Weld Size (see C2.34)

Table C2.1
Survey of Diameter/Thickness and Flat Width/Thickness Limits for Tubes (see C2.36.1)

	For AWS Connection Design				For Member Design					
	Local Failure Ult $V_p = 0.57\ F_{yo}$	General Collapse at Chord Sidewall Yield	Cone-Cylinder 1:4 Flare	Applicability of Rules in 2.40	Full Plastic Design	Plastic Moments, Limited Rotation	Yield Moment or Limit of Elastic Behavior	Full Yield Axial	Limit of Local Buckling Formulae	
Circular Tubes	16 for K-Connection 12 for T & Y 9 for X	—	30	$\frac{3300}{F_y}$	$\frac{1300}{F_y}$	$\frac{1500}{F_y}$	$\frac{6000}{F_y}$	60	300	API RP2A
Circular Tubes					—	$\frac{2070}{F_y}$	$\frac{8970}{F_y}$	$\frac{3300}{\sqrt{F_y}}$	$\frac{13\ 000}{F_y}$	AISC
Box Sections	8 for K & N	22	20	$\frac{210}{\sqrt{F_y}} \leq 35$ For Gap Connections	$\frac{190}{\sqrt{F_y}}$	$\frac{210}{\sqrt{F_y}}$	$\frac{238}{\sqrt{F_y} - 10}$ at $M = S(F_y - 10)$	$\frac{238}{\sqrt{F_y}}$	No Limit	AISI Class A
Box Sections	7 for T & K			$\frac{190}{\sqrt{F_y}}$ For Overlap	$\frac{150}{\sqrt{F_y}}$		$\frac{238}{\sqrt{F_y}}$			AISI Class B

F_y in ksi (1 ksi = 7 MPa)
AISI Class A = hot formed
AISI Class B = cold formed and welded
Flat width may be taken as D – 3t for box section member design.

shown in Figure C2.19. The α factor on the f_a has been introduced to combine the former curves K and T into a single curve. Other terms are illustrated in Figure C2.25.



At locations 1 & 2
Cyclic $V_p = \tau \sin\theta\ [\alpha\ f_a \pm 0.67\ f_{by}]$

At locations 3 & 4
Cyclic $V_p = \tau \sin\theta\ [\alpha\ f_a \pm 1.5\ f_{bz}]$

At the point of highest stress
Cyclic $V_p = \tau \sin\theta\ \left[\alpha\ f_a + \sqrt{(0.67\ f_{by})^2 + (1.5\ f_{bz})^2}\ \right]$

C2.36.6.3 Basic Allowable Stress Limitation. Fatigue data characteristically show a large amount of scatter. The design curves have been drawn to fall on the safe side of 95 percent of the data points. The AWS design criteria are appropriate for redundant, fail-safe structures in which localized fatigue failure of a single connection does not lead immediately to collapse. For critical members whose sole failure would be catastrophic, the cumulative fatigue damage ratio, D, as defined in 2.36.6.4, must be limited to a fractional value (i.e., 1/3) to provide an added safety factor. This statement presumes there is no conservative bias or hidden safety factor in the spectrum of applied loads used for fatigue analysis (many codes include such bias). References 8 and 9 discuss application of these criteria to offshore structures, including modifications that may be appropriate for high-cycle fatigue under random loading and corrosive environments.

C2.36.6.6 Fatigue Behavior Improvement. The fatigue behavior of as-welded joints can be improved by reducing the notch effect at the toe of the weld, or by reducing the tensile residual stresses, neither of which is included in the measured hot spot strain range which designers use. Various methods for improving the fatigue behavior of welded joints, as discussed in Reference 11, are as follows: improving the as-welded profile (including the use of special electrodes designed to give a smooth transition at the weld toe), full profile grinding, weld toe grinding, weld toe remelting (GTAW dressing or plasma arc dressing), hammer peening, and shot peening.

A long established (but not universally used) offshore industry practice for improved weld profile is shown in Figure C2.20. The desired profile is concave, with a mini-

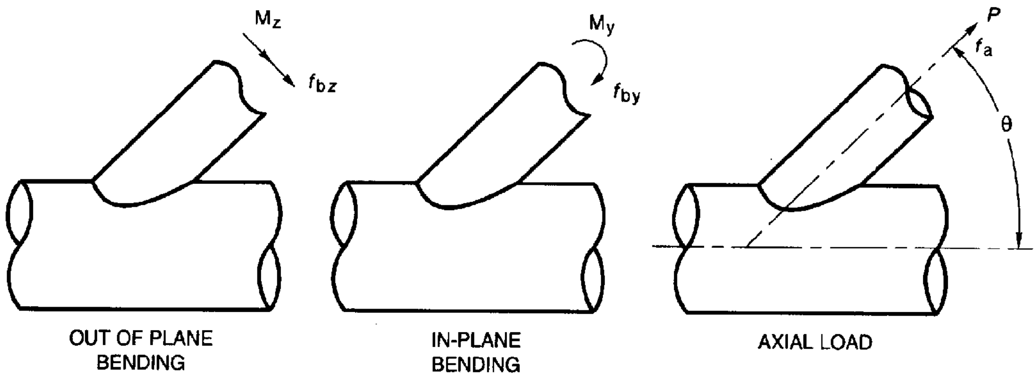
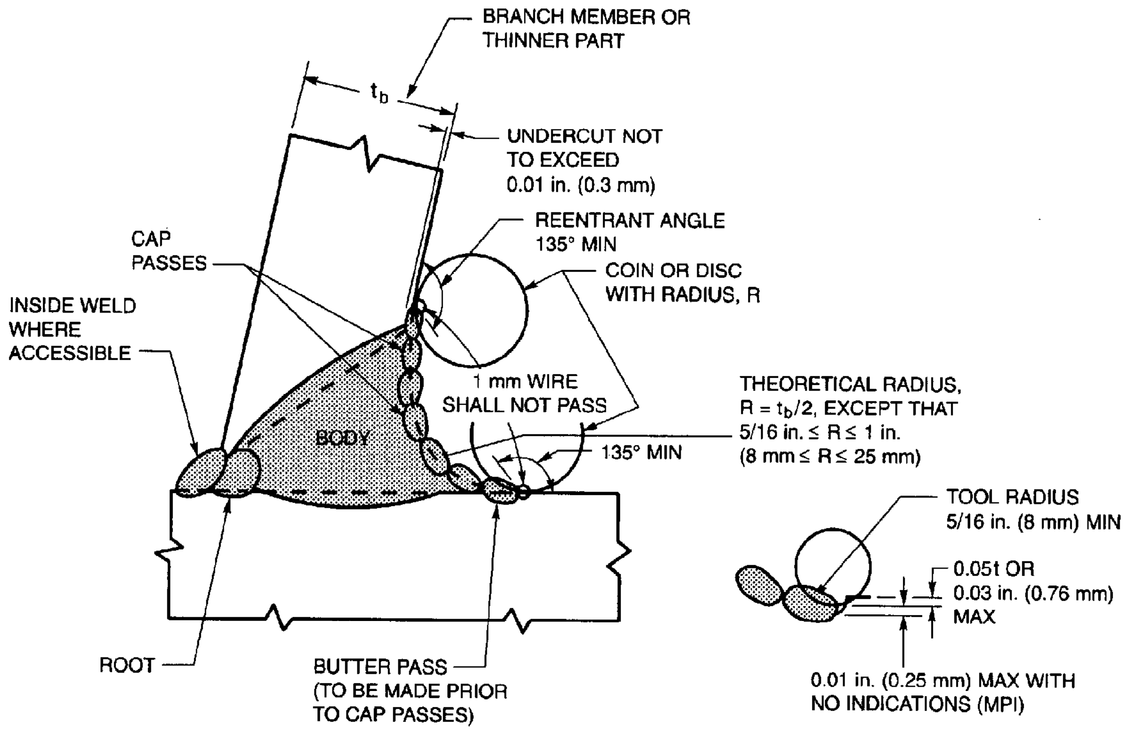


Figure C2.19—Illustrations of Branch Member Stresses Corresponding to Mode of Loading (see C2.36.6.2)



NOTE: MINIMUM REQUIREMENTS FOR OUTSIDE WELD AT TUBULAR CONNECTIONS DESIGNATED TO MEET 2.36.6.6(1).

MPI INDICATION, EXCESSIVE CONVEXITY, OR UNDERCUT IN WELD TOE PASSES OR BETWEEN ADJACENT PASSES MAY BE CORRECTED BY LIGHT GRINDING.

Figure C2.20—Improved Weld Profile Requirements (see C2.36.6.6)

mum radius of one-half the branch member thickness, and merges smoothly with the adjoining base metal. Achieving the desired profile as-welded generally requires the selection of welding materials having good wetting and profile characteristics, along with the services of a capping specialist who has mastered the stringer bead wash pass technique for various positions and geometries to be encountered. Difficulties in achieving this are often experienced with high deposition rate processes in the overhead and vertical positions. Inspection of the finished weld profile is mostly visual, with the disk test being applied to resolve borderline cases. Notches relative to the desired weld profile are considered unacceptable if a 0.04 in. (1 mm) wire can be inserted between the disk of the specified radius and the weld, either at the toe of the weld or between passes.

Earlier editions of ANSI/AWS D1.1 contained a less stringent weld profile requirement. Surprisingly poor weld profiles could pass this test, with the relative notch effect becoming increasingly more severe as the thickness of the members increased. Recent European research has shown the earlier D1.1 to be inadequate in distinguishing between welded tubular connections which meet the performance of AWS Fatigue Classification X1, and those which fall short (References 11 and 12).

Notch stress analysis and fracture mechanics considerations, while confirming the inadequacy of the old profile requirements for heavy sections, also indicate that the tighter requirements of Figure C2.20 are more effective in maintaining Class X1 fatigue performance over a wide range of thicknesses (Reference 13). Figure C2.20 also suggests the use of light grinding to correct toe defects, such as excessive notch depth or undercut. Once grinding starts, note that the permissible notch depth is reduced to 0.01 in. (0.25 mm); merely flattening the tops of the individual weld passes, while leaving sharp canyons in between, does little to improve the fatigue performance, even though it would meet the letter of the disk test.

Since the toes of welds frequently contain microscopic cracks and other crack-like defects, magnetic particle inspection (MPI) is necessary to make certain these defects have been eliminated. Judicious use of grinding to resolve MPI indication, often done routinely as part of the inspection, also enhances the weld profile.

Depending upon circumstances, it may be more cost effective to grind the entire weld profile smooth. This would avoid the use of special welding techniques, profile checking, corrective grinding, and MPI, as described above, for controlling the as-welded profile. For tubular connections, with multiple concave pass caps, fatigue cracks may start in the notch between passes; here, weld toe grinding alone is not as effective as with flat-fillet-weld profiles that were used in much of the research.

Weld toe remelting techniques can improve the geometry of the notch at the weld toe, and have been shown in the laboratory to improve the fatigue performance of welded connections. However, unless carefully controlled, the rapid cycle of heating and cooling tends to produce unacceptably hard heat-affected zones, with possible susceptibility to stress corrosion cracking in aggressive environments (e.g., seawater).

Hammer peening with a round-nose tool also improves the weld toe geometry; this additionally induces a compressive residual stress in the surface layers where fatigue cracks would otherwise be initiated. Excessive deformation of the base metal may render it susceptible to strain embrittlement from subsequent nearby welding. Also, surface layers may be so smeared as to obscure or obliterate pre-existing cracks; thus the requirement for MPI. Shot peening is less radical in its deformation effects, but also less effective in improving geometry.

It should be emphasized that, for many tubular structure applications, the performance of fatigue Classifications X2, K2, and ET will suffice, and the foregoing measures taken to improve fatigue performance are not required. Furthermore, the "standard" weld profile practices described in 3.13.4 can achieve the performance of fatigue Classifications X1, K1, and DT for all but the heaviest sections.

C2.36.6.7 Size and Profile Effects. The adverse size effect in the fatigue of welded connections is well documented (recent References 11, 12, and 13, as well as many earlier ones). For welded joints with a sharp notch at the weld toe, scaling up the size of the weld and the size of the notch results in a decrease in fatigue performance. When the application exceeds the scale of the data base, size effect should be accounted for in design. Reference 12 suggests decreasing the fatigue strength in proportion to

$$\left[\frac{\text{(size)}}{\text{(size limit)}}\right]^{-0.25}$$

Other authorities (Reference 14) indicate a milder size effect, approximating an exponent of −0.10.

The geometric notch effect largely responsible for the size effect in welds is not present in fully ground profiles and is relatively minor for those profiles which merge smoothly with the adjoining base metal (Fatigue Categories B and C1). The stated size limits (beyond which we are outside the historical data base) for most of the other categories are similar to those cited in Reference 12, except that the dimensions in inches have been rounded off. The larger size limits for Categories X2, K2, and DT reflect the fact that these S-N curves have already been drawn to fall below the recent large-scale test data.

Reference 13 discusses the role of size effect relative to weld profile, at various levels of fatigue performance.

The "standard" weld profile practices for T-, Y-, and K-connections referred to in 2.36.6.7 vary with thickness so as to define two fatigue performance levels which are size-independent. However, where an inferior profile is extended beyond its standard range, the size effect (reduction in performance) would come into play. "Improved" weld profiles which meet the requirements of 2.36.6.6(1) keep the notch effect constant over a wide range of thicknesses, thereby mitigating the size effect. The smooth surface profile of fully ground welds also exhibit no size effects. Since peening only improves a relative limited volume of the welded joint, the size effect would be expected to show up fairly soon if peening is the only measure taken; however, peening should not incur a size effect penalty where it is done in addition to profile control.

The size effect may also exhibit itself in static ultimate strength behavior, since the design rules are based in part on tests to tensile fracture. For tubular T-, Y-, and K-connections involving high-strength steels of low or unknown notch toughness, the Level I profile selections are recommended in preference to larger notches permitted by Level II.

C2.40 Limitations of the Strength of Welded Connections

A number of unique failure modes are possible in tubular connections. In addition to the usual checks on weld stress provided for in most design codes, the designer should check for the following:

	Circular	Box
(1) Local failure*	2.40.1.1	2.40.2.1
(2) General collapse	2.40.1.2	2.40.2.2
(3) Progressive failure (unzipping)	2.40.1.3	2.40.2.3
(4) Materials problems	2.42	2.42.1.5

*Overlapping connections are covered by 2.40.1.6 and 2.40.2.4 respectively.

C2.40.1.1 Local Failure. The design requirements are stated in terms of nominal punching shear stress (see Figure C2.21 for the simplified concept of punching shear). The actual localized stress situation is more complex than this simple concept suggests, and includes shell bending and membrane stress as well. Whatever the actual mode of main member failure, the allowable V_p is a conservative representation of the average shear stress at failure in static tests of simple welded tubular connections, including a safety factor of 1.8. For background data, the user should consult References 1-6.

Treatment of box sections has been made as consistent as possible with that of circular sections. Derivation of the basic allowable V_p for box sections included a safety factor of 1.8, based on limit analyses utilizing the ultimate tensile strength, which was assumed to be 1.5 times the specified minimum yield. This is why α (alpha) in Table 2.9 limits F_y in the design formula for punching shear to 2/3 the tensile strength.

A favorable redistribution of load was also assumed where appropriate. Localized yielding should be expected to occur within allowable load levels. Fairly general yielding with deflection exceeding 0.02D can be expected at loads exceeding 120–160% of the static allowable.

Alternatives to the punching shear approach for sizing tubular connections can be found in the literature (for example, Reference 3). However, such empirical rules, particularly design equations which are not dimensionally complete, should be limited in application to the tube configurations and sizes (and units) from which derived.

In the 1984 edition, substantial changes were made in the punching shear requirements for circular sections, to bring them up to date. These include:

(1) Elimination of K_a and K_b from the formula for acting V_p. Although logical from the standpoint of geometry and statics, these produce inappropriate trends in comparison to test data on the strength of tubular connections.

(2) New expressions for the allowable basic V_p and a new modifier Q_q which give results numerically similar to those in Reference 2.

(3) Introduction of the chord ovalizing parameter, α, which matches available results from single-plane joints and offers a promising extension to multiplanar joints (Reference 3).

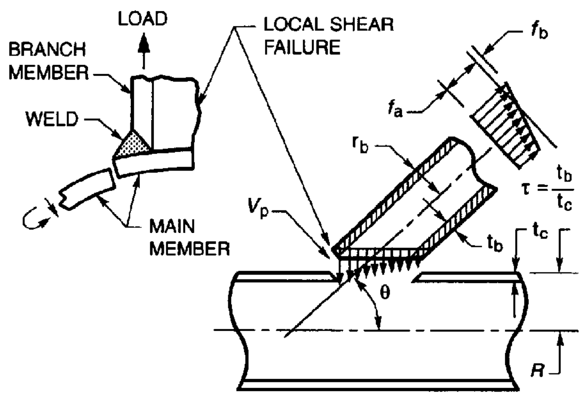


Figure C2.21—Simplified Concept of Punching Shear (see C2.40.1.1)

(4) A new expression for Q_f, based on the recent tests of Yura (Reference 4).

(5) Nonlinear interaction between axial load and bending in the branch member, based on the fully plastic behavior of tubular sections (Reference 5).

Figure C2.22 shows the reliability of the new punching shear criteria based on computed alpha, as a histogram of the ratio of test ultimate strength (P test) to the allowable. The data base of Reference 6 was used. Inappropriate tests have been deleted, and effective F_y conforming to the 2/3 rule have been estimated, as described in IIW-doc XV-405-77.

The test results cluster tightly just on the safe side of the nominal ultimate strength safety factor of 1.8. Using a log-normal safety index format, the median ultimate strength for joints failing by plastic collapse is 3.45 standard deviations above the design load, comparable to safety indices of 3 to 4 for connections in other types of construction. By discriminating between different joint types, the new criteria achieve similar overall economy and greater safety than the less precise criteria they replace.

The apparently large safety factor and safety index shown for tension tests is biased by the large number of small tubes in the data base. If only tubes with t_c = 0.25 inches are considered, the mean safety factor drops to 3.7; for t_c = 0.5 inches, the safety factor is only 2.2. Considering the singularity (sharp notch) at the toe of typical welds, and the unfavorable size effect in fracture-controlled failures, no bonus for tension loading has been allowed.

In the 1992 edition, the code has also included tubular connection design criteria in ultimate strength format, subsection 2.40.1.1(2) for circular sections. This was derived from, and intended to be equivalent to, the earlier punching shear criteria. The thin-wall assumption was made (i.e., no t_b/d_b correction), and the conversion for bending uses elastic section modulus.

When used in the context of AISC-LRFD, with a resistance factor of 0.8, this is nominally equivalent with the allowable stress design (ASD) safety factor of 1.8 for structures having 40% dead load and 60% service loads. The change of resistance factor on material shearing was done to maintain this equivalency.

LRFD falls on the safe side of ASD for structures having a lower proportion of dead load. AISC criteria for tension and compression members appear to make the equivalency trade-off at about 25% dead load; thus, the LRFD criteria given herein are nominally more conservative for a larger part of the population of structures. However, since the t_b/d_b correction to punching shear is not made acting $V_p = \tau \sin\theta f_n (1 - t_b/d_b)$

The ASD punching shear format also contains extra conservatism.

Figure C2.22 indicates a safety index of 3.45, appropriate for selection of the joint-can as a member (safety index is the safety margin of the design criteria, including hidden bias, expressed in standard deviations of total uncertainty). For further comparison, the ASCE Committee on Tubular Structures in Reference 2 derived a resistance factor of 0.81 for similar Yura-based tubular connection design criteria, targeting a safety index of 3.0.

Since the local failure criteria in 2.40 are used to select the main member or chord, the choice of safety index is comparable to that used for designing other structural members—rather than the higher values often cited for connection material such as rivets, bolts, or fillet welds, which raise additional reliability issues, e.g., local ductility and workmanship.

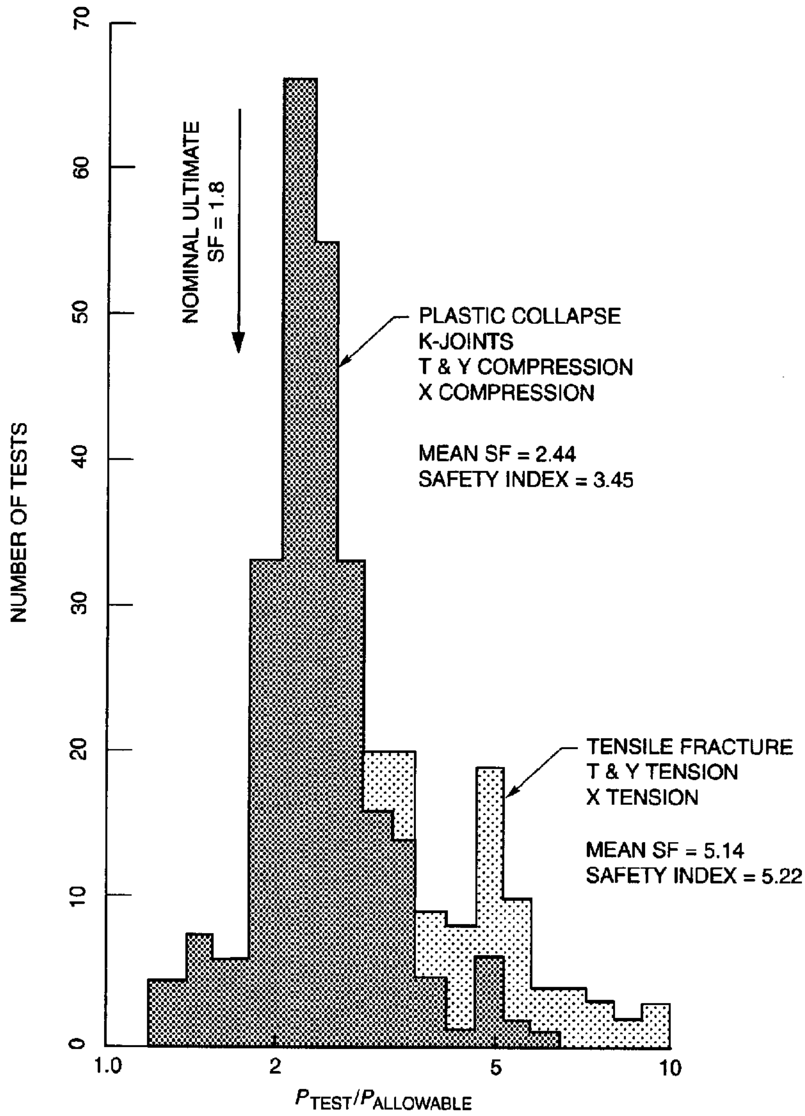
For offshore structures, typically dominated by environmental loading which occurs when they are unmanned, the 1986 draft of API RP2A-LRFD proposed more liberal resistance factors of 0.90 to 0.95, corresponding to a reduced target safety index of 2.5 (actually, as low as 2.1 for tension members). API also adjusted their allowable stress design criteria to reflect the benefit typical t_b/d_b ratios.

In Canada (Reference 21), using these resistance factors with slightly different load factors, a 4.2% difference in overall safety factor results. This is within calibration accuracy.

C2.40.1.2 General Collapse. In addition to localized failure of the main member, which occurs in the vicinity of the welded-on branch, a more widespread mode of general collapse failure may occur. In cylindrical members, this occurs by a general ovalizing plastic failure in the cylindrical shell of the main member. In box sections, this may involve web crippling or buckling of the side walls of the main member (see Reference 15).

C2.40.1.3 Uneven Distribution of Load (Weld Sizing). The initial elastic distribution of load transfer across the weld in a tubular connection is highly nonuniform, with peak line load (kips/inch) often being a factor of two or three higher than that indicated on the basis of nominal sections, geometry, and statics, as per 2.39.3. Some local yielding is required for tubular connections to redistribute this and reach their design capacity. If the weld is a weak link in the system, it may "unzip" before this re-distribution can happen.

The criteria given in the code are intended to prevent this unzipping, taking advantage of the higher safety factors in weld allowable stresses than elsewhere. For example, the line load ultimate strength of an 0.7t fillet weld made with E70XX electrodes is 0.7t (2.67 × 0.3 × 70) = 39t, adequate to match the yield strength of mild steel branch material.



SF = SAFETY FACTOR
DATA BASE: 306 (NON-OVERLAP) JOINTS. SEE REFERENCE 6.

Figure C.22—Reliability of Punching Shear Criteria Using Computed Alpha (see C2.40.1.1)

For another example, if the peak line load is really twice nominal, designing for 1.35 times the nominal line load will give a joint safety factor of 1.8, when the weld strength is 2.67 times its allowable stress. IIW rules, and LRFD-based strength calculations, suggest larger matching weld sizes are required, e.g., 1.0t or 1.2t (1.07t in the draft Eurocode). Given this easy way out of the problem, there has not been much testing to validate the foregoing AWS logic for smaller welds.

C2.40.2 Box T-, Y-, and K-Connections. In D1.1-90 and earlier editions of the code, treatment of box sections had been made as consistent as possible with that of circular sections. Derivation of the basic allowable punching shear V_p for box sections included a safety factor of 1.8, based on a simple yield line limit analysis, but utilizing the ultimate tensile strength, which was assumed to be 1.5 times the specified minimum yield. This is why F_y in the design formula for punching shear was limited to 2/3 times the tensile strength. A favorable redistribution of load was also assumed where appropriate. Localized yielding should be expected to occur within allowable load levels. Fairly general yielding, with connection distortion exceeding 0.02 D, can be expected at loads exceeding 120–160% of the static allowable.

A rational approach to the ultimate strength of stepped box connections can be taken, using the upper bound theorem of limit analysis (see Figure C2.25) and yield line patterns (similar to those shown in Figure C2.26). Various yield patterns for plastic chord face failure should be assumed in order to find the minimum computed capacity, which may be equal to or greater than the true value. Fan corners (as shown for the T- connection) often produce lower capacities than plain corners as shown for the other cases. Suggested design factors, given in Table C2.2, are consistent with the way we take advantage of strain hardening, load redistribution, etc., in using tests to failure as the basis for empirical design criteria. In general, the capacity will be found to be a function of the dimensionless topology parameters β, η and ξ (defined in the figure), as well as the chord thickness-squared (corresponding to τ and γ in the punching shear format).

For very large β (over 0.85) and K-connections with gap approaching zero, yield line analysis indicates extremely high and unrealistic connection capacity. In such cases, other limiting provisions based on material shear failure of the stiffer regions, and reduced capacity for the more flexible regions (i.e., effective width) must also be observed and checked.

Although the old AWS criteria covered these considerations (Reference 18), for bending as well as for axial load (Reference 19), more authoritative expressions representing a much larger data base have been developed over the years by CIDECT (Commitè International pour le Developpement et l'Etude de la Construction Tubulaire) (Reference 20) and by members of IIW Subcommittee XV-E (Reference 24). These criteria have been adapted for limit state design of steel structures in Canada (Packer et al Reference 21). The Canadian code is similar to the AISC-LRFD format. In the 1992 edition, these updated criteria were incorporated into the AWS code, using the thickness-squared ultimate strength format and Packer's resistance factors, where applicable.

C2.40.2.1 Local Failure. Load factors vary from equation to equation to reflect the differing amounts of bias and scatter apparent when these equations are compared to test data (Reference 21). For example, the equation for plastic chord face failure of T-, Y-, and cross connections is based on yield line analysis, ignoring the reserve strength which comes from strain hardening; this bias provides the safety factor with a Φ of unity. The second equation, for gap K- and N-connections was empirically derived, had less hidden bias on the safe side, and draws a lower resistance factor.

In the transition between gap connections and overlap connections, there is a region for which no criteria are given. See Figure C2.23. Offshore structure detailing practice typically provides a minimum gap "g" of 2-inches, or a 3-inch minimum overlap "q", to avoid weld interference. For smaller diameter box connections, the limitations are stated in relation to the member proportions. These limitations also serve to avoid the touching-toes case for stepped box connections, in which a disproportionately stiff load path is created that cannot handle all the load it attracts, possibly leading to progressive failure.

C2.40.2.2 General Collapse. To avoid a somewhat awkward adaptation of column buckling allowable to the box section web crippling problem (e.g., Reference 15), AISC-LRFD web yielding, crippling, and transverse buckling criteria have been adapted to tension, one-sided, and two-sided load cases, respectively. The resistance factors given are those of AISC. Packer (Reference 22) indicates a reasonably good correlation with available box connection test results, mostly of the two-sided variety.

C2.40.2.3 Uneven Distribution of Load (Effective Width). For box sections, this problem is now treated in terms of effective width concepts, in which load delivery to more flexible portions of the chord is ignored. Criteria for branch member checks are given in 2.40.2.3(1), based empirically on IIW/CIDECT work. Criteria for load calculation in welds (2.39.5) are based upon the testing of Packer (Reference 23) for gap K- and N-connections; and upon extrapolation and simplification of the IIW effective width concepts for T-, Y-, and cross connections.

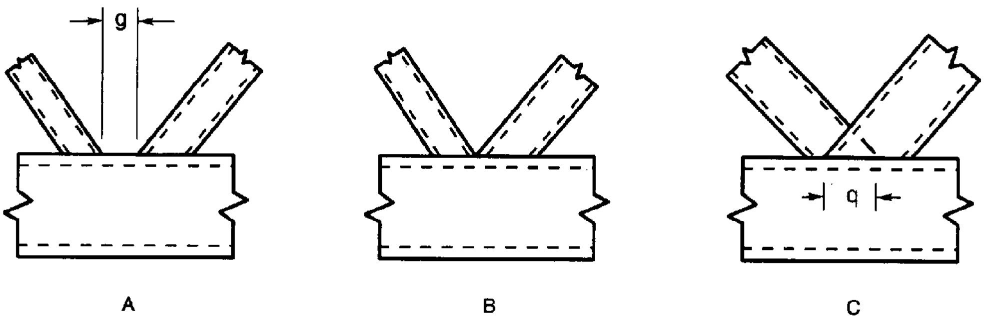


Figure C2.23—Transition Between Gap and Overlap Connections (see C2.40.2.1)

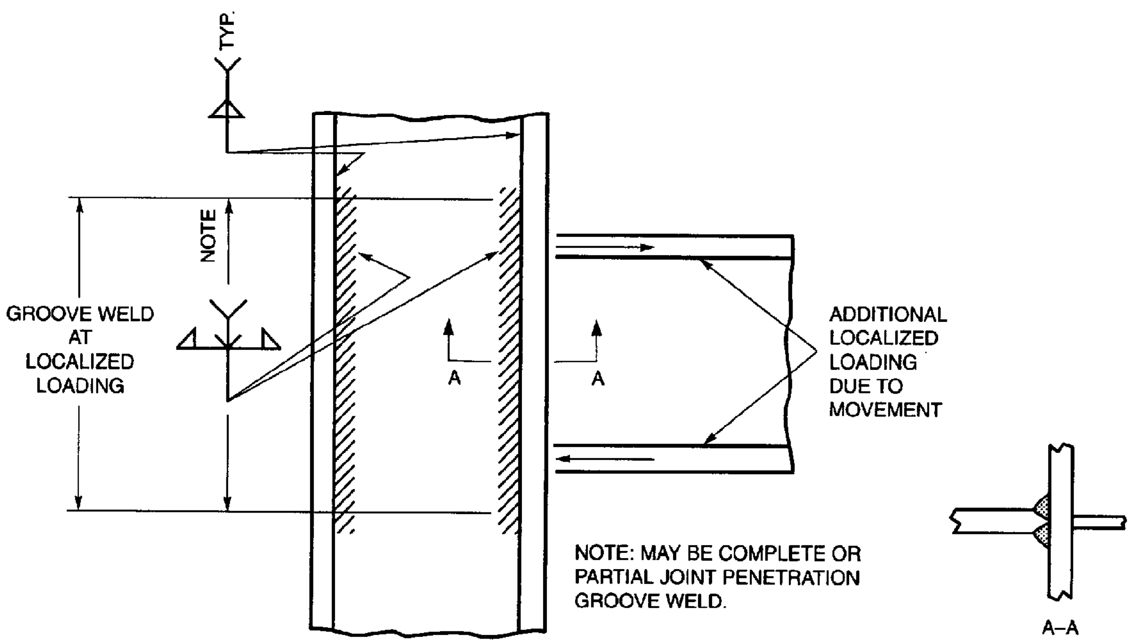
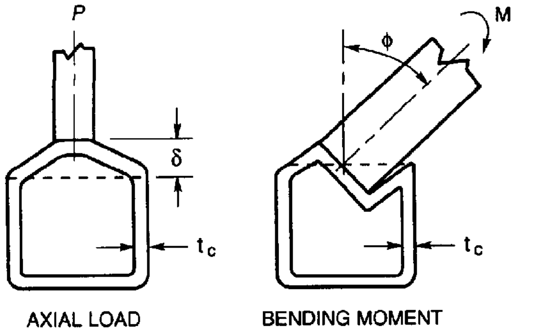


Figure C2.24—Partial Length Groove Weld (see 2.12.1)



$$\left.\begin{matrix}P\delta\\ \text{OR}\\ M\phi\end{matrix}\right\} = \frac{K}{SF}\,\frac{t_c^2F_y}{4}\sum_{\substack{\text{ALL}\\ \text{YIELD}\\ \text{LINES}}} a_i(L_i)$$

WHERE:

K = RESERVE STRENGTH FACTOR FOR STRAIN HARDENING, TRIAXIAL STRESS, LARGE DEFLECTION BEHAVIOR, ETC.

SF = SAFETY FACTOR

F_y = SPECIFIED YEILD STRENGTH OF MAIN MEMBER

a_i = REGULAR ROTATION OF YEILD LINE i AS DETERMINED BY GEOMETRY OF MECHANISM

L_i = LENGTH OF YIELD LINE SEGMENT

t_c = WALL THICKNESS OF CHORD

Figure C2.25—Upper Bound Theorem (see C2.36.6.2, C2.40.2, and C2.42)

C2.40.2.4 Overlapping Connections. By providing direct transfer of load from one branch member to the other in K- and N-connections, overlapping joints reduce the punching demands on the main member, permitting the use of thinner chord members in trusses. These are particularly advantageous in box sections, in that the member end preparations are not as complex as for circular tubes.

Fully overlapped connections, in which the overlapping brace is welded entirely to the through brace, with no chord contact whatsoever, have the advantage of even simpler end preparations. However, the punching problem that was in the chord for gap connections, is now transferred to the thru brace, which also has high beam shear and bending loads in carrying these loads to the chord.

Most of the testing of overlapped connections has been for perfectly balanced load cases, in which compressive transverse load of one branch is offset by the tension load of the other. In such overlapped connections, subjected to balanced and predominantly axial static loading, tests have shown that it is not necessary to complete the "hidden" weld at the toe of the through member. In real world design situations, however, localized chord shear loading or purlin loads delivered to the panel points of a truss result in unbalanced loads. In these unbalanced situations, the most heavily loaded member should be the through brace, with its full circumference welded to the chord, and additional checks of net load on the combined footprint of all braces are required.

C2.40.2.5 Bending. Since international criteria for bending capacity of tubular connections are not as well developed as for axial loads, the effects of primary bending moments are approximated as an additional axial load. In the design expression, JD represents half the moment arm between stress blocks creating the moment, analogous to concrete design—half, because only half the axial capacity lies on each side of the neutral axis. Various ultimate limit states are used in deriving the expressions for JD in Table C2.3. For chord face plastification, a uniform punching shear or line load capacity is assumed. For the material shear strength limit, the effective width is used. General collapse reflects a side wall failure mechanism. Finally, a simplified expression for JD is given, which may conservatively be used for any of the governing failure modes.

Caution should be exercised where deflections due to joint rotations could be important, e.g., sidesway of portal frames in architectural applications. Previous editions of the code provided a 1/3 decrease in allowable connection capacity for this situation.

C2.40.2.6 Other Configurations. The equivalence of box and circular branch members on box chords is based on their respective perimeters (0.785 is $\pi/4$). This in effect applies the concept of punching shear to the problem, even though these international criteria are always given in ultimate strength format. The results are on the safe side of available test results.

C2.42 Material Limitations

A rational approach to the ultimate strength of stepped box connections can be taken, using the upper bound theorem of limit analysis (see Figure C2.25) and yield line patterns similar to those shown in Figure C2.26. Various yield line patterns should be assumed in order to find the minimum computed capacity, which may be equal to or greater than the true value. Fan corners (as shown for the T-joint) often produce lower capacity than plain corners

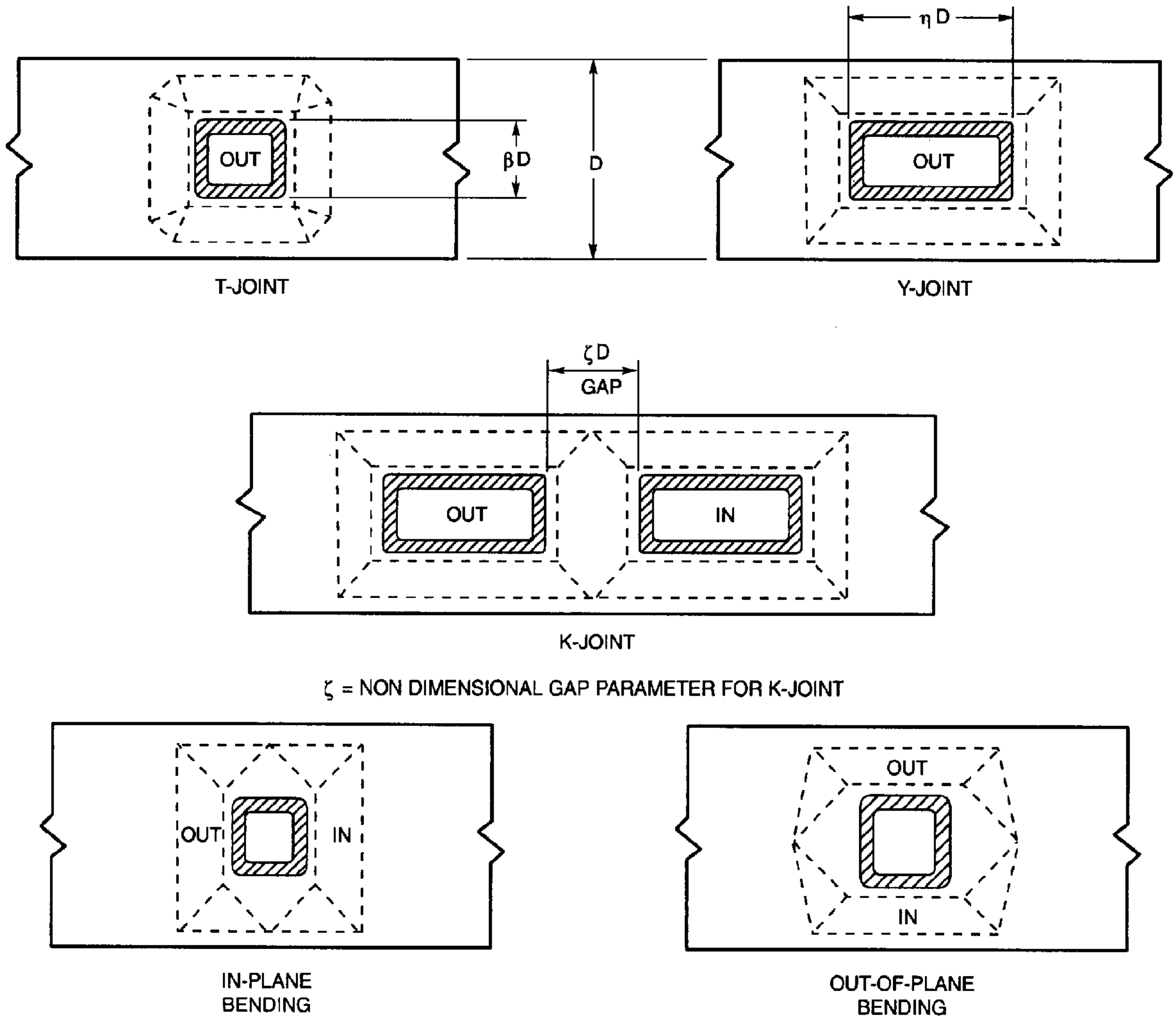


Figure C2.26—Yield Line Patterns (see C2.42 and C2.40.2)

Table C2.2
Suggested Design Factors (see C2.40.2)

	Assumed Value for K	SF for Static Loads	SF Where 1/3 Increase Applies
Where the ultimate breaking strength of the connection—includes effects of strain hardening, etc.,—can be utilized;			
Redundant fail-safe structures and designs consistent with 2.40.1	1.5*	1.8	1.4
Critical members whose sole failure would be catastrophic	1.5*	2.7	2.0
Architectural applications where localized deformation would be objectionable	1.0	1.7	1.3

*Applicable where main member, F_y, is not taken to exceed 2/3 the specified minimum tensile strength.

Table C2.3
Values of JD (see C2.40.2.5)

Governing Failure Mode	In-Plane Bending	Out-of-Plane Bending
Plastic Chord Wall Failure	$\frac{\eta D (\beta + \eta/2)}{2(\beta + \eta)}$	$\frac{\beta D (\eta + \beta/2)}{2(\eta + \beta)}$
Chord Material Shear Strength	$\frac{\eta D (\beta_{eop} + \eta/2)}{2(\beta_{eop} + \eta)}$	$\frac{\beta D [\eta + \beta_{eop}(1 - \beta_{eop}/2\beta)]}{2(\eta + \beta_{eop})}$
General Collapse	$\frac{\eta D + 5t_c}{4}$	$\frac{D}{2}$
Branch Member Effective Width	$\frac{\eta D (\beta_{eoi} + \eta/2)}{4}$	$\frac{\beta D [\eta + \beta_{eoi}(1 - b_{eoi}/2\beta)]}{2(\eta + \beta_{eoi})}$
Conservative Approximation for Any Mode	$\frac{\eta D}{4}$	$\frac{\beta D}{4}$

shown for the other cases. Suggested design factors are given in Table C2.2; these are intended to be consistent with those used in the body of the code. For T- and Y-connections, the geometry modifier is found to be a function of η as well as β, in contrast to the simpler expression given in 2.40.1. For K-connections, the gap parameter ξ also should be taken into account. The dimensionless geometry parameters, η, β, and ξ are defined in Figure C2.26.

For gaps approaching 0 and for very large β approaching unity, yield line analysis indicates extremely and unrealistically high joint capacity. The limiting provisions of 2.40.1.1 and 2.40.1.3 should also be checked.

C2.42.1.5 Box T-, Y-, or K-Connections. Tubular connections are subject to stress concentrations which may lead to local yielding and plastic strains. Sharp notches and flaws at the toe of the welds, and fatigue cracks which initiate under cyclic loading, place additional demands on the ductility and notch toughness of the steel, particularly under cyclic loads. These demands are particularly severe in the main member of tubular T-, Y-, and K-connections. Cold-formed box tubing (e.g., ASTM A500 and tubing fabricated from bent plates) is susceptible to degraded toughness due to strain aging in the corners, when these severely deformed regions are subjected to even moderate heat of nearby welding. Suitability of such tubing for the intended service should be evaluated using tests representing their final condition (i.e., strained and aged, if the tubing is not normalized after forming). See C2.42.2.2 for a discussion of impact testing requirements.

C2.42.2 Tubular Base-Metal Notch Toughness. Some steels are listed by strength group (Groups I, II, III, IV, and V) and toughness class (Classes A, B, and C) in Tables C2.4–C2.6. These listings are for guidance to designers, and follow long-established practice for offshore structures, as described in Reference 9 and the following: Strength Groups. Steels may be grouped according to strength level and welding characteristics as follows (also see 3.3 and 3.5):

(1) Group I designates mild structural carbon steels with specified minimum yield strengths of 40 ksi (280 MPa) or less. Carbon equivalent (defined in Annex XI, XI6.1.1) is generally 0.40% or less, and these steels may be welded by any of the welding processes as described in the code.

(2) Group II designates intermediate strength low alloy steels with specified minimum yield strengths of over 40 ksi through 52 ksi (280 through 360 MPa). Carbon equivalent ranges up to 0.45% and higher, and these steels require the use of low-hydrogen welding processes.

(3) Group III designates high-strength low-alloy steels with specified minimum yield strengths in excess of 52 ksi through 75 ksi (360 through 515 MPa). Such steels may be used, provided that each application is investigated with regard to the following:

(a) Weldability and special WPSs which may be required. Low-hydrogen welding procedures would generally be presumed.

Table C2.4
Structural Steel Plates (see C2.42.2)

Strength Group	Toughness Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	ASTM A36 (to 2 in. thick)	36	250	58–80	400–550
		ASTM A131 Grade A (to 1/2 in. thick)	34	235	58–71	440–490
I	B	ASTM A131 Grades B, D	34	235	58–71	400–490
		ASTM A573 Grade 65	35	240	65–77	450–550
		ASTM A709 Grade 36T2	36	250	58–80	400–550
I	A	ASTM A131 Grades CS, E	34	235	58–71	400–490
II	C	ASTM A242 (to 1/2 in. thick)	50	345	70	480
		ASTM A572 Grade 42 (to 2 in. thick)	42	290	60	415
		ASTM A572 Grade 50 (to 1/2 in thick)*	50	345	65	450
		ASTM A588 (4 in. and under)	50	345	70 min	485 min
II	B	ASTM A709 Grades 50T2, 50T3	50	345	65	450
		ASTM A131 Grade AH32	45.5	315	68–85	470–585
		ASTM A131 Grade AH36	51	350	71–90	490–620
		ASTM A808 (strength varies with thickness)	42–50	290–345	60–65	415–450
		ASTM A516 Grade 65	35	240	65–85	450–585
II	A	API Spec 2H Grade 42	42	290	62–80	430–550
		Grade 50 (to 2-1/2 in. thick)	50	345	70–90	483–620
		(over 2-1/2 in. thick)	47	325	70–90	483–620
		API Spec 2W Grade 42 (to 1 in. thick)	42–67	290–462	62	427
		(over 1 in. thick)	42–62	290–427	62	427
		Grade 50 (to 1 in. thick)	50–75	345–517	65	448
		(over 1 in. thick)	50–70	345–483	65	448
		Grade 50T (to 1 in. thick)	50–80	345–522	70	483
		(over 1 in. thick)	50–75	345–517	70	483
		API Spec 2Y Grade 42 (to 1 in. thick)	42–67	290–462	62	427
		(over 1 in. thick)	42–62	290–462	62	427
		Grade 50 (to 1 in. thick)	50–75	345–517	65	448
		(over 1 in. thick)	50–70	345–483	65	448
		Grade 50T (to 1 in. thick)	50–80	345–572	70	483
		(over 1 in. thick)	50–75	345–517	70	483
		ASTM A131 Grades DH32, EH32	45.5	315	68–85	470–585
		Grades DH36, EH36	51	350	71–90	490–620
		ASTM A537 Class I (to 2-1/2 in. thick)	50	345	70–90	485–620
		ASTM A633 Grade A	42	290	63–83	435–570
		Grades C, D	50	345	70–90	485–620
		ASTM A678 Grade A	50	345	70–90	485–620
III	C	ASTM A633 Grade E	60	415	80–100	550–690
III	A	ASTM A537 Class II (to 2-1/2 in. thick)	60	415	80–100	550–690
		ASTM A678 Grade B	60	415	80–100	550–690
		API Spec 2W Grade 60 (to 1 in. thick)	60–90	414–621	75	517
		(over 1 in. thick)	60–85	414–586	75	517
		API Spec 2Y Grade 60 (to 1 in. thick)	60–90	414–621	75	517
		(over 1 in. thick)	60–85	414–586	75	517
		ASTM A710 Grade A Class 3 (quenched and precipitation heat treated)				
		thru 2 in.	75	515	85	585
		2 in. to 4 in.	65	450	75	515
		over 4 in.	60	415	70	485
IV	C	ASTM A514 (over 2-1/2 in. thick)	90	620	110–130	760–890
		ASTM A517 (over 2-1/2 in. thick)	90	620	110–130	760–896
V	C	ASTM A514 (to 2-1/2 in. thick)	100	690	110–130	760–895
		ASTM A517 (to 2-1/2 in. thick)	100	690	110–130	760–895

*To 2 in. Thick for Type 1 or 2 Killed, Fine Grain Practice

Note: See list of Referenced Specifications for full titles of the above.

Table C2.5
Structural Steel Pipe and Tubular Shapes (see C2.42.2)

Group	Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	API Spec 5L Grade B*	35	240	60	415
		ASTM A53 Grade B	35	240	60	415
		ASTM 139 Grade B	35	240	60	415
		ASTM A500 Grade A (round)	33	230	45	310
		(shaped)	39	270	45	310
		ASTM A500 Grade B (round)	42	290	58	400
		(shaped	46	320	58	400
		ASTM A501 (round and shaped)	36	250	58	400
		API Spec 5L Grade X42 (2% max. cold expansion)	42	290	60	415
I	B	ASTM A106 Grade B (normalized)	35	240	60	415
		ASTM A524 Grade I (through 3/8 in. w.t.)	35	240	60	415
		Grade II (over 3/8 in. w.t.)	30	205	55–80	380–550
I	A	ASTM A333 Grade 6	35	240	60	415
		ASTM A334 Grade 6	35	240	60	415
II	C	API Spec 5L Grade X42 (2% max. cold expansion)	52	360	66	455
		ASTM A618	50	345	70	485
II	B	API Spec 5L Grade X52 with SR5, SR6, or SR8	52	360	66	455
III	C	ASTM A595 Grade A (tapered shapes)	55	380	65	450
		ASTM A595 Grades B and C (tapered shapes)	60	410	70	480

*Seamless or with longitudinal seam welds

Notes:
1. See list of Referenced Specifications for full titles of the above.
2. Structural pipe may also be fabricated in accordance with API Spec 2B, ASTM A139+, ASTM A252+, or ASTM A671 using grades of structural plate listed in Exhibit 1 except that hydrostatic testing may be omitted.

+ with longitudinal welds and circumferential butt welds.

Table C2.6
Structural Steel Shapes (see C2.42.2)

Group	Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	A36 (to 2 in. thick)	36	250	58–80	400–550
		A131 Grade A (to 1/2 in. thick)	34	235	58–80	400–550
I	B	A709 Grade 36T2	36	250	58–80	400–550
II	C	A572 Grade 42 (to 2 in. thick)	42	290	60	415
		A572 Grade 50 (to 1/2 in. thick)	50	345	65	480
		A588 (to 2 in. thick)	50	345	70	485
II	B	A709 Grades 50T2, 50T3	50	345	65	450
		A131 Grade AH32	46	320	68–85	470–585
		A131 Grade AH36	51	360	71–90	490–620

*To 2 in. Thick for Type 1 or 2 Killed, Fine Grain Practice

Note: This table is part of the commentary on toughness considerations for tubular structures (or composites of tubulars and other shapes), e.g., used for offshore platforms. It is not intended to imply that unlisted shapes are unsuitable for other applications.

(b) Fatigue problems which may result from the use of higher working stresses, and

(c) Notch toughness in relation to other elements of fracture control, such as fabrication, inspection procedures, service stress, and temperature environment.

(4) Groups IV and V include higher strength constructional steels in the range of over 75 ksi through 100 ksi yield (515 through 690 MPa). Extreme care should be exercised with regard to hydrogen control to avoid cracking and heat input to avoid loss of strength due to over-tempering.

Toughness Class. Toughness classifications A, B, and C may be used to cover various degrees of criticality shown in the matrix of Table C2.7, and as described below:

Primary (or fracture critical) structure covers elements whose sole failure would be catastrophic.

Secondary structure covers elements whose failure would not lead to catastrophic collapse, under conditions for which the structure could be occupied or capable of major off-site damages (e.g., pollution), or both.

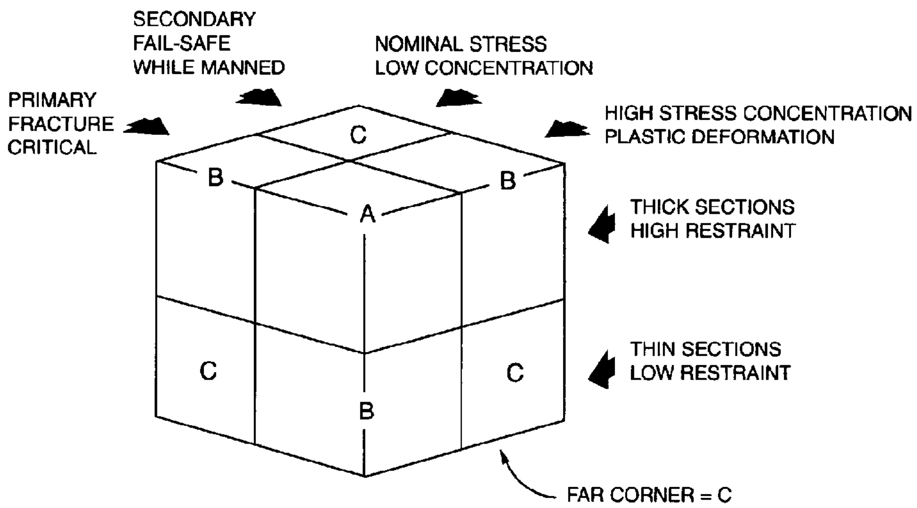
For highly redundant tubular space-frame structures, fracture of a single brace or its end connection is not likely to lead to collapse under normal or even moderately severe loads. The strength is reduced somewhat, however, and the risk of collapse under extreme overload increases correspondingly.

(1) Class C steels are those which have a history of successful application in welded structures at service temperatures above freezing, but for which impact tests are not specified. Such steels are applicable to structural members involving limited thickness, moderate forming, low restraint, modest stress concentration, quasi-static loading (rise time 1 second or longer) and structural redundancy such that an isolated fracture would not be catastrophic. Examples of such applications are piling, braces in redundant space frames, floor beams, and columns.

(2) Class B steels are suitable for use where thickness, cold work, restraint, stress concentration, and impact loading or lack of redundancy, or both, indicate the need for improved notch toughness. Where impact tests are specified, Class B steels should exhibit Charpy V-notch energy of 15 ft·lb (20J) for Group I, 25 ft·lb (34J) for Group II, and 35 ft·lb (48J) for Group III, at the lowest anticipated service temperature. Steels listed herein as Class B can generally meet these Charpy requirements at temperatures ranging from 50° to 32°F (10° to 0°C).

Examples of such applications are connections in secondary structure, and bracing in primary structure. When impact tests are specified for Class B steel, heat-lot testing in accordance with ASTM A673, Frequency H, is normally used. However, there is no positive assurance that Class B toughness will be present in pieces of steel that are not tested.

Table C2.7
Classification Matrix for Applications (see C2.42.2)



(3) Class A steels are suitable for use at subfreezing temperatures and for critical applications involving adverse combinations of the factors cited above. Critical applications may warrant Charpy testing at 36–54°F (20–30°C) below the lowest anticipated service temperature. This extra margin of notch toughness prevents the propagation of brittle fractures from large flaws, and provides for crack arrest in thicknesses of several inches. Steels enumerated herein as Class A can generally meet the Charpy requirements stated above at temperatures ranging from −4°F to −40°F (−20°C to −40°C). Impact testing frequency for Class A steels should be in accordance with the specification under which the steel is ordered; in the absence of other requirements, heat-lot testing may be used.

C2.42.2.1 Charpy V-Notch Requirements. These minimal notch toughness requirements for heavy-section tension members follow the provisions recently proposed by AISC. They rely to a considerable extent on the temperature-shift phenomenon described by Barsom (Reference 16). The temperature-shift effect is that statically loaded materials exhibit similar levels of ductility as cyclically loaded impact specimens tested at a higher temperature. For higher strength steels, Groups III, IV, and V, the temperature-shift is less effective; also fracture mechanics strain energy release considerations would suggest higher required energy values. Testing as-rolled steels on a heat-lot basis leaves one exposed to considerable variation within the heat, with impacts showing more scatter than strength properties. However, it is better than no testing at all.

C2.42.2.2 LAST Requirements. The main members in tubular connections are subject to local stress concentrations which may lead to local yielding and plastic strains at the design load. During the service life, cyclic loading may initiate fatigue cracks, making additional demands on the ductility of the steel, These demands are particularly severe in heavy-wall joint-cans designed for punching shear.

(1) Underwater Connections. For underwater portions of redundant template-type offshore platforms, API recommends that steel for joint cans (such as jacket leg joint cans, chords in major X and K joints, and through members in connections designed as overlapping) meet one of the following notch toughness criteria at the temperature given in the Table below.

(a) NRL Drop-Weight Test no-break performance. (preferred)

(b) Charpy V-notch energy: 15 ft·lb (20J) for Group I steels, 25 ft·lb (34J) for Group II steels, and 35 ft·lb (48J) for Group III steels (transverse test).

The preferred NRL crack arrest criteria follow from use of the Fracture Analysis Diagram (Reference 17), and from failures of heavy connections meeting temperature-shifted Charpy initiation criteria. For service temperatures at 40°F (4°C) or higher, these requirements may normally be met by using any of the Class A steels.

(2) Atmospheric Service. For connections exposed to lower temperatures and possible impact, or for critical connections at any location in which it is desired to prevent all brittle fractures, the tougher Class A steels should be considered, e.g., API Spec. 2H, Gr. 42 or Gr. 50. For 50 ksi (345 MPa) yield and higher strength steels, special attention should be given to welding procedures, in order to avoid degradation of the heat-affected zones. Even for the less demanding service of ordinary structures, the following group/class base metals are NOT recommended for use as the main members in tubular connections: IIC, IIIB, IIIC, IV, and V.

(3) Critical Connections. For critical connections involving high restraint (including adverse geometry, high yield strength, thick sections, or any combination of these conditions), and through-thickness tensile loads in service, consideration should be given to the use of steel having improved through-thickness (Z-direction) properties, e.g., API Spec. 2H, Supplements S4 and S5, or ASTM A770.

(4) Brace Ends. Although the brace ends at tubular connections are also subject to stress concentration, the conditions of service are not quite as severe as the main member (or joint-can). For critical braces, for which brittle fracture would be catastrophic, consideration should be given to the use of stub-ends in the braces having the same class as the joint-can, or one class lower. This provision need not apply to the body of braces (between connections).

References

1. Marshall, P. W. and Toprac, A. A. "Basis for tubular joint design." *Welding Journal.* Welding Research Supplement, May 1974. (Also available as American Society for Civil Engineers preprint 2008.)

2. Graff, W. J., et al. "Review of design considerations for tubular joints." *Progress Report of the Committee on Tubular Structures,* ASCE Preprint 810043. New York: May 1981.

3. Marshall, P. W. and Luyties, W. H. "Allowable stresses for fatigue design." *Proceedings of The 3rd International Conference on The Behavior of Offshore Structures.* Boston: August 1982.

4. Yura, Joseph A. et al. "Chord stress effects on the ultimate strength of tubular joints." PEMSEL Report 82.1. University of Texas: American Petroleum Institute, December 1982.

5. Stamenkovic, A. et al. "Load interaction in T-joints of steel circular, hollow sections." (with discussion by P. W. Marshall). *Journal of Structural Engineering.* ASCE 9 (109): September 1983. (See also Proceedings of International Conference on Joints in Stressed Steel Work. Teeside Polytechnical Institute, May 1981.)

6. Rodabaugh, E. C. "Review of data relevant to the design of tubular joints for use in fixed offshore platforms." *WRC Bulletin 256,* January 1980.

7. Cran, J. A., et al. *Hollow Structural Sections-Design Manual for Connections.* Canada: The Steel Company of Canada (STELCO), 1971.

8. Marshall, P. W. "Basic considerations for tubular joint design in offshore construction." *WRC Bulletin 193,* April 1974.

9. American Petroleum Institute. *Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms.* API RP 2A, 17th Ed. Dallas: American Petroleum Institute, 1987.

10. American Petroleum Institute. *Recommended Practice for Ultrasonic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Ultrasonic Techniques.* API RP 2X, 1st Ed. Dallas: American Petroleum Institute, 1980.

11. Haagensen, P. J. "Improving the fatigue performance of welded joints." *Proceedings of International Conference on Offshore Welded Structures,* 36. London, November 1982.

12. Snedden, N. W., *Background to Proposed New Fatigue Design Rules for Welded Joints in Offshore Structures.*" United Kingdom: United Kingdom Department of Energy, AERE Harwell, May 1981.

13. Marshall, P. W. "Size effect in tubular welded joints." ASCE Structures Congress 1983, Session ST6. Houston, October 1983.

14. Society of Automotive Engineers. *Society of Automotive Engineers Fatigue Design Handbook,* AE-4. Warrendale: Society of Automotive Engineers, 1968.

15. Davies, G., et al. "The behavior of full width RHJS cross joints." *Welding of Tubular Structures.* Proceedings of the 2nd International Conference, IIW. Boston: Pergamon Press, July 1984.

16. Rolfe, S. T. and Barsom, J. M. *Fracture and Fatigue Control in Structures.* Prentice Hall, 1977.

17. Carter, R. M., Marshall, P. W., et al. "Material problems in offshore structures," *Proc. Offshore Tech. Conf.,* OTC 1043, May 1969.

18. Marshall, P. W. "Designing tubular connections with AWS D1.1." *Welding Journal,* March 1989.

19. Sherman, D. R. and Herlache, S. M. "Beam connections to rectangular tubular columns," AISC National Steel Construction Conference. Miami, FL, June 1988.

20. Giddings, T. W. and Wardenier, J. *The Strength and Behavior of Statically Loaded Welded Connections in Structural Hollow Sections*, Section 6, CIDECT Monograph. British Steel Corp. Tubes Div., 1986.

21. Packer, J. A., Birkemoe, P. C., and Tucker, W. J. "Canadian implementation of CIDECT monograph 6," CIDECT Rept. 5AJ-84/9E, IIW Doc. SC-XV-84-072. Univ. of Toronto, July 1984.

22. Packer, J. A. "Review of American RHS web crippling provisions." *ASCE Journal of Structural Engineering*, December 1987.

23. Packer, J. A. and Frater, G. S. "Weldment design for hollow section joints," CIDECT Rept. 5AN-87/1-E, IIW Doc. XV-664-87. Univ. of Toronto, April 1987.

24. International Institute of Welding. IIW S/C XV-E, *Design Recommendations for Hollow Section Joints—Predominantly Static Loading*, 2nd Edition, IIW Doc. XV-701-89. Helsinki, Finland: International Institute of Welding Annual Assembly, September 1989.

25. American Petroleum Institute. *Recommended Practice for Pre-Production Qualification of Steel Plates for Offshore Structures*, API RP2Z, 1st Edition. Dallas: American Petroleum Institute, 1987.

C3. Prequalification of WPSs

C3.2.1 Prequalified Processes. Certain shielded metal arc, submerged arc, gas metal arc (excluding the short circuiting mode of metal transfer across the arc), and flux cored arc WPSs in conjunction with certain related types of joints have been thoroughly tested and have a long record of proven satisfactory performance. These WPSs and joints are designated as prequalified and may be used without tests or qualification (see section 4).

Prequalified provisions are given in section 3, which includes WPSs, with specific reference to preheat, filler metals, electrode size, and other pertinent requirements. Additional requirements for prequalified joints in tubular construction are given in section 3.

The use of prequalified joints and procedures does not necessarily guarantee sound welds. Fabrication capability is still required, together with effective and knowledgeable welding supervision to consistently produce sound welds.

The code does not prohibit the use of any welding process. It also imposes no limitation on the use of any other type of joint; nor does it impose any procedural restrictions on any of the welding processes. It provides for the acceptance of such joints, welding processes, and WPSs on the basis of a successful qualification by the contractor conducted in accordance with the requirements of the code (see section 4).

C3.3 Base Metal/Filler Metal Combinations

Filler metals with designators listed in note 7 of Table 3.1 obtain their classification tensile strength by PWHT at 1275°F or 1350°F (690°C or 730°C). In the as-welded condition their tensile strengths may exceed 100 ksi (690 MPa).

The electrodes and electrode-flux combinations matching the approved base metals for use in prequalified joints are listed in Table 3.1, matching filler metal requirements. In this table, groups of steel specifications are matched with filler metal classifications having similar tensile strengths. In joints involving base metals that differ in tensile strengths, electrodes applicable to the lower strength material may be used provided they are of the low-hydrogen type if the higher strength base metal requires the use of such electrodes.

C3.5 Minimum Preheat and Interpass Temperature Requirements

The principle of applying heat until a certain temperature is reached and then maintaining that temperature as a minimum is used to control the cooling rate of weld metal and adjacent base metal. The higher temperature permits more rapid hydrogen diffusion and reduces the tendency for cold cracking. The entire part or only the metal in the vicinity of the joint to be welded may be preheated (see Table 3.2). For a given set of welding conditions, cooling rates will be faster for a weld made without preheat than for a weld made with preheat. The higher preheat temperatures result in slower cooling rates. When cooling is sufficiently slow, it will effectively reduce hardening and cracking.

For quenched and tempered steels, slow cooling is not desirable and is not recommended by the steel producer.

It should be emphasized that temperatures in Table 3.2 are minimum temperatures, and preheat and interpass temperatures must be sufficiently high to ensure sound welds. The amount of preheat required to slow down cooling rates so as to produce crack-free, ductile joints will depend on:

(1) The ambient temperature
(2) Heat from the arc
(3) Heat dissipation of the joint
(4) Chemistry of the steel (weldability)
(5) Hydrogen content of deposited weld metal
(6) Degree of restraint in the joint

Point 1 is considered above.

Point 2 is not presently considered in the code.

Point 3 is partly expressed in the thickness of material.

Point 4 is expressed indirectly in grouping of steel designations.

Point 5 is presently expressed either as non-low hydrogen welding process or a low hydrogen welding process.

Point 6 is least tangible and only the general condition is recognized in the provisions of Table 3.2.

Based on these factors, the requirements of Table 3.2 should not be considered all-encompassing, and the emphasis on preheat and interpass temperatures as being minimum temperatures assumes added validity.

Caution should be used in preheating quenched and tempered steel, and the heat input must not exceed the steel producer's recommendation (see 5.7).

C3.6 Limitation of WPS Variables

Although prequalified WPSs are exempt from tests, the code does require that the contractor prepare a written WPS to be used in fabrication. This is a record of the materials and the welding variables which shows that the WPS meets the requirements for prequalified status.

It is the intent of the code that welders, welding operators, tack welders, and inspection personnel have access to the written prequalified WPS. The code requires that four critical variables be specified on the written prequalified WPS within limits that will insure that it provides meaningful guidance to those who implement its provisions. The allowable ranges for amperage, voltage, travel speed, and shielding gas, as applicable, are the same as those allowed for qualified WPSs in 4.7 of the code. The limitation imposed on these four variables are sufficiently conservative to permit rounding off.

C3.7.2 Width/Depth Pass Limitation. The weld nugget or bead shape is an important factor affecting weld cracking. Solidification of molten weld metal due to the quenching effect of the base metal starts along the sides of the weld metal and progresses inward until completed. The last liquid metal to solidify lies in a plane through the centerline of the weld. If the weld depth is greater than the width of the face, the weld surface may solidify prior to center solidification. When this occurs, the shrinkage forces acting on the still hot, semi-liquid center or core of the weld may cause a centerline crack to develop, as shown in Figure C3.1 (A) and (B). This crack may extend throughout the longitudinal length of the weld and may or may not be visible at the weld surface. This condition may also be obtained when fillet welds are made simultaneously on both sides of a joint with the arcs directly opposite each other, as shown in Figure C3.1 (C).

In view of the above, Table 3.7 requires that neither the depth nor the maximum width in the cross section of the weld metal deposited in each weld pass shall exceed the width at the surface of the weld pass. This is also illustrated in Figure 3.1. Weld bead dimensions may best be measured by sectioning and etching a sample weld.

C3.7.3 Weathering Steel Requirements. The requirements in this paragraph are for exposed, bare, unpainted applications of ASTM A588 steel where atmospheric corrosion resistance and coloring characteristics similar to those of the base metal are required. The filler metals specified in Table 3.3 are to be used to meet this requirement. When welding these steels for other applications, the electrode, the electrode-flux combination, or grade of weld metal specified in Table 3.1 is satisfactory.

The use of filler metals other than those listed in Table 3.3 for welding ASTM A588 steel (used in bare, exposed applications) is permitted for certain size single-pass fillets (related to welding process), as shown in 3.7.3. Here, the amount of weld metal-base metal admixture results in

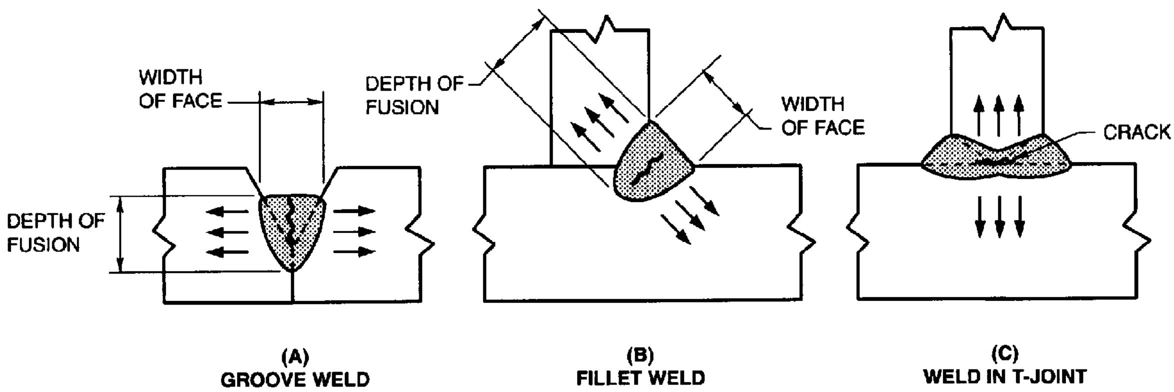


Figure C3.1—Examples of Centerline Cracking (see C3.7.2)

weld metal coloring and atmospheric corrosion characteristics similar to the base metal.

In multiple-pass welds, a filler metal from Table 3.1 may be used to fill the joint except for the last two layers. Filler metal as specified in Table 3.3 must be used for the last two surface layers and ends of welds.

C Table 3.7 Electrical Limitations. Tests have demonstrated that an empirical relation appears to exist between the angle at the root of the groove and the maximum current that can be used without producing weld profiles prone to cracking, as shown in Figure C3.1. Under these circumstances, only prequalified bevel and V-grooves without backing are effective.

J- and U-grooves have a greater angle at the root than the groove angle and, in their case, the probability of an undesirable crack-prone weld nugget is very small. However, the code makes no distinction between V-grooves and J- and U-grooves in this regard. It makes the requirements of Table 3.7 applicable to all grooves. Since the use of J-and U-grooves is less frequent, this requirement does not appear to be unreasonable.

The empirical relation defines the acceptable amount of current, in amperes, as approximately ten times the included groove angle. This applies primarily to prequalified joints welded without backing using bevel and V-grooves. Since the included angle for such prequalified joints is 60°, the maximum amperage permitted by the code is 600 A; for a 90° fillet weld, the maximum current permitted is 1000 A. This limitation applies only to passes fusing both faces of the joint, except for the cover pass.

C Table 3.7 Requirement for Multiple Electrode SAW. When using gas metal arc plus submerged arc in tandem (see Table 3.7), the maximum 15 in. (380 mm) spacing between the gas metal arc and the leading submerged arc is required to preserve the preheating effects of the first arc for the subsequent main weld deposited by the remaining two high deposition rate submerged arcs. The short spacing also provides a better condition for remelting the first pass.

C Table 3.7 Requirements for GMAW/FCAW. This section provides the requirements for gas metal arc welding and flux cored arc welding procedures when prequalified WPSs are used.

The gas shielding at the point of welding is to be protected from the wind to prevent interruption in shielding and resulting contamination of the weld by the atmosphere.

The prequalified provisions apply only to gas metal arc welding using spray and globular transfer modes of metal deposition. Gas metal arc welding in the short circuiting transfer mode is not prequalified and must be qualified in accordance with section 4. Experience has shown frequent cases of lack of penetration and fusion with this mode of metal transfer. A common reason for this unreliability is the low-heat input per unit of deposited weld metal resulting in a tendency toward little or no melting of the base metal. Therefore, each user is required to demonstrate the ability of the selected WPS to produce sound welds when using short circuiting transfer gas metal arc welding.

C3.10 Plug and Slot Weld Requirements

Plug and slot welds conforming to the dimensional requirements of 2.5, welded by techniques prescribed in 5.25 and using materials listed in Table 3.1 or Annex M are considered prequalified and may be used without performing joint welding procedure qualification tests.

C3.11.2 Corner Joint Preparation. The code permits an alternative option for preparation of the groove in one or both members for all bevel- and J-groove welds in corner joints as shown in Figure C3.2.

This provision was prompted by lamellar tearing considerations permitting all or part of the preparation in the vertical member of the joint. Such groove preparation reduces the residual tensile stresses, arising from shrinkage of welds on cooling, that act in the through-thickness direction in a single vertical plane, as shown in prequalified corner joints diagrammed in Figures 3.3, 3.4, and 3.11. Therefore, the probability of lamellar tearing can be reduced for these joints by the groove preparation now permitted by the code. However, some unprepared thickness, "a," as shown in Figure C3.2, must be maintained to prevent melting of the top part of the vertical plate. This can easily be done by preparing the groove in both members (angle β).

C3.13.1 Joint Dimensions. After preparation, the second side of double welded joints may not exactly match the sketches shown for prequalified welded joints in Figure 3.3 due to inherent limitations of the back gouging process. U- and J-shapes may appear to be combined with V- and bevel shapes. This is an acceptable condition.

C Figure 3.3—Effective Weld Size of Flare-Bevel-Groove Welded Joints. Tests have been performed on cold formed ASTM A500 material exhibiting a "c" dimension as small as T_1 with a nominal radius of 2t. As the radius increases, the "c" dimension also increases.

The corner curvature may not be a quadrant of a circle tangent to the sides. The corner dimension, "c", may be less than the radius of the corner.

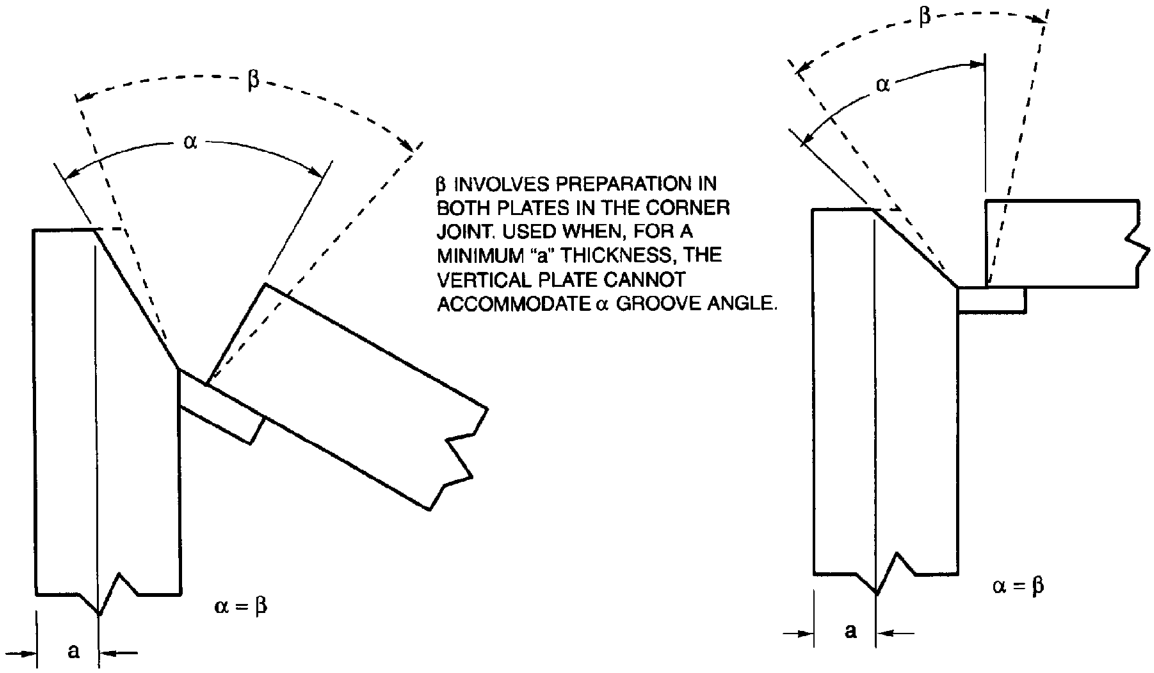


Figure C3.2—Details of Alternative Groove Preparations for Prequalified Corner Joints (see C3.11.2)

C4. Qualification

Part A
General Requirements

C4.1.1.1 Qualification Responsibility. All contractors are responsible for their final product. Therefore, it is their responsibility to comply with the qualification requirements of the code relative to WPSs. Properly documented WPSs and personnel qualification tests conducted by the contractor in accordance with this code are generally acceptable to the Engineer for the contract.

C4.1.2 Performance Qualification of Welding Personnel. The qualification tests are especially designed to determine the ability of the welders, welding operators, and tack welders to produce sound welds by following a WPS. The code does not imply that anyone who satisfactorily completes qualification tests can do the welding for which they are qualified for all conditions that might be encountered during production welding. It is essential that welders, welding operators, and tack welders have some degree of training for these differences.

Ideally, welders, welding operators and tack welders welding quenched and tempered high-strength steels should have experience welding such base metals. In lieu of such experience, the contractor should ensure that the contractor's personnel receive instruction and training in the welding of such steels. It is further recommended that other personnel, such as fitters and thermal cutters (burners) involved in fabrication utilizing quenched and tempered high-strength steel be experienced or receive instruction and training prior to the start of thermal cutting operations.

C4.1.2.1 Previous Performance Qualification. The acceptability of qualification to other standards is the Engineer's responsibility to be exercised upon the specific structures and service conditions. The Structural Welding Committee does not address qualification to any other welding standard.

C4.1.3.1 Period of Effectiveness—Welders and Welding Operators. This subsection controls the expiration date of a welder's qualification. The qualification remains in effect (1) for six months beyond the date that the welder last used the welding process, or (2) until there is a specific reason to question the welder's ability. For (1), the requalification test need be made only in 3/8 in. (9.5 mm) thickness using plate or pipe or both. If the welder fails this test, then requalification shall follow the requirements of section 4, Part C, Welding Personnel Performance Qualification. For (2), the type of test should be mutually agreed upon between the contractor and the Engineer and shall be within the requirements of section 4, Part C, Performance Qualification.

C4.2.4 Positions of Test Welds. This subsection defines welding positions for qualification test welds and production welds. Position is an essential variable for all of the WPSs, except for the electrogas and electroslag processes which are made in only one position. Each procedure shall be qualified for each position for which it will be used in fabrication. Relationships between the position and configuration of the qualification test weld and the type of weld and positions qualified are shown in Table 4.1. It is essential to perform testing and evaluation of the welds to be encountered in construction prior to their actual use on the job. This will assure that all the necessary positions are tested as part of the qualification process.

Part B
WPS Qualification

C4.4 Type of Qualification Tests

Table 4.2 summarizes the requirements for the number and type of test specimens and the range of thicknesses qualified. A test plate thickness of 1 in. (25.4 mm) or over qualifies a procedure for unlimited thickness. The 1 in. thickness has been shown to generally reflect the influence of weld metal chemistry, heat input, and preheat temperature on the weld metal and heat-affected zone. The term *direction of rolling* was made optional in the 1988 edition, although the mechanical properties of steel plate may vary significantly with the direction of rolling and may affect the test results. For example, tensile strength and impact toughness are often greater in the longitudinal direction than in the transverse direction unless cross rolling is used. Similarly, the rolling direction shown in the sketches often gives better results in the bend tests. For some applications, toughness results are required and the direction of rolling should be referenced on the test results.

Table 4.2 WPS Qualification—Complete Joint Penetration Groove Welds; Number and Type of Test Specimens and Range of Thickness and Diameter Qualified. The WPS qualification for pipe includes conditions for large diameter job size pipe. This is intended for WPS qualification of large diameter pipe by automatic welding processes, such as submerged arc welding, and may be applied to any welding process that can be used on large diameter pipe, but not on 8 in. (200 mm) Sch. 120 pipe.

C4.7 Essential Variables

This code allows some degree of departure from the variables used to qualify a WPS. However, departure from variables which affect the mechanical or chemical composition of material properties, or soundness of the weldment are not allowed without requalification. These latter variables are referred to as essential variables. The base metal essential variables are listed in 4.7.3. The welding process essential variables are listed in 4.7.1. The positions of test welds are listed in 4.2.4. Changes in these variables beyond the variation allowed by the subject subsections require requalification of the WPS. Similarly, changes beyond those shown in 4.7.2 require requalification using radiographic or ultrasonic testing only.

These essential variables are to be specific in the WPS document and followed in welding fabrication.

C4.7.1 SMAW, SAW, GMAW, GTAW, and FCAW. Travel speed affects heat input, weld cooling rates, and weld metallurgy, which are important for the heat-affected zone (HAZ), for fracture toughness control, and for welding quenched and tempered steels. Proper selection of travel speed is also necessary to avoid incomplete fusion and slag entrapment.

C Table C4.6 Electrode extension or contact tube to work distance is an important welding variable which affects the amperage as well as the transfer mode. At a set wire feed speed, using a constant-voltage power source, longer electrode extensions cause the welding current to decrease. This may reduce weld penetration and heat input and cause fusion discontinuities. Shorter extension causes an increase in welding current. A variation in electrode extension may cause a spray transfer to change to globular or short circuiting modes. It is important to control electrode extension as well as other welding variables.

Semiautomatic welding processes may be controlled by using wire feed speed, electrode extension and arc length, or voltage. For machine operation, electrode extension may be premeasured; for manual welding, it is visually estimated. Welding on pipe (or tubing) material product forms does not necessarily mean that pipe welding is being performed. There is obviously a difference between welding around a pipe as opposed to welding along a pipe parallel to the pipe axis (centerline). A girth weld in a butt joint is completely different from a longitudinal groove weld that joins rolled plate to make a pipe; a socket joint with a fillet weld is completely different from a fillet weld along the pipe length attaching a plate plug. Obviously, the skills for straight line progression parallel to the pipe axis are no different from the skills for welding plate wrought shapes using a straight line progression; therefore, the pipe product form limitation does not apply in these straight line cases. Refer to Figure C4.1.

C4.8.2 Nondestructive Testing. All WPS qualification test plates or test pipes are required to be radiographed or ultrasonically tested to demonstrate soundness before mechanical testing, regardless of the welding process used. Additionally, nondestructive testing reduces the expense and delays that result from machining and testing welds having discontinuities prohibited by the code.

C4.8.3.2 Longitudinal Bend Specimens. Provision has been made in this subsection for longitudinal bend tests when material combinations differ markedly in mechanical bending properties.

C4.8.3.3 Acceptance Criteria for Bend Tests. The new, more definitive wording for bend test acceptance was added to aid the interpretation of the test results. The purpose of the bend test is to prove the soundness of the weld. The statement regarding the total quantity of indications was added to restrict the accumulative amount of discontinuities.

A maximum limit on tears originating at the corners was added to prevent the case where the corner cracks might extend halfway across the specimen, and under the previous criteria, would be judged acceptable.

C4.10.1 Type and Number of Specimens to be Tested. This subsection addresses the requirements for qualification of partial joint penetration groove welds that require qualification by the contractor because the joint design and WPS to be used in construction do not meet prequalified status as described in 3.1, or a WPS qualified to produce complete penetration welds utilizing a specific joint design is proposed for use as a partial penetration weld. The intent is to establish the weld size that will be produced using the joint design and welding procedure proposed for construction. Certain joint designs in combination with a specific welding process and position may show that the groove preparation planned will not give the desired weld size (E).

Macroetch test specimens only are required for WPS qualifications that meet the requirements of 4.10.2 or 4.10.3. Additional testing is required for those WPS that fall under the criteria of 4.10.4. These test requirements are shown in Table 4.3.

C4.11.1 Type and Number of Specimens—Fillet Welds. When single-pass fillet welds are to be used, one test weld is required as shown in Figures 4.19 and 4.23 using the maximum size single-pass fillet weld. If multiple-pass fillet welds only are used, then one test weld is required, as shown in Figures 4.19 and 4.23, using the minimum size multiple-pass fillet weld to be used. Each of these tests is presumed to evaluate the most critical situation.

C4.12 Complete Joint Penetration Groove Welds for Tubular Connections

Welding on tubular members differs from that in conventional plate and wide flange construction in several important aspects. Position often changes continuously in going around the joint; in T-, Y-, and K-connections, the joint geometry also changes. Often there is no access to the root side of the weld; and circumstances may preclude the use of backing (e.g., the use of tubes as a conduit, or the complicated geometry of T-, Y-, and K-connections). Yet, for many structures, the conditions of service demand that these welds meet the strength and fatigue performance qualities conventionally associated with complete joint penetration groove welds. To meet these needs, a specialized set of practices regarding WPS and welder qualifications, as well as prequalified joint details, has evolved for tubular structures. These provisions supplement those given elsewhere in the code.

Several specialized tubular applications are defined in which complete joint penetration groove welds are permitted to be welded from the outside only, without backing:

(1) Pipe Butt Joints. In butt joints, complete joint penetration groove welds made from one side are prohibited under the conventional provisions for cyclically loaded structures and statically loaded structures, yet they are widely used in pressure piping applications. They are now permitted for tubular structures, but only when all the special provisions of 4.12.2 are followed.

(2) T-, Y-, and K-Connections. Prequalified joint details for both circular and box tube connections are described in 3.13.4. The situations under which these may be applied are described in Table 4.2, along with the required WPS and welder tests. These requirements are discussed further below.

Because of the special skills required to successfully execute a complete joint penetration groove weld in tubular T-, Y-, and K-connections, the 6GR level of welder qualification for the process being used is always required (see 4.26). Also, where groove angles less than 30° are to be used, the acute angle sample joint test of 4.12.4.2 is also required for each welder.

Where groove details in T-, Y-, and K-connections differ from the prequalified details of 3.13.4, or there is some question as to the suitability of the joint details for WPS, then a mock-up or sample joint in accordance with 4.12.4.1 is required, in order to validate the procedure.

Additional WPS qualification tests may be required on account of some essential variable other than joint design. These circumstances include (but are not limited to) the following:

(3) The use of a process outside the prequalified range (e.g., short-circuiting GMAW).

(4) The use of base metal or welding materials outside the prequalified range (e.g., the use of proprietary steels or a non-low hydrogen root pass on thick material).

(5) The use of welding conditions outside the prequalified range (e.g., amps, volts, preheat, speed, and direction of travel).

(6) The need to satisfy special owner testing requirements (e.g., impact tests).

Qualification for complete joint penetration welds using tubular box sections detailed with single-welded T-, Y-, and K-connections requires additional tests as stated in Table 4.1 and shown in Figure 4.28. In this test, the welder demonstrates the skill and technique to deposit sound weld metal around the corners of a box tube member. This macroetch test is not required for fillet or partial penetration groove welds. See Commentary C4.26 for further discussion.

For these tests, the joint configurations of Figures 4.27 and 4.28 are used in order to simulate the root condition and limited access of T-, Y-, and K-connections.

Conventional specimens for mechanical testing are then prepared in accordance with Table 4.2.

Partial joint penetration T-, Y-, and K-connections are also provided for. They can be executed by welders having the common pipe qualifications 2G plus 5G. This could be advantageous in areas where 6GR qualified welders are not readily available. Although lower fatigue allowables apply, the static strength of such joints is almost the same as for complete penetration, particularly where mild steel is used with E70 filler metal.

Fillet welded T-, Y-, and K-connections can be executed by welders having even lower levels of qualification. However, these can not be presumed to match the strength of members joined, but must be checked by the designer for the specific applied loads, in accordance with 2.40.2.3, 2.36.6, 2.39.1, as well as 2.40.1 and 2.40.2.

C4.12.4 T-, Y-, and K-Connections without Backing Welded from One Side Only. Under carefully prescribed conditions (see Figures 3.6, and Figures 3.8 through 3.10), the code permits complete joint penetration groove welds in tubular T-, Y-, and K-connections to be made from one side without backing. Lack of access and complex geometry preclude more conventional techniques. A very high level of welder skill (as demonstrated by the 6GR test) is required. When matching materials (see Table 3.1) are used, such joints may be presumed to equal the strength of the sections joined subject to the limitations of 2.40 and 2.36.6.

In making the weld in a T-, Y-, or K-connection, the geometry and position vary continuously as one progresses around the joint. The details shown in Figures 3.6, and Figures 3.8 through 3.10 were developed from experience with all-position shielded metal arc welding (SMAW) and fast-freezing short circuiting transfer gas metal arc welding (GMAW-S). These details are also applicable to flux cored arc welding processes with similar fast-freezing characteristics. The wider grooves (and wider root openings) shown for GMAW were found necessary to accommodate the shrouded tip of the welding gun. Although the later process is not prequalified for short circuiting transfer, the joint details are still applicable to such GMAW procedures.

In many applications, particularly with small tubes, the partial penetration joint of 3.12.4 will be entirely adequate. Although requiring additional strength checks by the designer, the less stringent requirements for fit-up and welder's skill result in significant economies on the job. For very large tubes in which inside access is possible, the conventional complete joint penetration groove welds made from both sides are applicable.

For applications where increased fatigue performance associated with complete joint penetration groove welds is needed for T-, Y-, and K-connections, the code refers to a consistent set of "standard" weld profiles, as described earlier in C2.36.6.7. Once learned, these should become a natural progression with thickness for the welders to follow. They have evolved from the following experience.

For very thin tubular connections, flat profiles (Figure 3.8) represent those commonly obtained on small tubular connections used for onshore applications. They also are similar to the profiles obtained on some of the scale models used to develop the historical fatigue data base. Here the entire weld cap is made in one pass, with weaving as required. Using E6010 electrodes, the more artistic capping specialist could make this a concave profile, merging smoothly with the adjoining base metal. With the advent of higher strength steels and heavier sections, requiring low-hydrogen electrodes, and with the introduction of high deposition rates, semiautomatic welding processes, this seems to have become a lost art.

For heavier thicknesses, a definite fillet is added at the weld toe as required to limit the weld toe notch effect to that of a 45° fillet weld. See Figure 3.9. These fillet welds are scaled to the branch member thickness so as to approximate a concave weld shape. However, we are also constrained by the need to maintain minimum fillet weld sizes to avoid creating dangerously high hardnesses in the heat-affected zone at the weld toe (this is also the location of the "hot spot" which may experience localized yielding at the design load levels). This alternative "standard" profile is easier to communicate to the welders, and easier for them to achieve out of position than the idealized concave weld profile shown in earlier editions of the code. The resulting weld profile is much like that observed on early Gulf of Mexico offshore platforms, whose fatigue performance over several decades of service has been consistent with Categories X1, K1, and DT.

For branch member thicknesses in excess of 0.625 in. (15.9 mm) (typically associated with chord thicknesses in excess of 1.25 in. [31.7 mm]) designers are going beyond the historical fatigue data base and the experience of early Gulf of Mexico platforms.

The size effect begins to manifest itself, and fatigue performance would begin to decline toward the lower level defined by fatigue Categories X2 and K2, unless the profile is further improved. Branch members of 1.50 in. (38.1 mm) and chord thicknesses of 3.0 in. (76.2 mm), represent the limits of the recent large-scale European tests, and further adverse size effects (performance below X2 and K2) would be expected if sharply notched weld profiles were to be scaled up even further. Figure 3.10 describes a concave weld profile which merges smoothly with the adjoining base metal, mitigating the notch effect and providing an improved level of fatigue performance for heavier sections.

The standardized pipe butt joint test specimens, specified in Part B of section 4 for WPS qualification, are satisfactory for establishing metallurgical soundness of WPSs and materials. They cannot cover the full range of continuously varying geometry and position encountered in structural T-, Y-, and K-connections.

The prequalified joint details given in 3.13.4 are based on experience with full scale mock-ups of such connections that often reveal practical problems that do not show up in the standard test specimen. Qualification of processes not prequalified and of WPSs with essential variables outside prequalified ranges are required to meet the provisions of 4.12.4.1. This subsection provides for sample joint or tubular mock-up tests. WPS for box sections may be based on either plate or pipe tests for position and compatibility. When mock-up tests for box sections for T-, Y-, and K-connections are considered, box tubes should be used.

Additional tests are required for connections with groove angles less than 30° as outlined in 4.12.4.2.

C4.12.4.4 Weldments Requiring Notch Toughness. Weld metal and heat-affected zone toughness should be based on the same engineering considerations as used to establish the base metal toughness requirements. However, fracture avoidance, by increasing toughness alone, is not cost effective. Fatigue cracking, hydrogen-induced cold cracking, and solidification hot cracking must also be dealt with. Other parts of the code address these other problems, via design, qualification, technique, and inspection requirements. Notch toughness just helps us live with imperfect solutions.

Weld Metal. Notch tough base metals should be joined with filler metals possessing compatible properties. The test temperatures and minimum energy values in Table C4.1 are recommended for matching the performance of the various steel grades as listed in Tables C2.4–C2.6. When WPS qualification by test is required (i.e., when the procedure is not prequalified, when comparable impact performance has not been previously demonstrated, or when the welding consumables are to be employed outside the range of essential variables covered by prior testing), qualification should include Charpy V-notch testing of the as-deposited weld metal. Specimens should be removed from the test weld, and impact tested, in accordance with Annex III, Requirements for Impact Testing. Single specimen energy values (one of three) may be 5 ft·lb (7J) lower without requiring retest.

Since AWS WPS requirements are concerned primarily with tensile strength and soundness (with minor emphasis on fracture toughness), it is appropriate to consider additional essential variables which have an influence on fracture toughness—e.g., specific brand wire/flux combinations, and the restriction of SAW consumables to the limits actually tested for AWS classification. Note that, for Class A steels, specified energy levels higher than the AWS classifications will require that all WPSs be qualified by test, rather than having prequalified status.

Table C4.1
Weld Notch Toughness (see C4.12.4.4)

Steel Group	Steel Class	Impact Test Temperature	Weld Metal Avg. ft·lb	(Joules)
I	C	0°F (−18°C)	20	(27)
I	B	0°F (−18°C)	20	(27)
I	A	−20°F (−29°C)	20	(27)
II	C	0°F (−18°C)	20	(27)
II	B	−20°F (−29°C)	20	(27)
II	A	−40°F (−40°C)	25	(34)
III	C	−20°F (−29°C)	20	(27)
III	B	−40°F (−40°C)	20	(27)
III	A	−40°F (−40°C)	30	(40)
IV and V		Special Investigation		

Note: Code requirements represent the lowest common denominator from the foregoing table.

Charpy impact testing is a method for qualitative assessment of material toughness. Although lacking the fracture mechanics basis of crack tip opening displacement (CTOD) testing, the method has been and continues to be a reasonable measure of fracture safety, when employed with a definitive program of nondestructive examination to eliminate weld area defects. The recommendations contained herein are based on practices which have generally provided satisfactory fracture experience in structures located in moderate temperature environments (e.g., 40°F sea water and 14°F air exposure). For environments which are either more or less hostile, impact testing temperatures should be reconsidered, based on local temperature exposures.

For critical welded connections, the more technical CTOD test is appropriate. CTOD tests are run at realistic temperatures and strain rates, representing those of the engineering application, using specimens having the full prototype thickness. This yields quantitative information useful for engineering fracture mechanics analysis and defect assessment, in which the required CTOD is related to anticipated stress levels (including residual stress) and flaw sizes.

Representative CTOD requirements range from 0.004 inch at 40°F (0.10 mm at 4°C) to 0.015 inch at

14°F (0.38 mm at –10°C). Achieving the higher levels of toughness may require some difficult trade-offs against other desirable attributes of the welding process—for example, the deep penetration and relative freedom from trapped slag of uphill passes, versus the lower heat input and highly refined weld layers of downhill passes.

Heat-Affected Zone. In addition to weld metal toughness, consideration should be given to controlling the properties of the heat-affected zone (HAZ). Although the heat cycle of welding sometimes improves as-rolled base metals of low toughness, this region will often have degraded toughness properties. The HAZ is often the site of hydrogen-induced underbead cracking. A number of early failures in welded tubular joints involved fractures which either initiated in or propagated through the HAZ, often before significant fatigue loading.

Annex III gives requirements for sampling both weld metal and HAZ, with Charpy energy and temperature to be specified in contract documents. The average HAZ values in Table C4.2 have been found by experience to be reasonably attainable, where single-specimen energy values (one of three) 5 ft·lb (7J) lower are allowed without requiring retest.

As criticality of the component's performance increases, lower testing temperatures (implying more restrictive WPSs) would provide HAZs which more closely match the performance of the adjoining weld metal and parent material, rather than being a potential weak link in the system. The owner may also wish to consider more extensive sampling of the HAZ than the single set of Charpy tests required by Annex III, e.g., sampling at 0.4 mm, 2 mm, and 5 mm from the fusion line. (These dimensions may change with heat input.) More extensive sampling increases the likelihood of finding local brittle zones with low toughness values.

Since HAZ toughness is as much dependent on the steel as on the welding parameters, a preferable alternative for addressing this issue is through weldability prequalification of the steel. Reference 25 of section C2 spells out such a prequalification procedure, using CTOD as well as Charpy testing. This prequalification testing is presently being applied as a supplementary requirement for high-performance steels such as API Specs 2W and 2Y, and is accepted as a requirement by some producers.

Caution: *Section 4 of this code permits testing one 50 ksi steel to qualify all other grades of 50 ksi and below. Consequently, selection of API-2H-50-Z (very low sulfur, 200 ft·lb upper shelf Charpies) for qualification test plates will virtually assure satisfying a HAZ impact requirement of 25 ft·lb, even when welded with high-heat inputs and high interpass temperatures. There is no reasonable way to extrapolate this test to ordinary A572 Grade 50 with the expectation of reproducing either the HAZ impact energies or the 8:1 degradation of the test on API-2H-50-Z. Thus, separate Charpy testing of different steel grades, thickness ranges, and processing routes should be considered, if HAZ toughness is being addressed via WPQ testing.*

Local Brittle Zones (LBZ). Within the weld heat-affected zones (HAZ) there may exist locally embrittled regions. Under certain conditions, those LBZs may be detrimental. The engineer should consider the risk of LBZs and determine if counter measures should be employed to limit the extent of LBZs and their influence on structural performance. Some counter measures and mitigating circumstances in offshore practice are listed below:

(1) The use of steels with moderate crack-arrest capabilities, as demonstrated by no-break in the NRL drop-weight test (small flaw)

(2) Overmatch and strain hardening in conventional normalized 42 to 50 ksi carbon-manganese steels in which the weld metal and HAZ have higher yield strength than adjacent base metal, forcing plastic strains to go elsewhere

(3) The tendency for fatigue cracks in welded tubular joints to grow out of the HAZ before they reach appreciable size (assuming one avoids unfavorable tangency of joining can weld seam with the brace footprint)

(4) Prequalified limits on weld layer thickness in welding procedures, which along with observing limits on heat input, promote grain refinement in the HAZ and minimize the extent LBZ

(5) Composition changes, e.g., reduced limits on vanadium and nitrogen, and increased titanium

Table C4.2
HAZ Notch Toughness (see C4.12.4.4)

Steel Group	Steel Class	Impact Temperature	Heat-Affected Zone ft·lb	(Joules)
I	C	50°F (10°C)	For information only	
I	B	40°F (4°C)	15	(20)
I	A	14°F (–10°C)	15	(20)
II	C	50°F (10°C)	For information only	
II	B	40°F (4°C)	15	(20)
II	A	14°F (–10°C)	25	(34)
III	A	14°F (–10°C)	30	(40)

C4.15 Welding Processes Requiring Qualification

The code does not restrict welding to the prequalified WPSs described in 3.1. As other WPSs and new ideas become available, their use is permitted, provided they are qualified by the requirements prescribed in section 4, Part B. Where a contractor has previously qualified a WPS meeting all the requirements prescribed in Part B of this section, the code recommends that the Engineer accept properly documented evidence of a previous test and not require the test be performed again. Proper documentation means that the contractor has complied with the requirements of section 4, Part B, and the results of the qualification tests are recorded on appropriate forms such as those found in Annex E. When used, the form in Annex E should provide appropriate information listing all essential variables and the results of qualification tests performed.

There are general stipulations applicable to any situation. The acceptability of qualification to other standards is the Engineer's responsibility to be exercised based on the specific structures and service conditions. The Structural Welding Committee does not address qualification to any other welding standard.

C4.17 WPS Requirements (ESW/EGW)

The welding processes, procedures, and joint details for electroslag and electrogas welding are not accorded prequalified status in the code. The WPSs must comply with the requirements of section 4, and must be established in accordance with section 4. Welding of quenched and tempered steels with either of these processes is prohibited since the high-heat input associated with them causes serious deterioration of the mechanical properties of the heat-affected zone.

C4.17.2 All-Weld-Metal Tension Test Requirements. Testing of each procedure is necessary to demonstrate that the weld metal will have properties corresponding with those of the base metal. All-weld-metal tension test specimens must meet the mechanical property requirements specified in the latest edition of ANSI/AWS A5.25, *Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding*, or the latest edition of ANSI/AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes Welding for Electrogas Welding*, as applicable.

Part C
Performance Qualification

C4.18 General

The welder qualification test is specifically designed to determine a welder's ability to produce sound welds in any given test joint. After successfully completing the welder qualification tests, the welder should be considered to have minimum acceptable qualifications.

Knowledge of the material to be welded is beneficial to the welder in producing a sound weldment; therefore, it is recommended that before welding quenched and tempered steels, welders should be given instructions relative to the properties of this material or have had prior experience in welding the particular steel.

From time to time, the contractor may upgrade or add new control equipment. The previously qualified welding operator may need training to become familiar with this new equipment. The emphasis is placed on the word "training" rather than "requalification" since several beads on a plate or a tube, as appropriate, may be sufficient. The intention is that the contractor would train the welding operator to weld using the new equipment.

C4.22 Essential Variables

The ability of a welder to produce a sound weld is considered by the code to be dependent upon certain essential variables, and these are listed in Table 4.10.

C Table 4.11 Electrodes for shielded metal arc welding (SMAW) are grouped relative to the skill required of the welder. The F Group designation permits a welder qualified with an electrode of one group designation to use other electrodes listed in a numerically lower designation. For example, a welder qualified with an E6010 electrode will also be qualified to weld an E6011 electrode, group designation F3 and is permitted to weld with electrodes having group designation F2 and F1; the welder is not qualified to weld with electrodes having a group designation F4.

C Table 4.8 Welding on pipe (or tubing) material product forms does not necessarily mean that pipe welding is being performed. There is obviously a difference between welding around a pipe as opposed to welding along a pipe parallel to the pipe axis (centerline). A girth weld in a butt joint is completely different from a longitudinal groove weld that joins rolled plate to make a pipe; a socket joint with a fillet weld is completely different from a fillet weld along the pipe length attaching a plate plug. Obviously, the skills for straight line progression parallel to the pipe axis are no different from the skills for welding plate wrought shapes using a straight line progression; therefore, the pipe product form limitation does not apply in these straight line cases. Refer to Figure C5.1.

Qualification of welders using job size pipe or tubing is permitted because pipe sizes specified in Table 4.9 for welder qualification are not always available to the contractor.

C4.26 CJP Groove Welds for Tubular Connections

When box sections are used in performance qualification, bend tests taken from the faces do not evaluate the welder's ability to carry sound weld metal around the relatively abrupt corners. These bend tests do not fulfill the needs of complete joint penetration groove welds in T-, Y-, and K-connections because the corners in these connections may be highly stressed. Due to the concerns for welders to demonstrate their skill to weld the corners of box tubes when complete joint penetration is required, the corner macroetch test of Figure 4.28 was developed.

The corner macroetch test shown in Figure 4.28 is an additional performance test required for welders expected to make complete joint penetration groove welds in box tube T-, Y-, and K-connections.

For this case, qualified 6GR welders tested on round tubes or pipe per Figure 4.27 would only be required to pass the additional corner macroetch test per Figure 4.28, provided all the requirements of Table 4.8 and 4.12.4.2 are met.

If the contractor wishes to qualify a welder without existing 6GR status for complete joint penetration groove welds in T-, Y-, and K-connections using box tubes, the welder must weld the 6GR test assembly of Figure 4.27 using either a round or box tube in accordance with the limitations of Table 4.9. In addition, the welder must successfully pass the corner macroetch test using Figure 4.28 or, as an option, if box sections were used for Figure 4.27, remove and macroetch the corner sections from the test weldment.

Qualification on 2G plus 5G or 6G pipe tests also qualifies for butt joints in box sections (with applicability based on thickness, neglecting diameter) but not vice versa. For these butt joints, the macroetch corner test of Figure 4.28 is not necessary because all production joints require nondestructive examination per 6.11.1.

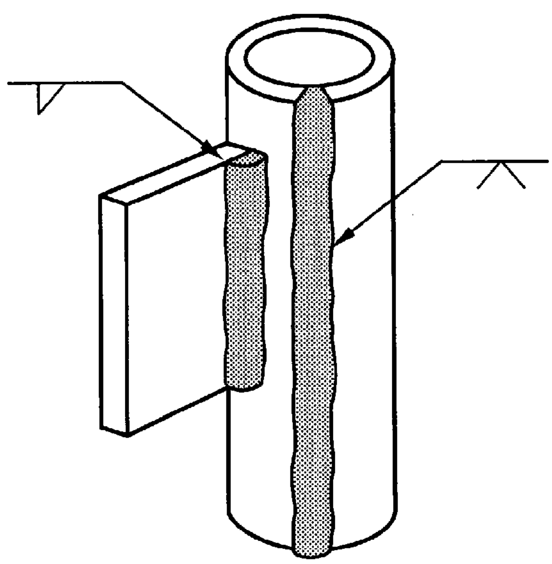
Table 4.9 does not differentiate between pipe (circular tubing) and box sections. For this reason, the following interpretation is appropriate:

(1) Qualification on the 6GR pipe test also qualifies for T-, Y-, and K-connections and groove welds in box sections.

(2) Qualification on 5G and 2G pipe tests also qualifies for box sections (with applicability based on thickness, neglecting diameter), but not vice versa.

(3) Qualification for groove welds in box sections also qualifies for plate (and vice versa if within the limitation of Table 4.8 and 4.22 of the code).

(4) When box sections are used in qualification, bend tests taken from the faces do not evaluate the welder's ability to carry sound welding around corners. These bend tests do not fulfill the needs of T-, Y-, and K-connections, because the corners in these connections are highly stressed. Where a 6GR test utilizes box sections, radiography is recommended to evaluate the corners.



PIPE QUALIFICATION IS NOT REQUIRED AND PLATE QUALIFICATION IS ACCEPTABLE FOR 3G, 3F, 4G, 4F AND FOR 1F, 1G, 2F AND 2G.

Figure C4.1—Type of Welding on Pipe That Does Not Require Pipe Qualification (see Table 4.8)

C5. Fabrication

C5.1 Scope

The criteria contained in section 5, are intended to provide definition to the producer, supervisor, engineer and welder of what constitutes good workmanship during fabrication and erection. Compliance with the criteria is achievable and expected. If the workmanship criteria are not generally met, it constitutes a signal for corrective action.

C5.2 Base Metal

The ASTM A6 and A20 specifications govern the delivery requirements for steels, provide for dimensional tolerances, delineate the quality requirements, and outline the type of mill conditioning.

Material used for structural applications is usually furnished in the as-rolled condition. The Engineer should recognize that surface imperfections (seams, scabs, etc.) acceptable under A6 and A20 may be present on the material received at the fabricating shop. Special surface finish quality, when needed in as-rolled products, should be specified in the information furnished to the bidders.

The steels listed as approved in Table 3.1 and Annex M of the code include those considered suitable for welded cyclically loaded structures and statically loaded structures as well as tubular structures. Also listed are other ASTM specifications, American Bureau of Shipping (ABS) specifications, and American Petroleum Institute (API) specifications that cover types of materials that have been used in tubular structures. All of the steels approved are considered weldable by the procedures that may be qualified or prequalified to this code. Every Code approved steel is listed in Table 3.1 and Annex M.

The ASTM specifications for grades of structural steel used in building construction for which welding procedures are well established are listed in Table 3.1 and Annex M together with other ASTM specifications covering other types of material having infrequent application but which are suitable for use in statically loaded structures. The ASTM A588, A514, and A517 specifications contain grades with chemistries that are considered suitable for use in the unpainted or weathered condition. ASTM A618 is available with enhanced corrosion resistance.

Structural steels that are generally considered applicable for use in welded steel cyclically loaded structures are listed in Table 3.1 and Annex M as approved steels. Other ASTM specifications for other types of steel having infrequent applications, but suitable for use in cyclically loaded structures, are also listed as approved steels. Steels conforming to these additional ASTM specifications, A500, A501, and A618, covering structural tubing, and A516 and A517 pressure vessel plates are considered weldable and are included in the list of approved steels for cyclically loaded structures.

The complete listing of approved steels in Table 3.1 and Annex M provides the designer with a group of weldable steels having a minimum specified yield strength range from 30 ksi to 100 ksi (210 MPa to 690 MPa), and in the case of some of the materials, notch toughness characteristics which make them suitable for low-temperature application.

Other steels may be used when their weldability has been established according to the qualification procedure required by section 4.

The code restricts the use of steels to those whose specified minimum yield strength does not exceed 100 ksi (690 MPa). Some provisions of 2.40.1 rely upon the ability of steel to strain harden.

C5.3.1.3 Dew Point/Manufacturer's Certification. From information supplied by the manufacturers of shielding gas, it has been determined that a dew point of −40°F (−40°C) is a practical upper limit providing adequate moisture protection. A dew point of −40°F (−40°C) converts to approximately 128 parts per million (ppm) by volume of water vapor or about 0.01% available moisture. This moisture content appears very low but, when dissociated at welding temperatures, would contribute hydrogen to that already associated with the electrode. Therefore, it is mandatory to have –40°F (–40°C) or lower dew point in shielding gas.

C5.3.2 SMAW Electrodes. The ability of low-hydrogen electrodes to prevent underbead cracking is dependent on the moisture content in the coating. During welding, the moisture dissociates into hydrogen and oxygen; hydrogen is absorbed in the molten metal, and porosity and cracks may appear in the weld after the weld metal solidifies. The provisions of the code for handling, storage, drying, and use of low-hydrogen electrodes should be strictly adhered to in order to prevent moisture absorption by the coating material.

C5.3.2.1 Low-Hydrogen Electrode Storage Condition. For carbon steel low-hydrogen electrodes, ANSI/AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, specifies no moisture limit for the low-hydrogen coating.

However, the appendix to ANSI/AWS A5.1 states it should be less than 0.6%. Alloy steel low-hydrogen electrodes covered in ANSI/AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*, have a specified maximum moisture content in the as manufactured condition. For the E70XX-X class electrodes, it is 0.4%; for E80XX-X electrodes, it is 0.2%; for the E90XX-X, E100XX-X, E110XX-X, and E120XX-X class electrodes, it is 0.15%.

Experience has shown that the limits specified above for moisture contents in electrode coverings are not always sufficiently restrictive for some applications using the E90XX-X and lower classes. Electrodes of classifications lower than E100XX-X are subject to more stringent moisture level requirements when used for welding the high-strength quenched and tempered steels, ASTM A514 and A517. All such electrodes are required to be dried between 700 and 800°F (370 and 430°C) before use. Electrodes of classification below E90XX-X are not required by ANSI/AWS A5.5 to have a moisture content less than 0.15%, and the required drying will achieve at least this moisture level. This precaution was necessary because of the sensitivity of high-strength steels and weld metal to hydrogen cracking.

Tests have shown there can be a wide variation in the moisture absorption rate of various brands of electrodes representing a given AWS classification. Some electrodes absorb very little moisture during standard exposure times while others absorb moisture very rapidly. The moisture control requirements of 5.3.2.1 are necessarily conservative to cover this condition and ensure that sound welds can be produced.

The time restrictions on the use of electrodes after removal from a storage oven may seem overly restrictive to some users. The rate of moisture absorption in areas of low humidity is lower than that encountered in areas of high humidity. The code covers the most restrictive situations.

C5.3.3.1 Electrode-Flux Combinations. ANSI/AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, was published in 1976 and revised in 1980. Electrodes and fluxes conforming to the classification designation of this specification may be used as prequalified, provided the provisions of 3.3 and Table 3.1 are observed. The contractor should follow the supplier's recommendations for the proper use of fluxes.

C5.3.3.2 Condition of Flux. The requirements of this section are necessary to assure that the flux is not a medium for introduction of hydrogen into the weld because of absorbed moisture in the flux. Whenever there is a question about the suitability of the flux due to improper storage or package damage, the flux should be discarded or dried in accordance with the manufacturer's recommendations.

C5.3.3.3 Flux Reclamation. For recovery of the unfused flux through the vacuum recovery system, a distinction has to be made between fused and bonded fluxes. Fused fluxes, in general, tend to become more coarse as they are recycled (especially where particles are less than 200 mesh). In this case, the vacuum system generally filters out some of the fines—and hence at least 25% virgin material should be added to replenish the fines before it is reused. Bonded fluxes on the other hand, because of their method of manufacture, tend to break up in the flux recovery system giving rise to a greater proportion of smaller particles. In order to compensate for the flux break-up, at least 25% virgin material (although 50% is more common among users) needs to be added to the recycled flux before it is reused. For both categories of fluxes, it is essential to separate out any possible metallics (from plate rust or mill scale) before recycling the flux.

The quality of recovered flux from manual collection systems is dependent on the consistency of that collection technique. Extraneous material and moisture contamination must be controlled. In addition, the welding fabricator should follow a procedure that assures that a consistent ratio of virgin flux is added and mixed with the recovered flux.

C5.3.3.4 Recrushed Slag. The slag formed during submerged arc welding (SAW) may not have the same chemical composition as unused (virgin) flux. Its composition is affected by the composition of the original flux, the base metal plate and electrode composition, and the welding parameters.

Although it may be possible to recrush and reuse some SAW slag as a welding flux, the recrushed slag, regardless of any addition of virgin flux to it, may be a new chemically different flux. It can be classified under the ANSI/AWS A5.17 or A5.23 specification, but should not be considered to be the same as virgin flux.

C5.3.4 GMAW/FCAW Electrodes. AWS filler metal specifications are now available for low-alloy weld metal for both gas metal arc welding (GMAW) and flux cored arc welding (FCAW). The use of low alloy electrodes is permitted with prequalified procedures when the electrodes conform to either ANSI/AWS A5.28, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding* or ANSI/AWS A5.29, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding.*

C5.4 Electroslag and Electrogas Welding Processes

The procedures to be used for electroslag and electrogas welding are detailed in 5.4, and the essential variables for these procedures are given in 4.7.2.

The code requires the qualification of WPSs since welding variables influence the operation of the process with respect to adequate penetration, complete fusion of the joint area, and ability to produce a sound weld.

These are relatively new processes, and insufficient experience is the justification for not according a prequalified status to them.

C5.7 Heat Input Control for Quenched and Tempered Steel

The strength and toughness of the heat-affected zone (HAZ) of welds in quenched and tempered steels are related to the cooling rate. Contrary to principles applicable to other steels, the fairly rapid dissipation of welding heat is needed to retain adequate strength and toughness. The cooling rate of the austenitized HAZ must be sufficiently rapid to ensure the formation of the hardening constituents in the steel microstructure. Overheating of quenched and tempered steel followed by slow cooling prevents the formation of a hardened microstructure.

The deposition of many small weld beads improves the notch toughness of the weld by grain refining and the tempering action of ensuing passes. A weave bead, with its slower travel speed, increases heat input and is therefore not recommended. Because the maximum heat input for various quenched and tempered steels varies over a wide range, heat input as developed and recommended by the steel producers should be strictly observed.

C5.8 Stress Relief Heat Treatment

This paragraph provides for two postweld heat treatment methods for stress relief of a welded assembly. The first method requires the assembly to be heated to 1100°F (595°C) max for quenched and tempered steels, and between 1100 and 1200°F (595 to 650°C) for other steels. The assembly is held at this temperature for the time specified in Table 5.2. In 5.8.2, an alternative method permits a decrease in temperature below the minimum specified in the first method, when the holding time is increased. The alternative method is used when it is impractical to postweld heat treat the welded assembly at higher temperatures. These temperatures are sufficiently below the critical temperature to preclude any change in properties.

If the purpose of the postweld heat treatment is to stress relieve the weld, the holding time is based on the weld metal thickness even though some material in the weldment is thicker than the weld. If the purpose of the postweld heat treatment is to maintain dimensional stability during subsequent machining, the holding time is based on the thickest component in the weldment. Certain quenched and tempered steels, if stress relieved as a carbon or low-alloy steel, may undergo undesirable changes in microstructure, causing a deterioration of mechanical properties or cracking, or both. Such steels should only be stress relieved after consultation with the steel producer and in strict accordance with the producer's recommendations.

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

C5.10 Backing

All prequalified complete joint penetration groove welds made from one side only, except as permitted for tubular structures, are required to have complete fusion of the weld metal with a steel backing. Other backing, such as listed in 5.22.1, may be used, if qualified in accordance with section 4. When steel backing is used, it shall be continuous for the entire length of the weld (see 5.10.2). When not continuous, the unwelded butt joint of the backing will act as a stress raiser that may initiate cracking.

C5.10.2 Full-Length Backing. It is imperative that steel backing be continuous for the full length of the weld. Experience has shown that a tightly fitted, but unwelded square butt joint in steel backing constitutes a severe notch that potentially leads to transverse cracks in the weld. Such cracks will, in most cases, propagate into the base metal.

C5.10.4 Cyclically Loaded Nontubular Connections. Steel backing transverse to applied stress forms a point of stress concentration and may be a source of fatigue crack initiation in cyclically loaded structures. Therefore, the provisions of 5.10.4 require the removal of backing that is transverse to the direction of computed stress in cyclically loaded structures.

C5.12.2 Minimum Ambient Temperature. Experience has shown that welding personnel cannot produce optimum results when working in an environment where the temperature is lower than 0°F (−18°C). Reference is made in 5.12.2 relative to the use of a heated structure or shelter to protect the welder, and the area being welded, from inclement weather conditions. If the temperature in this structure or shelter provides an environment at 0°F (−18°C), or above, the prohibition of 5.12.2 is not applicable. The environmental conditions inside the structure or shelter do not alter the preheat or interpass temperature requirements for base metals stated elsewhere in the code.

C5.13 Compliance with Design

Either or both legs of fillet welds may be oversized without correction, provided the excess does not interfere with satisfactory end use of a member. Attempts to remove excess material from oversized welds serve no purpose. Adequacy of throat dimension and conformance to the weld profiles of 5.4 should be the only acceptance criteria.

C5.14 Minimum Fillet Weld Sizes

The code specifies minimum fillet weld sizes based upon two independent considerations.

(1) For non-low-hydrogen processes, the minimum size specified is intended to ensure sufficient heat input to reduce the possibility of cracking in either the heat-affected zone or weld metal.

(2) When possibility of cracking is reduced by use of low-hydrogen processes or by non-low-hydrogen processes using a procedure established in accordance with 3.5.2, the specified minimum is intended to maintain reasonable proportionality with the thinner connected parts.

In both cases, the minimum size applies if it is larger than the size required to satisfy design requirements.

The intent of Table 5.8 is further clarified as follows: Base metal thickness of 3/4 in. (19 mm) and under are exempt from preheat in accordance with Table 3.2. Should fillet weld sizes greater than the minimum sizes be required for these thicknesses, then each individual pass of multiple-pass welds must represent the same heat input per inch of weld length as provided by the minimum fillet size required by Table 5.8.

C5.15 Preparation of Base Metal

Girder web-to-flange welds are usually minimum size fillet welds deposited at relatively high speeds; these welds may exhibit piping porosity when welded over heavy mill scale often found on thick flange plates. It is only for these flange-to-web welds in girders that the mandatory requirement to completely remove mill scale applies.

In stiffener-to-web welds, light mill scale on the thin members forming the joints reduces the probability of piping porosity. In columns, the web-to-flange welds are usually large, the multiple-pass welds are made at comparatively slow speeds, and, under these conditions, gases formed may have time to escape before the molten metal solidifies.

When discontinuities that would adversely affect weld quality are present at locations to be welded, the contractor is expected to repair them in accordance with 5.15.1.2.

C5.15.1.2 Repair. Mill induced defects observed on cut surfaces are caused by entrapped slag or refractory inclusions, deoxidation products, or blow holes. The repair procedures for discontinuities of cut surfaces may not be adequate where tension is applied in the through-thickness direction of the material. For other directions of loading, this article permits some lamination-type discontinuities in the material. Experience and tests have shown that laminations parallel to the direction of tensile stresses do not generally adversely affect the load-carrying capacity of a structural member. The user should note that the repair procedures of 5.15.1.2 are only intended for correction of material with sheared or thermal cut edges.

C5.15.2 Joint Preparation. Oxygen gouging on quenched and tempered or normalized steel is prohibited because of the high-heat input of the process (see C5.7).

C5.15.4.3 Roughness Requirements. Corrections are permitted for thermal cut surfaces that exceed the maximum permissible surface roughness values. Occasional notches or gouges of limited depth may be corrected, the deeper ones only with approval. Depth limitations represent the collective judgement of the Committee and reflect on the structural requirements and typical workmanship capability of the contractor.

By referring to "occasional notches and gouges," the Committee refrained from assigning any numerical values on the assumption that the Engineer—being the one most familiar with the specific conditions of the structure—will be a better judge of what is acceptable. The Engineer may choose to establish the acceptance criteria for occasional notches and gouges.

C5.16 Reentrant Corners

Statically loaded and tubular structures permit, and generally require, a smaller reentrant corner radius than is permitted for cyclically loaded structures. The smaller radius is necessary for some standard bolted or riveted connections.

See Figure C5.1 for examples of unacceptable reentrant corners.

C5.17 Beam Copes and Weld Access Holes

The code does not specify a minimum radius for corners of beam copes and weld access holes of hot rolled beams or welded built-up cross sections because any arbitrarily selected minimum radius would extend up into the beam fillet or the bottom of the flange, in some cases, making the radius extremely difficult or impossible to provide. Further, the peak stress can be accommodated only by localized yielding, and the magnitude of the elastic stress concentration factors is not significantly affected by the differences in radii of any practical size. Figure C5.2 shows examples of good practice for forming copes and weld access holes.

C5.17.1 Weld Access Hole Dimensions. Solidified but still hot weld metal contracts significantly as it cools to ambient temperature. Shrinkage of large welds between elements which are not free to move to accommodate the shrinkage induced strains in the material adjacent to the weld can exceed the yield point strain. In thick material, the weld shrinkage is restrained in the thickness directions as well as in the width and length directions, causing triaxial stresses to develop that may inhibit the ability of ductile steel to deform in a ductile manner. Under these conditions, the possibility of brittle fracture increases.

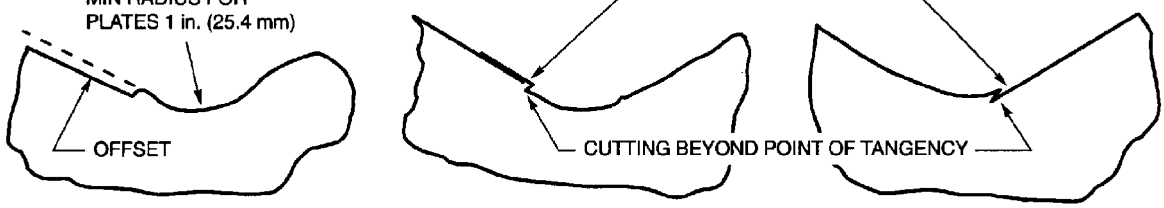


Figure C5.1—Examples of Unacceptable Reentrant Corners (see C5.16)

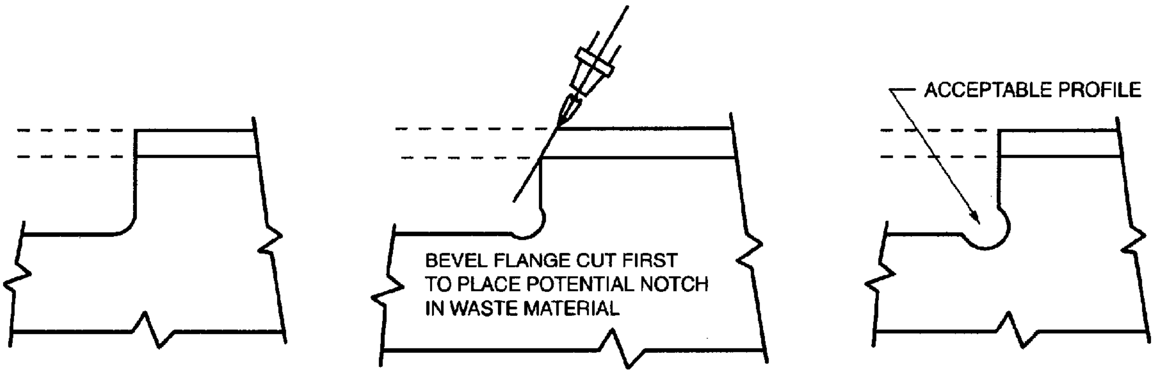


Figure C5.2—Examples of Good Practice for Cutting Copes (see C5.17)

Generously sized weld access holes, Figure 5.2, are required to provide increased relief from concentrated weld shrinkage strains, to avoid close juncture of welds in orthogonal directions, and to provide adequate clearance for the exercise of high-quality workmanship in hole preparation, welding, and ease of inspection.

Welded closure of weld access holes is not recommended.

When weld access holes must be closed for cosmetic or corrosion protection reasons, sealing by use of mastic materials is preferable to welding.

C5.18.2 General Requirements for Tack Welds. Tack welds must comply with the same workmanship, preheat, etc., and quality criteria required for finished welds, unless remelted and incorporated in final submerged arc welds.

C5.19 Camber in Built-Up Members

Heat upsetting (also referred to as *flame shrinking*) is deformation of a member by application of localized heat. It is permitted for the correction of moderate variations from specified dimensions. The upsetting is accomplished by careful application of heat with the resulting temperature not exceeding the maximum temperature specified in 5.26.2.

C5.22.1 Fillet Weld Assembly. Except for the separation of faying surfaces in lap joints and backing bars, a gap of 3/16 in. (5 mm) maximum is permitted for fillet welding material not exceeding 3 in. (76 mm) in thickness. For material over 3 in. (76 mm), the maximum permissible gap is 5/16 in. (8 mm).

These gaps are necessitated by the allowable mill tolerances and inability to bring thick parts into closer alignment. The code presupposes straightening of material prior to assembly or an application of external load mechanism to force and keep the material in alignment during assembly.

These gaps may require sealing either with a weld or other material capable of supporting molten weld metal. It should be realized that upon release of any external jacking loads, additional stresses may act upon the welds. Any gap 1/16 in. (1.6 mm) or greater in size requires an increase in size of fillet by the amount of separation.

C5.22.2 Partial Joint Penetration Groove Weld Assembly. See C5.22.1.

C5.22.3 Butt Joint Alignment. Typical sketches of the application of the alignment requirements for abutting parts to be joined in welds in butt joints are shown in Figures C5.3 and C5.4.

C5.22.4.2 Tubular Cross-Sectional Variations. In comparison with the static and cyclic nontubular requirements of section 2 stricter tolerances are required for complete joint penetration groove welds made from one side only without backing.

C5.22.4.3 Correction. Root openings wider than those permitted by Table 5.5 may be corrected by building up one or both sides of the groove faces by welding. In correcting root openings, the user is cautioned to obtain the necessary approvals from the Engineer where required. The final weld is to be made only after the joint has been corrected to conform to the specified root opening tolerance, thus keeping shrinkage to a minimum.

C5.23.2 and C5.23.3 Beam and Girder Straightness. Permissible variation in straightness of welded built-up members are the same as those specified in ASTM A6 for hot rolled shapes.

C5.23.4 Beam and Girder Camber (without Designed Concrete Haunch). The cambering of welded beams or girders is used to eliminate the appearance of sagging or to match elevation of adjacent building components when the member is fully loaded.

Although the tolerance on camber is of less importance than camber per se, for consistency, allowable variation in camber is based upon the typical loading case of distributed load which causes a parabolic deflected shape.

The tolerances shown are to be measured when members are assembled to drill holes for field splices or to prepare field welded splices (see Figure C5.6).

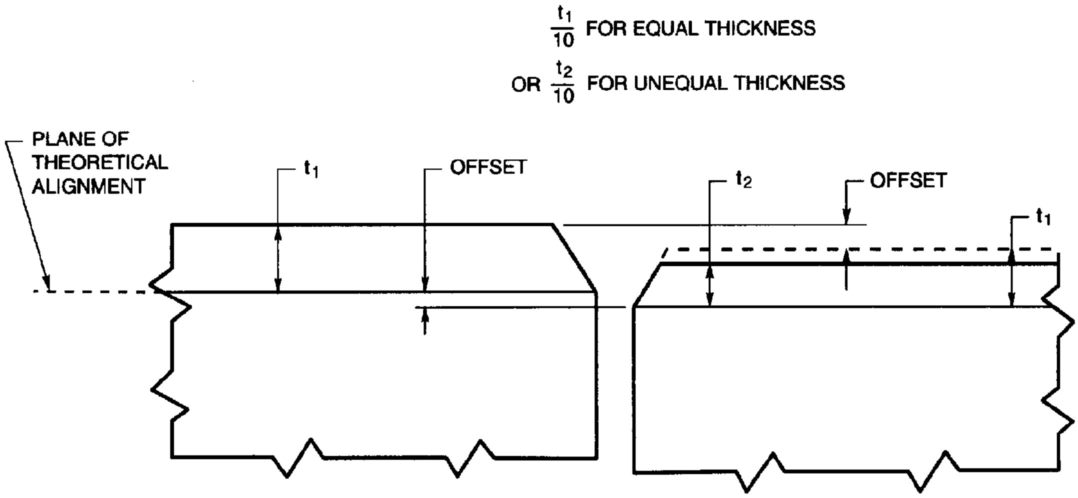
When the deck is designed with a concrete haunch, the 1-1/2 in. (38 mm) tolerance at mid-span is based upon an assumed 2 in. (50 mm) design haunch. The 1/2 in. (13 mm) difference is for field deviations and other contingencies.

When the contractor checks individual members, care should be exercised to assure that the tolerances of the assembly will be met.

There are two sets of tolerances for permissible variation from specified camber. The first set of tolerances applies to all welded beams and girders, except members whose top flange is embedded in concrete without a designed concrete haunch. Here the camber tolerance is positive with no minus tolerance permitted.

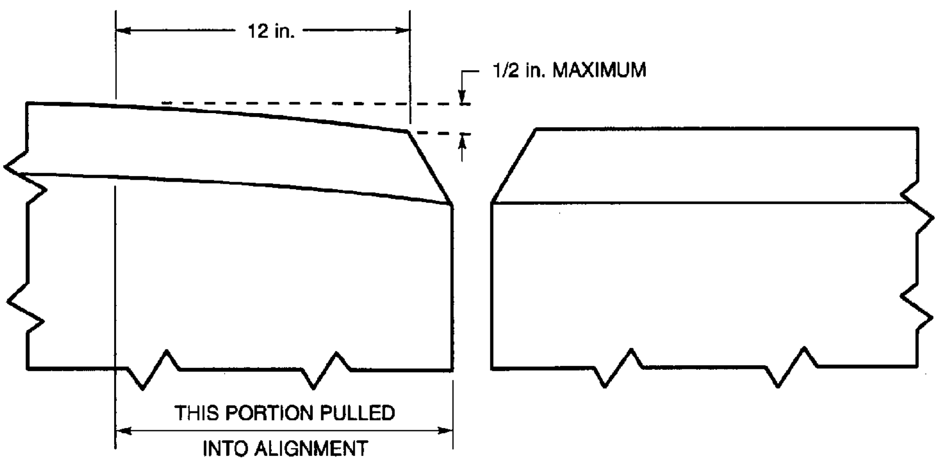
The second set of tolerances applies to welded members where the top flange is embedded in concrete without a designed haunch; the variation permitted has both a plus and minus tolerance.

C5.23.6.1 Measurements. Permissible tolerances for variations from flatness of dynamically loaded girder webs are given in the code separately for interior and fascia girders. The stricter tolerance for fascia girders is



NOTE: AN OFFSET NOT EXCEEDING 10% OF THE THICKNESS OF THE THINNER PART JOINED, BUT IN NO CASE MORE THAN 1/8 in. (3 mm), MAY BE PERMITTED AS A DEPARTURE FROM THE THEORETICAL ALIGNMENT.

Figure C5.3—Permissible Offset in Abutting Members (see C5.22.3)



NOTE: IN CORRECTING MISALIGNMENT THAT EXCEEDS THE PERMISSIBLE ALLOWANCE, THE PARTS SHALL NOT BE DRAWN TO A SLOPE GREATER THAN 1/2 in. (13 mm) IN 12 in. (305 mm).

Figure C5.4—Correction of Misaligned Members (see C5.22.3)

based only on appearance as there are no structural requirements for the difference. Even fascia girder distortion permitted will be somewhat noticeable, particularly when members are painted with a glossy finish. The fascia tolerances are considered satisfactory for most requirements. If more stringent tolerances are needed for appearance, they should be included in contract documents as stated in 5.23.6.1, but some degree of distortion is unavoidable.

Variations from flatness in girder webs are determined by measuring offset from the nominal web centerline to a straight edge whose length is greater than the least panel dimension and placed on a plane parallel to the nominal web plane. Measurements shall be made prior to erection. Determining the offset can be measured as shown in Figure C5.5.

C5.23.6.2 Statically Loaded Nontubular Structures. The flatness tolerances for webs with intermediate stiffeners on both sides and subject to dynamic loading is the same as that for interior bridge girders (see 5.23.6.3). When subject to static loading only, the tolerance is somewhat more liberal. The tolerance given for intermediate stiffeners, placed only on one side of the web, is the same for either cyclic or static loading and is the same as that for interior bridge girders.

Note: The AISC Specification for Design, Fabrication, and Erection of Structural Steel for Buildings states that the tolerances for flatness of girder webs given in 5.23.6.2 need not apply for statically loaded girders.

C5.23.6.4 Excessive Distortion. Web distortions of twice the amount permitted for interior or fascia girder panels are permitted in end panels of girders if the installation of field bolted splice plates will reduce the distortion to the level otherwise permitted. To avoid the possibility of costly field correction, the contractor should determine by a shop assembly that the bolted splice plate will reduce the distortion to acceptable limits.

C5.23.8 Flange Warpage and Tilt. The combined warpage and tilt Δ of the flange of welded beams and girders is measured as shown in Figure C5.7. In the Committee's judgement, this tolerance is easier to use than the ASTM A6 specification criteria, although both sets of tolerances are in reasonable agreement.

Tolerance on twist is not specified because the torsional stiffness of open (nonbox) shapes is very low, such that twist is readily eliminated by interconnection with other members during erection. Members of box cross sections are approximately 1000 times as stiff in torsion as an open I or W shape with equivalent bending and area section properties. Once a closed box section has been welded, it is extremely difficult to correct any twist that may have been built in without cutting one corner apart and rewelding. Because twist resulting from welding is not entirely predictable and extremely difficult to correct in closed box members, the following apply.

(1) Appropriate provisions should be incorporated in design to ensure reliable service performance of such members with some arbitrary measure of twist.

(2) Due cognizance should be taken of the size of the element, of the effect of the twist when placing cement on the structure, and the use of such connection details that will satisfactorily accommodate the twist.

C5.23.10 Bearing at Points of Loading. Figure C5.8 illustrates application of the code requirement.

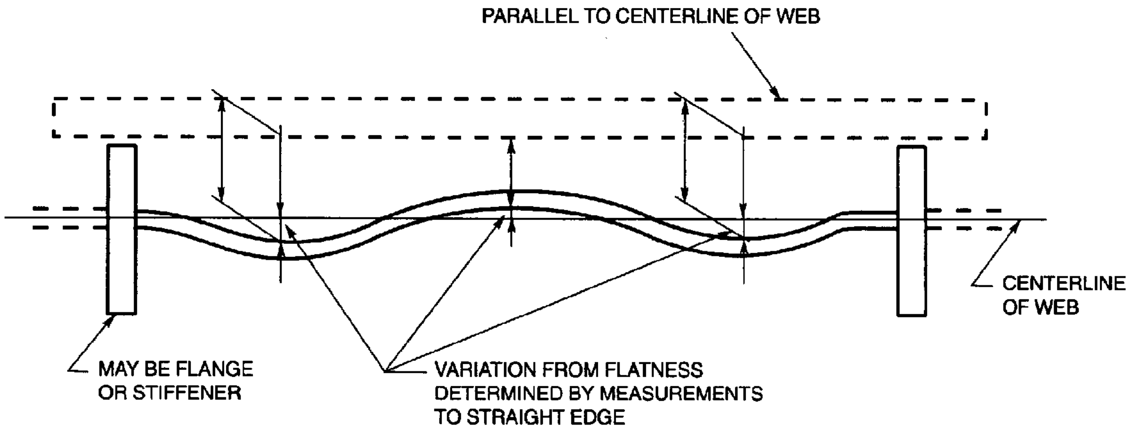
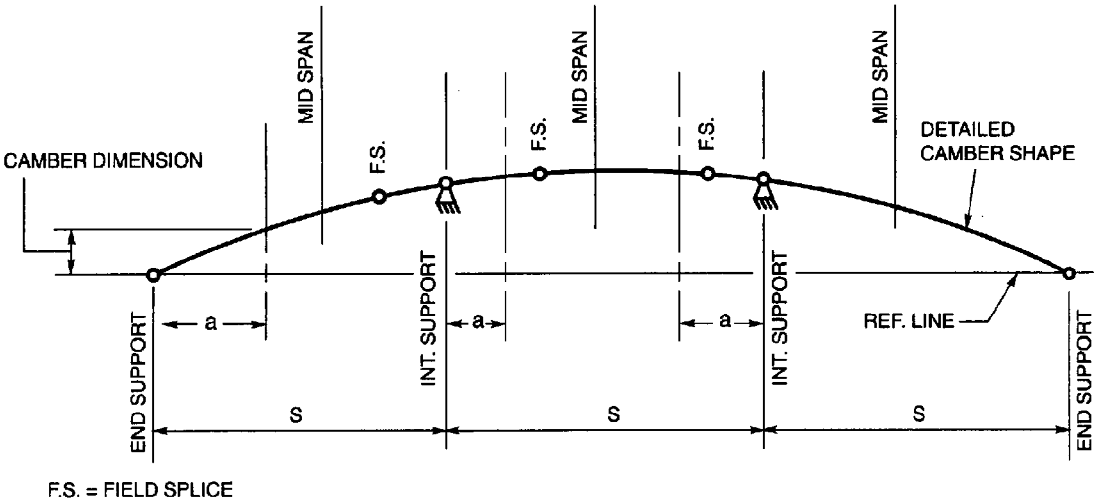
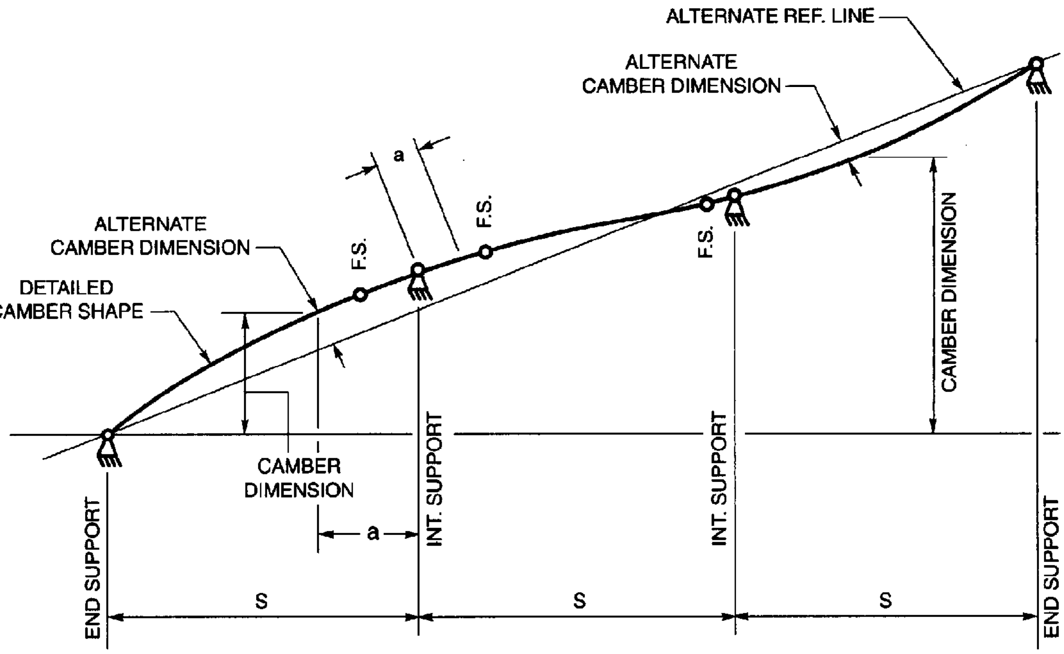


Figure C5.5—Typical Method to Determine Variations in Girder Web Flatness (see C5.23.6.1)



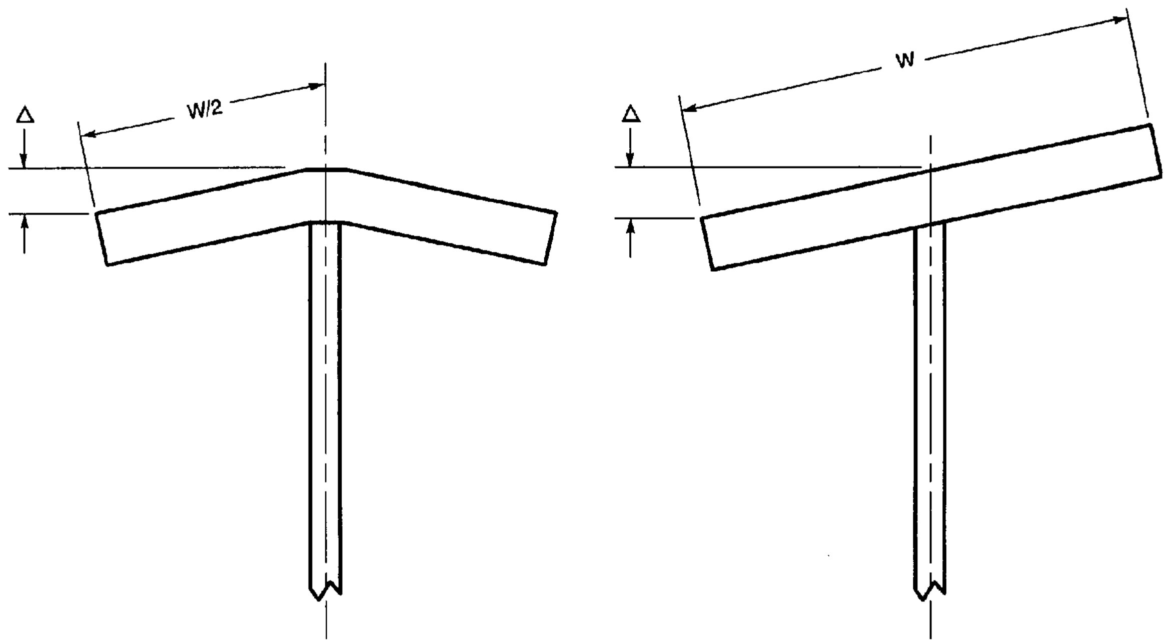
TYPICAL GIRDER ASSEMBLY



TYPICAL GIRDER ASSEMBLY SHOWING SAG CURVE

NOTE: PLUS TOLERANCE INDICATES POINT IS ABOVE THE DETAILED CAMBER SHAPE.
MINUS TOLERANCE INDICATES POINT IS BELOW THE DETAILED CAMBER SURFACE.

Figure C5.6—Illustration Showing Camber Measurement Methods (see C5.23.4)



Δ (in.) $\leq \frac{W \text{ (in.)}}{100}$ OR 1/4 in. (6 mm), WHICHEVER IS GREATER

Figure C5.7—Measurement of Flange Warpage and Tilt (see C5.23.8)

C5.23.11.4 Other Dimensional Tolerances. Tolerances specified in 5.23 are limited to routinely encountered cases. Dimensional tolerances not covered in 5.23 should be established to reflect construction or suitability for service requirements.

C5.24 Weld Profiles

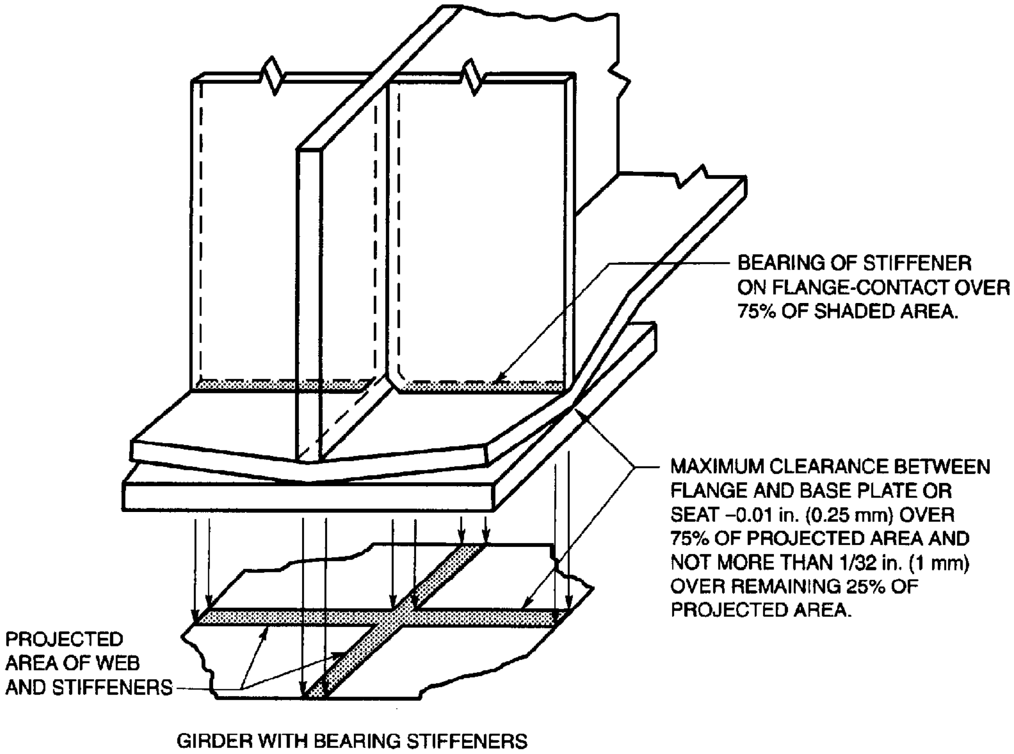
The 1982 edition changed the fillet weld convexity requirements in such a way that the maximum convexity formula applies not only to the total face width of the weld, but also to the width of an individual bead on the face of a multiple-pass weld. This was done to eliminate the possibility of accepting a narrow "ropey" bead on the face of an otherwise acceptable weld. The new formula, which is based on the "width of face," provides the same convexity requirement as the previous formula which was based on "leg size."

When a fillet weld is started, the weld metal, due to its surface tension, is rounded at the end. Sometimes this is such that there is a slight curve inward. Also, at both the start and finishing ends, this curve prevents the weld from being full size to the very end. Therefore, these portions are not included as part of the effective weld length. If the designer has any concern relative to the notch effects of the ends, a continuous fillet weld should be specified which would generally reduce the required weld size.

C5.26.1 Contractor Option (Repair). The code permits the contractors, at their option, to either repair or remove and replace an unacceptable weld. It is not the intent of the code to give the Inspector authority to specify the mode of correction.

C5.26.2 Localized Heat Repair Temperature Limitations. Application of localized heat is permitted for straightening members; however, this must be done carefully so as not to exceed temperature limitations that would adversely affect the properties of the steel. Quenched and tempered steels should not be heated above 1100°F (595°C) because deterioration of mechanical properties may possibly result from the formation of an undesirable microstructure when cooled to room temperature. Other steels should not be heated above 1200°F (650°C) to avoid the possibility of undesirable transformation products or grain coarsening, or both. However, these maximums are sufficiently below the metal lower transformation temperature to allow some tolerance in temperature measurement method.

C5.26.5 Welded Restoration of Base Metal with Mislocated Holes. The technique for making plug welds set forth in 5.25.1 of this code is not satisfactory for restoring the entire cross section of the base metal at mislocated holes. Plug welds are intended to transmit shear



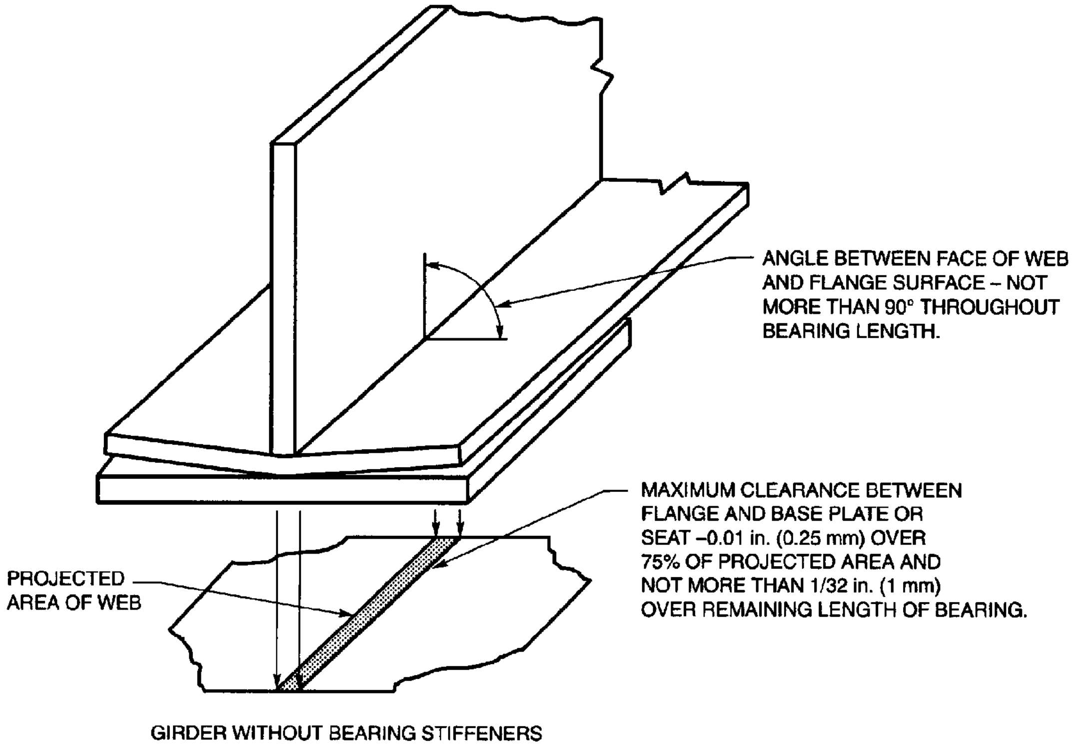


Figure C5.8—Tolerances Bearing Points (see C5.23.10)

from one plane surface to another and not to develop the full cross section of the hole. One method of restoring unacceptable holes is to fill one-half the depth or less with steel backing of the same material specification as the base metal, gouge an elongated boat-shaped cavity down to the backing, then fill the cavity by welding using the stringer bead technique. After the first side is welded, gouge another elongated boat-shaped cavity completely removing the temporary backing on the second side, and complete by welding using the stringer bead technique.

C5.27 Peening

Except as provided in 2.36.6.6(3), peening of the surface layer of the weld is prohibited because mechanical working of the surface may mask otherwise rejectable surface discontinuities. For similar reasons, the use of lightweight vibrating tools for slag removal should be used with discretion.

C5.29 Arc Strikes

Arc strikes result in heating and very rapid cooling. When located outside the intended weld area, they may result in hardening or localized cracking, and may serve as potential sites for initiating fracture.

C5.30 Weld Cleaning

The removal of slag from a deposited weld bead is mandatory to prevent the inclusion of the slag in any following bead and to allow for visual inspection.

C5.31 Weld Tabs

The termination, start or stop, of a groove weld tends to have more discontinuities than are generally found elsewhere in the weld. This is due to the mechanism of starting and stopping the arc. Hence, weld tabs should be used to place these zones outside the finished, functional weld where they can be removed as required by 5.31.2 or 5.31.3. Weld tabs will also help maintain the full cross section of the weld throughout its specified length. It is important that they be installed in a manner that will prevent cracks from forming in the area where the weld tab is joined to the member.

C6. Inspection

C6.1 Scope

This section of the code has been the subject of extensive revisions, which appeared for the first time in the 1980 code. The revisions are designed to clarify the separate responsibilities of the contractor/fabricator/erector, as opposed to the owner/Building Commissioner/Engineer, etc.

The revisions clarify the basic premise of contractual obligations when providing product and services. Those who submit competitive bids or otherwise enter into a contract to provide materials and workmanship for structural weldments in accordance with the provisions of the code assume an obligation to furnish the products as specified in the contract documents and are fully responsible for product quality.

In this section, the term *fabrication/erection inspection* is separated from verification inspection. In the original draft of this section, these separate functions were designated as quality control and quality assurance, respectively. These terms were replaced with the broader terms now contained in the code to avoid confusion with the usage in some industries (e.g., nuclear). Quality assurance means specific tasks and documentation procedures to some users of the code. It was advantageous to use more general terms that place greater emphasis on timely inspection. The contractor is solely responsible for the ordering of materials, and assembly and welding of the structural weldments. Inspection by the owner must be planned and timely if it is to improve the quality of the construction.

C6.1.1 Information Furnished to Bidders. It is essential that the contractor know in advance which welds are subject to nondestructive tests and which testing procedures will be used. Unless otherwise provided in the contract documents, the quality criteria for acceptance of welds are stated in section 6, Part C. It is not necessary to write in the contract documents exactly which weld or what portions of specific welds will be examined by a specific test method. A general description of weld test requirements may be specified (e.g., "10% of the length of all fillet welds shall be inspected by magnetic particle testing," or "All complete joint penetration butt joint welds in tension flanges of girders shall be radiographed").

If the location of tension flange butt joint welds is not obvious, their location should be designated on the plans.

When spot checking is specified (e.g., 10% of all fillet welds), it should not be taken to imply that the contractor be notified prior to welding which specific welds or portion of welds shall be tested. It is a basic premise of the specifications that if random tests or spot tests are made, there should be a sufficient number of random tests to give a reliable indication of weld quality.

There are different acceptance criteria for statically loaded structures, cyclically loaded structures, and tubular structures. The basic difference in acceptance criteria for each of these structures is based upon the difference between static, and fatigue loading.

When fatigue crack growth is anticipated, acceptable initial weld flaw sizes must of necessity be smaller. All criteria are established in an attempt to preclude weld failure during the anticipated service life of the weldment.

C6.1.2 Inspection and Contract Stipulations. This subsection describes the responsibility of the contractor for fabrication/erection inspection and testing, which is basically the quality control responsibility described in other contract documents. The owner has the right, but generally not the responsibility, to provide independent inspection to verify that the product meets specified requirements. This quality assurance function may be done independently by the owner or their representative or, when provided in the contract, verification inspection may be waived or it may be stipulated that the contractor shall perform both the inspection and the verification. When this is done, quality control and quality assurance remain separate functions. Verification inspection should be performed independently by personnel whose primary responsibility is quality assurance and not production.

C6.1.3 Definition of Inspector Categories. This subsection describes the difference between the Inspector representing the owner and the Inspector representing the contractor.

C6.1.5 Inspector Responsibility. This subsection requires that the Inspector verify that all fabrication and erection by welding is performed in accordance with the requirements of the contract documents. This includes not only welding but also materials, assembly, preheating, nondestructive testing, and all other requirements of the code and provisions of the contract documents.

C6.1.6 Items to be Furnished to the Inspector. Inspectors need a complete set of approved drawings to enable them to properly do their work. They need be furnished only the portion of the contract documents describing the requirements of products that they will inspect. Much of the contract documents deal with matters that are not the responsibility of the Inspector; these portions need not be furnished.

C6.1.7 Inspector Notification. If the Inspectors are not notified in advance of the start of operations, they cannot properly perform the functions required of them by the code.

C6.2 Inspection of Materials

This code provision is all-encompassing. It requires inspection of materials and review of materials certification and mill test reports. It is important that this work be done in a timely manner so that unacceptable materials are not incorporated in the work.

C6.3 Inspection of WPS Qualification and Equipment

The requirements of 6.3.1 and 6.3.2, including any qualification testing required by section 4, should be completed before any welding is begun on any weldments required by the contract documents. Qualification should always be done before work is started, but all qualification does not have to be completed before any work can be started.

C6.4 Inspection of Welder, Welding Operator, and Tack Welder Qualifications

C6.4.1 Determination of Qualification. It is important that the Inspector determine that all welders are qualified before work is begun on the project. If discovered after welding has begun, lack of welder qualification documentation may cause serious delays in the acceptance of weldments.

C6.4.2 Retesting Based on Quality of Work. The inspector must regularly appraise the quality of welds produced by welders, welding operators, and tack welders. Individuals producing unacceptable welds should be required to produce satisfactory test welds of the type causing difficulties. Complete requalification may not always be necessary. Only qualified welders producing acceptable welds may be employed in the work.

C6.4.3 Retesting Based on Certification Expiration. Welders who cannot provide evidence that they have used, without interruption, the welding process for which they were qualified, for a period exceeding six months, shall be requalified by appropriate tests. Since active welders can maintain their certification as long as they continue to do good work, it is essential that Inspectors regularly evaluate the quality of the welds produced by each welder, welding operator, and tack welder.

C6.5 Inspection of Work and Records

Except for final visual inspection, which is required for every weld, the Inspector shall inspect the work at suitable intervals to make certain that the requirements of the applicable sections of the code are met. Such inspections, on a sampling basis, shall be prior to assembly, during assembly, and during welding. The inspector shall identify final acceptance or rejection of the work either by marking on the work or with other recording methods. The method of identification should not be destructive to the weldment. Die stamping of welds is not recommended since die stamp marks may form sites for crack initiation.

C6.6.1 Contractor Responsibilities. Contractors are responsible for the acceptability of their products. They shall conduct inspection to the extent necessary to ensure conformance with the code, except as provided in 6.6.5.

C6.6.2 Inspector Requests. If the Inspector(s) find deficiencies in the materials and workmanship, regardless of whether the Inspector(s) is a representative of the owner or an employee of the contractor, the contractor shall be responsible for all necessary corrections.

C6.6.4 Specified Nondestructive Testing Other Than Visual. When nondestructive testing is specified in the information furnished to bidders, the contractor shall take necessary steps to ensure that the nondestructive testing acceptance criteria prescribed by the code are met. When nondestructive testing other than visual inspection is not specified, the owner shall be responsible for all associated costs of testing and surface preparation plus the repair of discontinuities not reasonably expected to be discovered during visual inspection. Since there is a limit to the defects that might reasonably be expected to be found in welds, welds that contain defects which are considered beyond reasonable weld quality standards and which appear to result from gross nonconformance to this code shall be repaired or replaced at the contractor's expense in accordance with 5.26.1.

Part C
Acceptance Criteria

C6.7 Scope

Visual and radiographic weld quality requirements for tubular structures are essentially the same as for statically loaded structures (see section 6, Part C, and the Commentary). Radiography can generally not be applied successfully to inspection of tubular T-, Y-, and K-connections.

C6.8 Engineer's Approval for Alternate Acceptance Criteria

The criteria provided in section 5, Fabrication, are based upon knowledgeable judgment of what is achievable by a qualified welder. The criteria in section 5 should not be considered as a boundary of suitability for service. Suitability for service analysis would lead to widely varying workmanship criteria unsuitable for a standard code. Furthermore, in some cases, the criteria would be more liberal than what is desirable and producible by a qualified welder. In general, the appropriate quality acceptance criteria and whether a deviation produces a harmful product should be the Engineer's decision. When modifications are approved, evaluation of suitability for service using modern fracture mechanics techniques, a history of satisfactory service in similar structures, or experimental evidence is recognized as a suitable basis for alternate acceptance criteria for welds.

C6.9 Visual Inspection

This article makes visual inspection of welds mandatory and contains the acceptance criteria for it. The workmanship requirements of section 5, are also subject to visual inspection. Permissible depth of undercut was revised in the 1980 edition of the code to more accurately reflect an acceptable percentage reduction of cross-sectional area for three categories of stress. The undercut values are for structures and individual members that are essentially statically loaded.

Undercut values for cyclically loaded structures or tubular structures (6.9) have not been changed and should be specified for structures and individual members subject to cyclic loading.

C6.10 Liquid Penetrant and Magnetic Particle Inspection

The magnetic-particle acceptance criteria included in the code are based on the size of the actual discontinuity, and not the size of the discontinuity as indicated by the magnetic particle indicating medium. When surface discontinuities are revealed by magnetic-particle means, acceptance shall be based on a direct visual measurement of the actual discontinuity. Where the discontinuity cannot be visually seen (with magnification if required) after removal of the indicating medium, evaluation shall be based on the size and nature of the magnetic-particle indication. For subsurface discontinuities, the evaluation must be based on the size of the discontinuity indication because the discontinuity is not accessible.

The code does not include acceptance criteria for liquid penetrant testing based on bleedout of the dye. When liquid penetrant testing is used, the acceptance of any discontinuity shall be based on a visual evaluation of the discontinuity after the removal of the indicating medium. Where the discontinuity cannot be seen (with magnification if required) after removal of the indicating medium, evaluation shall be based on the size and nature of the liquid penetrant indication. Observation of the penetrant as it bleeds out will provide useful information concerning the nature of the discontinuity.

C6.11 Nondestructive Testing

The weld quality requirements for nondestructive testing are not a part of the contract unless nondestructive testing is specified in information furnished to the bidders or is subsequently made a part of the contract. Both the owner and contractor should give careful attention to the provisions of 6.6.5 and 6.14.1. When, in addition to the requirement for visual inspection, nondestructive testing is specified, the acceptance criteria of 6.11, 6.12, or 6.13 apply. The acceptance criteria for ASTM A514 and A517 high-strength quenched and tempered steels are based on inspection, visual or nondestructive, conducted at least 48 hours after completion of the weld. Since high-strength steels, when welded, and weld metals are susceptible to delayed cracking caused by hydrogen embrittlement, stress rupture, etc., it has been necessary to impose this time restriction to assure that any delayed cracking has a reasonable chance of being discovered during inspection.

C6.12.2 Acceptance Criteria for Cyclically Loaded Nontubular Connections. Except for ultrasonic testing, the nondestructive test acceptance criteria are divided into three categories as follows:

(1) Discontinuities 1/16 in. (1.6 mm) or larger in groove welds subject to tensile stress under any condition of loading are specified in 6.12.2.1 and Figure 6.4. It should be noted that Figure 6.4 includes both a permissible size and spacing for discontinuities.

(2) Discontinuities 1/8 in. (3 mm) or larger in groove welds subject to compressive stress only and which are specifically indicated as such on shop drawings have their quality requirements specified in 6.12.2.2 and Figure 6.5. Discontinuity sizes constitute the only difference in relation to Figure 6.4. Further restrictions are specified in the note (*) in Figure 6.5.

(3) Discontinuities less than 1/16 in. (1.6 mm) may coexist with larger discontinuities in members subject to tension with no restriction on their location or spacing except the sum of their greatest dimensions shall not exceed 3/8 in. (10 mm) in any linear inch of weld. These quality requirements are specified in 6.12.2.3.

C6.13.1 Acceptance Criteria for Statically Loaded Nontubular Connections. In Note (2) of Table 6.2, the key words that are most often misinterpreted are "...from weld ends carrying primary tensile stress." This phrase generally refers to the ends of groove welds subject to applied tensile stress by the design loads. The tensile stress must be normal to the weld throat. When box columns are used with moment connection members welded to the outside surface and diaphragm plates welded on the inside to transfer the primary stress through the box column member, the ends of the moment plate-to-box column plate welds are subject to the 2L distance from the end of the weld clause, but the welds on diaphragm plates on the inside of the box are not subject to this restriction. The weld ends of the diaphragm plates do not carry primary tensile stress because this stress is carried through the width of the adjacent box member plates.

Note (4) of Table 6.2 was added because experience with ultrasonic acceptance level provisions previously required by the code resulted in acceptance of some rather large gas pockets and piping porosity that can occur in electroslag and electrogas welds. The shape of these gas defects, which are peculiar to electroslag and electrogas welds, is such that they reflect less ultrasound than the usual weld discontinuities. Testing at 6 dB more sensitive than standard testing amplitudes will not guarantee accurate evaluation of gas defects in electroslag or electrogas welds. This type of discontinuity is easily evaluated by RT, which is recommended if indications of pipe or other gas discontinuities are seen at scanning levels.

For example, the application of these acceptance criteria for evaluation of a 2 in. (50 mm) thick weld, using a 70° probe, is shown in Table C6.1.

C6.13.2 Acceptance Criteria for Cyclically Loaded Nontubular Connections. See section C6, Part F. The code provides acceptance criteria for welds subject to tensile stresses that differ from those subject only to compressive stresses. Groove welds subject to compressive stresses only and which are indicated on design or shop drawings are required to conform to the acceptance criteria of Table 6.2. Groove welds subject to tensile stresses under any condition of loading and welds subject only to compressive stresses but not specifically designated as such on design or shop drawings are required to conform to the acceptance criteria of Table 6.3, which are up to 6 dB higher than those in Table 6.2.

Table C6.1
Ultrasonic Acceptance Criteria for 2 in. (50 mm) Welding, Using a 70° Probe (see C6.13.1)

Indication Rating*	Discontinuity Severity Class
−2 or less	Class A (large discontinuities) Unconditionally rejectable regardless of length
−1 or 0	Class B (medium discontinuities)** Accept if length is ≤ 3/4 in. Reject if length > 3/4 in.
+1 or +2	Class C (small discontinuities)** Accept if length is ≤ 2 in. Reject if length > 2 in.
+3 or Greater	Class D (minor discontinuities) Accept without limits on length or location

Note: For cyclically loaded structures, Table 6.3 requires that discontinuities more serious than Class D discontinuities and which exceed 3/4 in. (19 mm) in length be permitted only in the middle half of the weld thickness. This is not a requirement of Part C, section 2.

*See 6.26.6.5 and Annex D, Form D11, Report of Ultrasonic Examination of Welds.

**The separation between Class B and C discontinuities or between Class B and C discontinuities and the end of a weld must be a distance of at least 2L except where the end of a weld does not carry primary tensile stress, as in the corners of diaphragm plates in box sections. (L = The length of the longer two discontinuities or the length of a discontinuity which is being evaluated in relationship to the end of a weld.) The combined length of adjacent discontinuities may be required to be measured as a single discontinuity. See Note 1 in Table 6.2.

C6.13.3 Ultrasonic Acceptance Criteria for Tubular Connections. The ultrasonic testing procedures and acceptance criteria set forth in section 6, i.e., 6.13.1 and 6.13.2, are not applicable to tubular T-, Y-, and K-connections. Acceptance criteria for the latter are set forth in 6.13.3. Contract documents should state the extent of testing, which of the acceptance criteria apply (Class R or Class X), and where applicable. Because of the complex geometry of tubular T-, Y-, and K-connections, standardized step-by-step ultrasonic testing procedures, such as those given in section 6, do not apply. Any variety of equipment and techniques may be satisfactory providing the following general principles are recognized.

The inspection technique should fully consider the geometry of the joint. This can be simplified by idealizing localized portions of welds as joining two flat plates, in which case the principal variables are local dihedral angles, material thickness, and bevel preparation; curvature effects may then be reintroduced as minor corrections. Plotting cards superimposing the sound beam on a cross-sectional view of the weld are helpful. Inspections should be referenced to the local weld axis rather than to the brace axis. Every effort should be made to orient the sound beams perpendicular to the weld fusion line; in some cases this will mean multiple inspection with a variety of transducer angles.

The use of amplitude calibrations to estimate flaw size should consider sound path attenuation, transfer mechanism (to correct differences in surface roughness and curvature), and discontinuity orientation (e.g., a surface discontinuity may produce a larger echo than an interior discontinuity of the same size). Transfer correction is described in section 3.6.5 of Reference 10 of C2.

Amplitude calibration becomes increasingly difficult for small diameter [under 12 in.(305 mm)] or with thin wall [under 1/2 in. (12.7 mm)], or both. In the root area of tubular T-, Y-, and K-connections, prominent corner reflectors are often present which cannot be evaluated solely on the basis of amplitude; in this case, beam boundary techniques are useful for determining the size of the larger discontinuities of real concern. Beam boundary techniques are described in section 3.8.3.2 of Reference 10 of C2.

The ultrasonic acceptance criteria should be applied with the judgement of the Engineer, considering the following factors:

(1) For tubular T-, Y-, and K-connections having complete joint penetration groove welds made from the outside only (see Figures 3.6, Figures 3.8 through 3.10), root discontinuities are less detrimental and more difficult to repair than those elsewhere in the weld.

(2) It should be recognized that both false alarms (ultrasonic testing discontinuities that are not subsequently verified during the repair) and occasionally missed discontinuities may occur. The former are a part of the cost of the inspection, while the latter emphasize the need for structural redundancy and notch-tough steel.

Part D
Nondestructive Testing

C6.14 Procedures

In addition to visual inspection, which is always necessary to achieve compliance with code requirements, four nondestructive testing (NDT) methods are provided for in the code: (1) radiographic testing (RT), (2) ultrasonic testing (UT), (3) magnetic-particle testing (MT), and (4) dye penetrant testing (PT).

Radiographic and ultrasonic testing are used to detect both surface and internal discontinuities. Magnetic-particle testing is used to detect surface and near surface discontinuities. Dye penetrant testing is used to detect discontinuities open to the surface. Other NDT methods may be used upon agreement between owner and contractor.

C6.14.7 Personnel Qualification. Only individuals that qualify to SNT-TC-1A NDT Level II may perform nondestructive tests without supervision. Level III individuals may also perform NDT tests provided they meet the requirements of NDT Level II. NDT Level III engineers and technicians are generally supervisors and may not be actively engaged in the actual work of testing. Since there is no performance qualification test for individuals qualified to NDT Level III, all individuals providing testing services under the code must be qualified to Level II, which has specific performance qualification requirements.

C6.15 Extent of Testing

It is important that joints to be nondestructively examined be clearly described in the information furnished to bidders as explained in Part A of this Commentary.

C6.15.3 Spot Testing. It is assumed that if rejectable discontinuities are found in one spot and again in either of the additional required spot radiographs, the remainder of the weld shall be tested to determine the extent of remaining defects, if any. This subsection has been added for clarification of partial testing coverage. Prior to the 1980 edition of the code, no specific procedure was outlined for follow through of procedure requirements for additional testing requirements due to flaw detection in the first spot tested.

C6.16.1 Procedures and Standards (Radiographic Testing). The procedures and standards set forth in this section are primarily designed for the radiographic inspection of complete joint penetration groove welds in cyclically loaded structures and statically loaded structures. Typical geometries for structural connections and design requirements for these structures were taken into account in the preparation of the specification. An effort was made to incorporate the methodology of ASTM and to utilize procedures described in the ASME *Boiler and Pressure Vessel Code* whenever possible.

C6.16.2 Variations. Since this section does not provide for the radiographic testing of welds in tubular structures, variations are permitted based upon agreement between the contractor and the owner. The provisions of 6.12.3, shall apply when radiographic testing welds in tubular structures.

C6.17 Radiographic Procedure

The single source of inspecting radiation is specified to avoid confusion or blurring of the radiographic image. Elsewhere in the code, limits are placed on the size of the source to limit geometric unsharpness. Radiographic sensitivity is judged solely on the quality of the image quality indicator (IQI) [penetrameter] image(s), as in both ASTM and ASME.

C6.17.2 Safety Requirements. Ionizing radiation and chemicals used in radiographic inspection can present serious health hazards. All safety regulations must be complied with.

C6.17.3 Removal of Reinforcement. When the owner wishes weld surfaces to be ground flush or otherwise smoothed in preparation for radiographic testing, it should be stated in the contract documents. The owner and the contractor should attempt to agree in advance on which weld surface irregularities will not be ground unless surface irregularities interfere with interpretation of the radiograph. It is extremely difficult and often impossible to separate internal discontinuities from surface discontinuities when reviewing radiographs in the absence of information describing the weld surface. When agreement can be reached on weld surface preparation prior to radiography, rejections and delays will generally be reduced.

C6.17.3.1 Tabs. Weld tabs are generally removed prior to radiographic inspection so that the radiograph will represent the weld as finished and placed in service. Contraction cracks are commonly found in the weld at the interface between weld tabs and the edge of the plate or shape joined by the weld. These cracks are hard to identify in the radiograph under the best conditions. It is considered necessary to remove the weld tabs before attempting to radiograph the boundaries of the welded joint (see also C6.17.8).

C6.17.3.3 Reinforcement. When weld reinforcement, or backing, or both, is not removed, shims placed under the image quality indicators (IQIs) are required so that the IQI image may be evaluated on the average total thickness of steel (weld metal, backing, reinforcement) exposed to the inspecting radiation.

C6.17.4 Radiographic Film. Provisions of this section are to provide fine-grain film and to avoid coarseness in the image that may result from the use of fluorescent screens.

C6.17.5 Technique. The source of radiation is centered with respect to the portion of the weld being examined to avoid as much geometric distortion as possible.

C6.17.5.1 Geometric Unsharpness. This subsection is provided to limit geometric unsharpness, which causes distortion and blurring of the radiographic image.

C6.17.5.2, C6.17.5.3 Source-to-Subject Distance and Limitations. These sections are intended to limit geometric distortion of the object as shown in the radiograph. An exception is made for panoramic exposures in tubular structures, which are covered by 6.18 of the code.

C6.17.6 Sources. This subsection intends that x-ray units, 600 kvp maximum, and iridium 192 sources may be used for all radiographic inspection, provided they have adequate penetrating ability and can produce acceptable radiographic sensitivity based upon IQI image as provided in 6.17.7. Since cobalt 60 produces poor radiographic contrast in materials of limited thickness, it is not approved as a radiographic source when the thickness of steel being radiographed is equal to, or less than, 2-1/2 in. (63.5 mm). When the thickness of steel being radiographed exceeds 2-1/2 inches, cobalt 60 is often preferred for its penetrating ability. Care should be taken to ensure that the effective size of the radiograph source is small enough to preclude excessive geometric unsharpness.

C6.17.7 IQI Selection and Placement. Since radiographic sensitivity and the acceptability of radiographs are based upon the image of the required IQIs, care is taken in describing the manufacture and use of the required IQIs. IQIs are placed at the extremities of weld joints where geometric distortion is anticipated to contribute to lack of sensitivity in the radiograph as shown in Figures 6.11 through 6.14.

IQIs may only be placed on the source side unless otherwise approved by the Engineer. Failure to place the IQIs on the source side during the radiographic exposure, without prior approval of the Engineer, shall be cause for rejection of the radiographs.

C6.17.8.3 Backscatter. Backscattered radiation can cause general fogging and produce artifacts in the radiograph. The method described in this section will identify backscattered radiation so that corrective steps can be taken.

C6.17.9 Film Width. Radiographic inspection is designed to inspect all of the weld zone. Defects in the weld metal or the adjacent heat-affected zones can produce weld failure. Film widths shall be sufficient to inspect all portions of the weld joint and have sufficient room for weld identification.

C6.17.10 Quality of Radiographs. Quality radiographs with the appropriate IQI sensitivity are the only indicators of proper radiographic inspection. Defective radiographs will not be accepted.

C6.17.11.1 H & D Density. It is the intent of the specification to use radiographic films within the full limits of the useful film density. An effort is made in this code to avoid the necessity of making multiple exposures or using films of more than one exposure speed when examining welded joints routinely expected to be encountered in cyclically loaded structures and statically loaded structures.

C6.17.11.2 Transitions. The weld transitions in thickness provided for in this section are expected to be gradual with a maximum slope of 1 on 2-1/2 as shown in Figures 2.6 and 2.7.

C6.17.12 Identification Marks. This section describes all information required to identify the radiograph and also provides methods for matching the radiograph to the weld joint, so that weld repairs, when necessary, may be made without repetitive or unnecessarily large excavations. Radiograph identification marks and location identification marks shall be used to locate discontinuities requiring repair and to verify that unacceptable discontinuities have been repaired as demonstrated by the subsequent repair radiograph.

C6.17.13 Edge Blocks. Flange-to-flange welded butt joints that join segments of thick flanges in beams and girders are particularly difficult to radiograph due to geometric distortion and undercut from scattered radiation at the ends of the weld that represent the flange edges. Weld defects at these critical locations are limited under the provisions of 6.12.

On weldments over 1/2 in. (13 mm) in thickness, it was demonstrated by using drilled holes and lead indicators near the top edge of a weldment that a substantial portion of this edge was over exposed and could not be shown, which left the possibility of not showing defects. By using edge blocks and a standard source alignment, lead indicators and drilled holes could be shown on a radiograph at the plate edge.

C6.19 Examination, Report, and Disposition of Radiographs

C6.19.1 Equipment Provided by Contractor. A suitable, variable intensity illuminator with spot review or masked spot review capability is required since more accurate film viewing is possible when the viewers' eyes are not subjected to light from portions of the radiograph not under examination. The ability to adjust the light intensity reduces eye discomfort and enhances visibility of film discontinuities. Subdued light in the viewing area allows the reviewer's eyes to adjust so that small discontinuities in the radiographic image can be seen. Film review in complete darkness is not advisable since the contrast between darkness and the intense light from portions of the radiograph with low density cause discomfort and loss of accuracy. Film densities within the range of 2.5 to 3.5 are preferred as described in 6.17.11.1. The viewer must have sufficient capacity to properly illuminate radiographs with densities up to 4.0. In general, within the limits of density approved by the code, the greater the film density, the greater the radiographic sensitivity.

C6.19.2, C6.19.3 Reports and Retention. After the radiographic inspection technician and the fabrication/erection Inspector have reviewed and approved both the radiographs and the report interpreting them, the radiographic examination report shall be submitted to the Verification Inspector for a separate review on behalf of the owner. All radiographs, including those showing unacceptable quality prior to repair, shall, unless otherwise provided in the contract documents, become the property of the owner. The contractor shall not discard radiographs or reports under the provisions of the code until the owner has been given, and generally has acknowledged, prior notice in writing.

The term *a full set of radiographs* as used in 6.19.3 means one radiograph of acceptable quality from each radiographic exposure required for complete radiographic inspection. If contractors elect to load more than one film in each cassette to produce an extra radiograph for their own use or to avoid possible delays, extra exposures due to film artifacts, or both, the extra radiographs, unless otherwise specified, are the property of the contractor.

Part E
Ultrasonic Testing of Groove Welds

C6.20.1 UT Procedures and Standards. The ultrasonic testing (UT) provisions are written as a precise, direct method of testing weldments. These provisions were designed to ensure reproducibility of test results when examining specific reflectors. Most groove welds may be satisfactorily tested using the provisions of section 6, Part E.

Provisions for ultrasonic testing of welds in T-, Y-, and K-tubular connections can be found in 6.13.3 and 6.27. Detailed procedures have not been included in this section of the code because of the complex geometry associated with these welds. Ultrasonic testing procedures for these welded joints should be approved by both the Engineer and Contractor.

The ultrasonic testing of fillet welds was not included in the code because of the inability to formulate a simple procedure giving satisfactory results. Considerable information can be obtained about the location of a discontinuity in a fillet weld, as well as its size and orientation, when using special techniques. The complexity and limitations of ultrasonic testing increase as the size of the fillet weld decreases. Fillet weld sizes less than 3/4 in. (19 mm) usually require the use of miniature search units for complete evaluation. The frequency for miniature search units should be higher than the 2.25 MHz nominal frequency normally required, in order to control the sound beam divergence. This frequency change would also affect the 2 decibels per inch (25 mm) attenuation factor used for indication evaluation. Variations from the code provisions for UT are permitted upon agreement from the Engineer. It is recommended that details of such agreements be in writing so that all parties know how the welds are to be inspected.

C6.20.2 Variations. Ultrasonic testing through paint layers on painted surfaces has been changed to an essential variable requiring approval by the Engineer. Although the code prohibits routine ultrasonic testing through paint layers, it does not necessarily mean that a good, tight, uniform coat of paint will interfere with the application of ultrasonic testing procedure. When paint is present, it should be measured and reported.

During routine fabrication of structural steel, all welds should be inspected and accepted prior to being painted. Most testing where painted surfaces are involved is on members that have been in service, and the condition of that test surface should be considered before routine testing is done.

C6.20.3 Piping Porosity. The code recommends that spot radiography be used as a supplement to UT when examining electroslag and electrogas welds in materials over 2 in. (50.8 mm) thick. This is based on the inability of UT to evaluate porosity on an amplitude basis. Piping porosity in this type of weld, although appearing cylindrical, has usually a series of cascaded surfaces throughout its length. The sound reflectivity of these cascaded surfaces does not generally respond ultrasonically as a straight line reflector as would be expected from a side drilled hole, which is in itself a difficult discontinuity to quantify. Piping porosity often responds to ultrasonic tests as a series of single point reflectors as if received from a series of spherical reflectors in line. This results in a low amplitude-response reflecting surface, reflecting sound that has no reliable relationship to diameter and length of this particular type of discontinuity.

In addition to this problem, the general nature of piping porosity in electroslag and electrogas welds is usually such that holes in the central portion of the weld may be masked by other surrounding holes. The branches or tunnels of piping porosity have a tendency to tail out toward the edges of the weld nugget. UT can only effectively evaluate the first major reflector intercepted by the sound path. Some discontinuities may be masked in this manner; this is true for all ultrasonic testing.

Radiographic testing should be used to evaluate suspected piping porosity in electroslag and electrogas welds used in building construction. See Note 4 of Table 6.2. No mention of additional radiographic testing is presently made with reference to testing electroslag and electrogas welds in Table 6.3 since these processes are not presently accepted for tension welds. Ultrasonic testing of electroslag and electrogas welds at higher scanning levels will give intermittent responses from piping porosity. This indicates RT should be used as described above.

The pitch-and-catch technique for evaluating incomplete fusion by UT in electroslag and electrogas welds is intended to be used only as a secondary test to be conducted in an area along the original groove face in the middle half of the plate thickness. This test is specified to further evaluate an ultrasonic indication in this area which appears on the display at scanning level but is not rejectable by indication rating. The expected pitch-catch amplitude response from such a reflector is very high, making it unnecessary to use the applicable amplitude acceptance levels. However, since no alternative is provided, these decibel ratings must be used. Since only a specific location is being evaluated, predetermined positioning of the probe can be made. Probe-holding fixtures are most helpful in this operation.

The use of the 70° probe in the primary application is adequate in testing electroslag and electrogas weld fusion surfaces of material 2-1/2 in. (63.5 mm) and less in thickness because acceptance levels are such that proper evaluation can be expected.

C6.22 Ultrasonic Equipment

Standards are established for ultrasonic flaw detectors to ensure adequate mechanical and electrical performance when used in conformance with the requirements of the code.

Subsections 6.22.1 through 6.22.5 cover the specific equipment features that must be considered for equipment qualification; 6.23.1 covers the reference standards; subsections 6.24.1 through 6.24.4 cover the time interval requirements and references to the applicable 6.29 reference block usage; and 6.30 presents detailed qualification procedures. Examples of these applications are included in Annex D, Form D8.

C6.22.6 Straight Beam (Longitudinal Wave) Search Unit. The size limitations of the active areas of straight beam transducers have not been changed; however, the sizes being given as 1/2 in.^{2} (160 mm^2) and 1 in.^{2} (645 mm^2) have been misinterpreted as being 1/2 in. (12.7 mm) square and 1 in. (25.4 mm) square, instead of the intended 1/2 square in. and 1 square in., respectively.

These active area requirements are now written out to eliminate the confusion.

C6.22.7.2 Transducer Dimensions. In the 1980 code, transducer size and shape limitations were changed in an effort to reduce the scatter in the results of discontinuity evaluation, which is thought to be attributed solely to transducer size.

The Structural Welding Committee for the 1988 code has withdrawn approval of the 1/2 in. × 1 in. (12.7 mm × 25.4 mm) transducer. This size transducer is not acceptable.

C6.23.1 IIW Standard. All of the blocks used for calibration and certification of equipment have now been called reference blocks and are detailed in one figure. Note: The DS block has been added in Annex X.

C Figure 6.22 All of the notes shown herewith pertain to all of the reference blocks in both Figure 6.22 and Annex X.

C6.23.2 Prohibited Reflectors. The code prohibits the use of square corners for calibration purposes because of the inability of acquiring amplitude standardization from various corners that are called "square." Factors that can affect amplitude standardization are the size of the fillet or chamfer on the corner, if any; the amount the corner is out of square (variation from 90°); and surface finish of the material. When a 60° probe is used, it is very difficult to identify the indication from the corner due to high amplitude wave mode conversions occurring at the corner.

C6.24.1 Horizontal Linearity. The use of ASTM E317 for horizontal linearity qualification has been eliminated, and a step-by-step procedure outlined in 6.30.1 is used for certification.

C6.24.2 Gain Control. The vertical linearity of the ultrasonic unit must be calibrated every two months by the procedure described in 6.30.2 to verify continued accuracy. Certification must be maintained with use of information tabulated on a form similar to Annex D, Form D8 (example information is also shown). Caution must be used in the application of alternate methods for vertical linearity certification. Normal ways of translating voltage ratios to dB graduations generally cannot be used due to potentiometer loading and capacitance problems created by the high-frequency current transfer. A high degree of shielding must also be maintained in all wiring.

C6.24.4 Calibration of Angle Beam Search Units. Since the contact surfaces of search units wear and cause loss of indication location accuracy, the code requires accuracy checks of the search unit after a maximum of eight hours use. The responsibility for checking the accuracy of the search unit after this time interval is placed on the individual performing the work.

C6.25.4.1 Sweep. Indications of at least two plate thicknesses must be displayed in order to ensure proper distance calibration because the initial pulse location may be incorrect due to a time delay between the transducer crystal face and the search unit face.

C6.25.5.1 Horizontal Sweep. At least two indications other than the initial pulse must also be used for this distance calibration due to the built-in time delay between the transducer face and the face of the search unit.

Notes: *(1) The initial pulse location will always be off to the left of the zero point on the display.*
(2) Care must be taken to ensure that the pulse at the left side of the screen is the initial pulse and not one from a reference reflector. (Verify by removing search unit from workpiece.)

The note has been added to the end of this subsection to ensure duplication of location data.

C6.26.4 Couplants. It is recognized that couplants, other than those specifically required in the code, may work equally well or better for some applications. It is beyond the scope of the code to list all fluids and greases that could be acceptable couplant materials. Any couplant material, other than those listed in the code, that has demonstrated its capability of performing to code requirements, may be used in inspection upon agreement between the Engineer and the ultrasonic testing inspector.

Tests should be conducted to determine if there is a difference in responses from the reference reflector, due to differences between the couplant used for calibration compared to the couplant used in actual testing. Any measurable difference should be taken into account in discontinuity evaluation.

See Annex D, Form D11 for a sample ultrasonic test report form.

C6.26.5 Extent of Testing. The provision to search the base metal for laminar reflectors is not intended as a check of the acceptability of the base metal, but rather to determine the ability of the base metal to accept specified ultrasonic test procedures.

C6.26.5.1 Reflector Size. A procedure for lamellar size evaluation is now included in 6.31.1.

C6.26.5.2 Inaccessibility. The requirement in this subsection to grind the weld surface or surfaces flush is necessary only to obtain geometric accessibility for an alternate UT procedure when laminar discontinuities in the base metal prohibit testing using standard procedure. Contract documents may require flush grinding of tension groove welds to improve fatigue performance and facilitate more accurate RT and UT.

C Table 6.6 The procedure chart was established on the basis that a search unit angle of 70° will best detect and more accurately evaluate discontinuities having a major dimension oriented normal or near normal to the combined residual and applied tensile stresses (most detrimental to weld integrity). It should be assumed that all discontinuities could be oriented in this direction, and the 70° probe should be used whenever possible. For optimum results, a 10 in. (255 mm) sound path has been established as a routine maximum. There are, however, some joint sizes and configurations that require longer sound paths to inspect the weld completely.

Testing procedures 6, 8, 9, 12, 14, and 15 in the procedure legend of Table 6.6, identified by the top quarter designation GA or the bottom quarter designation GB, require evaluation of discontinuities directly beneath the search unit. More accurate results may be obtained by testing these large welds from both face A and face B, as also provided for in this table.

The procedure chart was developed taking into account the above factors. Note 6 of Table 6.6 provides that discontinuities in tension welds in cyclically loaded structures shall not be evaluated directly beneath the search unit.

C Table 6.6 The reason for the very exacting requirements of the code with respect to the application of the search unit (frequency, size, angle) is to maintain the best condition for reproducibility of results. It is the intent of the code that welds be examined using search unit angles and weld faces specified in Table 6.6. Use of other angles or weld faces may result in a more critical examination than established by the code.

Legend "P" The use of 60° probes is not permitted for evaluation when using the pitch-and-catch method of testing because of the high energy loss that is possible due to wave mode conversion.

C6.26.6 Testing of Welds. When required by Tables 6.2 and 6.3 as applicable, the sensitivity for scanning is increased by at least four decibels above the maximum reject level at the maximum testing sound path. This increased sensitivity assures that rejectable discontinuities are not missed during scanning.

C6.26.6.4 Attenuation Factor. The attenuation rate of 2 decibels per inch (2 dB per 25 mm) of sound travel, excluding the first inch (25 mm), is established to provide for the combination of two factors: the distance square law and the attenuation (absorption) of sound energy in the test material. The sound path used is the dimension shown on the display. The rounding off of numbers to the nearest decibel is accomplished by maintaining the fractional or decimal values throughout the calculation, and at the final step, advancing to the nearest whole decibel value when values of one-half decibel or more are calculated or by dropping the part of the decibel less than one-half.

C6.26.7 Length of Flaws. The required six decibel drop in sound energy may be determined by adding six decibels of gain to the indication level with the calibrated gain control and then rescanning the weld area until the amplitude of the discontinuity indication drops back to the reference line.

When evaluating the length of a discontinuity that does not have equal reflectivity over its full length, its length evaluation could be misinterpreted. When a six decibel variation in amplitude is obtained by probe movement and the indication rating is greater than that of a minor reflector, the operator should record each portion of the discontinuity that varies by ± 6 dB as a separate discontinuity to determine whether it is acceptable under the code based on length, location, and spacing.

C6.26.8 Basis for Acceptance or Rejection. In procedures specified for ultrasonic testing, the zero reference level for discontinuity evaluation is the maximum indication reflected from a 0.06 in. (1.5mm) diameter hole in the IIW ultrasonic reference block. When actual testing of welds is performed, the minimum acceptable levels are given in decibels for various weld thicknesses. The minimum acceptance levels for statically loaded structures are given in Table 6.2 and the minimum acceptance levels for cyclically loaded structures are given in Table 6.3. In general, the higher the indication rating or acceptance level, the smaller the cross-sectional area of the discontinuity normal to the applied stress in the weld.

Indication ratings up to 6 dB more sensitive than rejectable must be recorded on the test report for welds designated as being "Fracture Critical" so that future testing, if performed, may determine if there is flaw growth.

The acceptance-rejection levels have been eased in the 5/16 to 3/4 in. (8 to 19.0 mm) thickness category by 2 dB because it was felt to be unnecessarily restrictive.

The thickness ranges from greater than 4 to 6 and greater than 6 to 8 have been combined and the maximum disregard level increased to a + 3 dB level. Previous requirements permitted the UT acceptance of some discontinuities that were later discovered to be cracks.

C6.27 Ultrasonic Testing of Tubular T-, Y-, and K-Connections

This section sets forth requirements for procedures, personnel, and their qualifications. It is based largely on practices that have been developed for fixed offshore platforms of welded tubular construction. These are described in detail in Reference 10 of Section C2.

C7. Stud Welding

C7.1 Scope

Stud welding is unique among the approved welding processes in this code in that not only are the arc length and the weld time automatically controlled, but it also lends itself to a significant production proof test. Once the equipment is properly set, the process is capable of a large number of identical sound welds when attention is given to proper workmanship and techniques. Many millions of studs have been successfully applied. For other reasons outlined above, formal procedure qualifications are not required when studs are welded in the flat (downhand) position to materials listed in Table 3.1, Group I and II. Procedures developed under the application qualification requirements of 7.6 are an exception to the foregoing. Since this constitutes the basic change from other approved welding processes in this code, stud welding has been moved to section 7.

There are provisions for the following:

(1) Tests to establish mechanical properties and the qualification of stud bases by the stud manufacturer

(2) Tests to establish or verify the welding setup (essential variables) and to qualify the operator and applications

(3) Tests for inspection requirement

C7.2 General Requirements

General requirements prescribe the physical dimensions of studs and describe the arc shield and stabilizing flux to be used. These stud base assemblies must be qualified by the manufacturer as prescribed in Annex IX of this code.

C7.2.5 Stud Finish. Heads of shear connectors or anchor studs are subject to cracks or bursts, which are names for the same thing. Cracks or bursts designate an abrupt interruption of the periphery of the stud head by radial separation of the metal. Such interruptions do not adversely affect the structural strength, corrosion resistance, or other functional requirements of headed studs.

C7.3 Mechanical Requirements

The section on mechanical requirements has been expanded to show three strength levels of studs. The lower strength level, Type A, is used for general purpose studs and the higher strength level, Type B, is used as an essential component of composite beam design and construction. Type B studs are the most used in composite construction for highway bridges.

C7.4 Workmanship

Several items of cleanliness are needed to produce sound quality studs. There is new emphasis on keeping the studs. Type B studs are used as an essential component in composite beam construction for highway bridges and buildings. Type C studs are commonly used as embedded connections in concrete/steel construction.

C7.4.6 and C7.4.7 Arc Shield Removal. These subsections clearly call for used arc shields to be removed and a visual inspection to be made by the applicator. Good judgement would call for this check to be performed as soon as practical after the stud is welded to avoid a large number of defective studs in the case of equipment malfunction.

The expelled metal around the base of the stud is designated as flash in accordance with the definition of flash in Annex B of this code. It is not a fillet weld such as those formed by conventional arc welding. The expelled metal, which is excess to the weld required for strength, is not detrimental but, on the contrary, is essential to provide a good weld. The containment of this excess molten metal around a welded stud by the ferrule (arc shield) assists in securing sound fusion of the entire cross section of the stud base. The stud weld flash may have nonfusion in its vertical leg and overlap on its horizontal leg; and it may contain occasional small shrink fissures or other discontinuities that usually form at the top of the weld flash with essentially radial or longitudinal orientation, or both, to the axis of the stud. Such nonfusion on the vertical leg of the flash and small shrink fissures are acceptable.

C7.5.1 Automatic Machine Welding. Technique is a subsection that covers the requirements for equipment and initial settings.

C7.5.5 FCAW, GMAW, SMAW Fillet Weld Option. The code also permits studs to be fillet welded, at the option of the contractor, by the shielded metal arc welding (SMAW) process, although the use of automatically-timed equipment is generally preferred. Welders must be qualified in accordance with section 4 for this application. The option was included for situations where only limited numbers of studs are to be welded in the field. Obviously, the contractor's decision in this matter would be one of economics. The electrode diameter is specified to help ensure that minimum heat input is provided in conjunction with the applicable preheat requirements of Table 3.2.

Studs welded by the use of automatically timed welding equipment or fillet welded by the shielded metal arc process are considered to have been welded by a prequalified procedure.

C7.6 Stud Application Qualification Requirements

Studs applied to a vertical surface may require modified arc shields and modified arc shields may also be required when welding to other than flat surfaces. Since this and other special cases are not covered by the manufacture's stud base qualification, the contractor shall be responsible for the performance of these tests. Test data serve the same purpose as procedure qualification for other processes. Inspectors should accept evidence of previous special application tests based on satisfactory preproduction tests with the specific stud welding set up in use.

C7.6.1 Purpose. Special conditions where application qualification requirements apply have been enlarged from consideration of modified arc shields and weld position to include welds through decking and for studs welded to other than Group I or II steels from Table 3.1.

The weld through decking application has been added because of problems inherent for the Manufacturer Stud Base Qualification Requirements in determining the number of plies or the gages of decking which would require testing. Further limits would have to be established for the coating types or thicknesses which would require testing. The committee would recommend that the heaviest metal decking thickness, whether one or two plies, be tested along with the thickest coating (galvanized if used) to qualify work for each project. While the welding variables developed for this worst case would not necessarily apply to every stud to be used on the project, the equipment to be used would have been proven for the worst case, and pre-production testing of 7.7.1 should be used for each other set up.

The Engineer should accept properly documented evidence of weld through decking application tests where new work would fall within previous limits.

The Application test for other than Group I or II steels has been added to serve as a reminder that the Engineer should evaluate each such application.

Most steels in Group III of Table 3.1 and the steels in Annex M are heat-treated steels, and the heat from stud welding can lead to reduced base plate static or dynamic physical properties. For example, thin quenched-and-tempered steels may have reduced tensile properties, and thicker quenched-and-tempered steels are more likely to have reduced notch toughness in the stud weld heat-affected zone. The Engineer should particularly evaluate the application where studs will be welded in members subject to cyclic tensile stress or to stress reversal. The application test will serve to prove only that the stud itself is acceptable with the metal used.

C7.7 Production Control

Applicator testing is required for the first two studs in each day's production or any change in the set up such as changing of any one of the following: stud gun, timer, power source, stud diameter, gun lift and plunge, total welding lead length, or changes greater than 5% in current (amperage) and time. Users who are unfamiliar with any of these terms are encouraged to refer to the latest edition ANSI/AWS C5.4, *Recommended Practices for Stud Welding*. At the very high currents used in stud welding, it is very important to have adequate lead size and good lead connections.

C7.7.1.4 Bending. Bending some stud and base materials at temperatures below 50°F (10°C), creates inadequate toughness to pass a hammer test.

C7.8 Fabrication and Verification Inspection Requirements

In addition to visual and bend tests by the applicator, studs are to be visually inspected and bend tested by the inspector.

C7.8.2 and C7.8.4 Additional Tests. The code provides provisions for the Verification Inspector to test additional studs. Where the stud weld failure rate is high, in the judgement of the Engineer, corrective action shall be required of the contractor at the contractor's own expense.

Annex CIX: Manufacturer's Stud Base Qualification Requirements

This section has been removed from the main body of the code since it applies to the stud manufacturer. The code similarly refers to but does not reprint filler metal specifications required to be met by the electrode manufacturer. Information from the required test data does provide applicator procedure values for prequalified studs applied to material in the flat position.

C8. Strengthening and Repairing Existing Structures

C8.1 General

There are many technical and workmanship conditions that are common to strengthening, repairing, and heat straightening steel members, and as a result, section 8 has been expanded to include heat straightening, a form of repairing steel members.

Section 8 of this document is not intended to replace ASTM A6 provisions for conditioning new steel, but to provide recommendations for repair and strengthening of members in existing structures.

C8.2 Base Metal

C8.2.1 Investigation. The first essential requirement in strengthening, repairing, and heat straightening existing structures is the identification of the material.

Weldability of the existing steel is of primary importance. Together with the mechanical properties of the material, it will provide information essential for the establishment of safe and sound welding procedures. Only then will realistic data be available for reliable cost estimates. Should poor weldability make such cost economically prohibitive, other means of joining should be considered by the Engineer.

Mechanical properties may be subject to variability, determined by tests of representative samples taken from the existing structure. Hardness testing may also provide, by correlation, an estimation of the tensile properties of the material.

If the chemical composition must be established by test, then it is advisable to take samples from the greater thicknesses which are indicative of the extremes in chemistry.

In cases of unknown weldability, References 1 and 2 provide examples of simple and inexpensive techniques to make a preliminary determination whether or not the base metal is suitable for welding.

Low melting temperature base-metal elements such as sulfur, phosphorus, copper, tin, lead, and zinc can cause solidification or "hot" cracking. Utilizing low admixture welding procedures and joint details that do not rely on penetration to gain strength may help minimize hot cracking tendencies. Higher levels of carbon, coupled with higher levels of alloys, whether intentionally or unintentionally added, increase steel hardenability and increase hydrogen-related or "cold" cracking tendencies. Low-hydrogen practice, higher preheat and interpass temperature, as well as postheat operations, reduce cold cracking tendencies. The material may range from easily weldable to unacceptable weldability. Investigation into the relative weldability is essential. See references 3, 5, and 6.

C8.2.2 Suitability for Welding. Welding to stainless steel, wrought iron and cast iron is not addressed in the general body of this code. However, these materials are sometimes encountered in older structures that are being renovated. As shown in Table C8.1, a Welding Procedure Specification (WPS) and qualified welding supervision is needed in each case because of the inherent difficulty in welding. Guidance for welding stainless steel is given in References 3 and 4. Guidance for welding wrought iron is given in Reference 5. Guidance for welding cast iron is given in References 3, 4, 5, and 6.

C8.3 Design for Strengthening and Repair

C8.3.1 Design Process. It is strongly recommended that locations that are considered for welding or heating be inspected. Thermal expansion associated with either process can extend any existing crack further into the member.

C8.3.3 Fatigue History. Generally, in the case of cyclically loaded structures, sufficient data regarding past service are not available to estimate the remaining fatigue life. A conservative estimate of remaining fatigue life should be made based on whatever loading history is available. Practical methods to extend the expected fatigue life of a member include: reducing the stress or stress range, providing connection geometry less susceptible to fatigue failure, and using fatigue life enhancement techniques.

Table C8.1
Guide to Welding Suitability(1) (See C8.2.2)

Structure Category	Base Metal: ASTM, ABS and API steels per subsection 3.3 and Table 3.1	Discontinued, Unknown Steels, Cast Steels and Stainless Steels	Wrought Iron	Cast Iron
Static or Cyclic Nontubular section 2, Part B	Check for prequalified status per section 3. Prequalified WPSs may be used per section 3.	ASTM A7, A373, A441—Use Table 3.1 (Group II) and section 3. Others, see Note 2.	Notes 2 and 3 apply.	Notes 2 and 3 apply.
Cyclic Nontubular section 2, Part C	Check for prequalified status per section 3. Prequalified WPSs may be used per section 3.	ASTM A7, A373, A441—Use Table 3.1 (Group II) and section 3. Others, see Note 2.	Notes 2 and 3 apply.	Not recommended.
Tubular section 2, Part D	Prequalified WPSs may be used per section 3.			
Static Tubular	Check for prequalified status per section 3.	Note 2 applies.	Notes 2 and 3 apply.	Notes 2 and 3 apply. Not recommended.
Cyclic Tubular	Check for prequalified status per section 3.	Note 2 applies.	Notes 2 and 3 apply.	Not recommended.

Notes:
(1) A written Welding Procedure Specification (WPS) is required subject to Engineer approval.
(2) Established Welding Suitability: Existence of previous satisfactory welding may justify the use of Table 3.1 (Group II) filler metals. If not previously welded, obtain samples and prepare WPS qualification. Conduct in place weld test on safe area of structure if samples are not available.
(3) Persons qualified to establish welding suitability shall provide written WPS and monitor welding operation, all as approved by the Engineer.

C8.3.5 Loading During Operations. Repair, strengthening and heat straightening of existing structures differ from new construction inasmuch as these operations may have to be executed with the structure or the structural element under some condition of working stress.

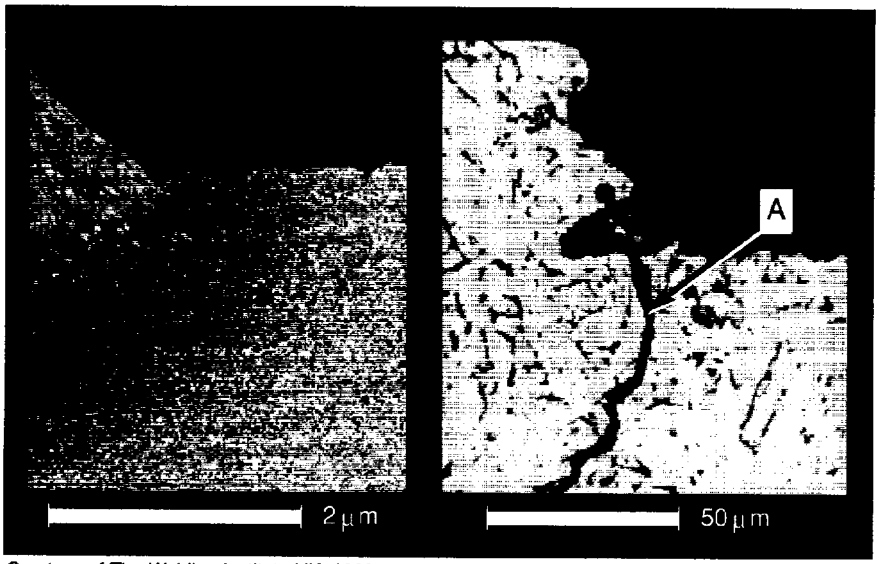
There is guidance in the literature (References 1, 2, 7, 8, 9, 10, 11, and 12) with respect to welding of structural members under load. Each situation must be evaluated on its own merits, and sound engineering judgment must be exercised.

Research (References 7, 11, and 19) indicates that residual stresses due to mill rolling practice and welding only have an affect on member capacity for some specific structural functions. Because of offsetting tensile and compressive residual force levels, residual stresses result in no quantifiable degradation of a member's flexural capacity. A similar condition exists for tensile members, provided that the heating or welding affects only a portion of the member's cross-sectional area. Compression members are more sensitive to residual stress distribution because of overall and local buckling possibilities. Balanced flame heating or welding about the neutral axis may be essential to avoid this type of problem. Regardless of the stress conditions, the heating or welding should not be performed over the entire cross section at the same time.

C8.3.7 Use of Existing Fasteners. The retrofitting provisions for combining welds with overstressed rivets or bolts is more restrictive than 2.6.3 which deals with connecting elements not overstressed at the time of retrofitting. See Reference 22.

C8.4.1 Fatigue Life Enhancement. When properly administered, these reconditioning methods may be used for enhancing the fatigue life of existing structures, particularly when the applied stress is normal to the axis of the weldment. The following techniques affect fatigue life only from the point of view of failure from the weld toe. The possibility of fatigue crack initiation from other features of the weld, e.g., the root area, should not be overlooked. Typical uses include the repair of fatigue cracks and the extension of fatigue life of existing buildings and equipment.

Welded joints represent particularly severe stress concentrations. Research at The Welding Institute (TWI), Cambridge, England, identified an acute line of microscopic slag intrusions along the toes of all welds made by all arc processes except gas tungsten arc welding (GTAW). All processes however, were found to produce some degree of undercut at the toe, notwithstanding ideal weld profiles (Figure C8.1). The practical implication was that all welds have a pre-existing discontinuity



Courtesy of The Welding Institute UK, 1980.

NOTE: MICROSCOPIC INTRUSIONS AT WELD TOE ACT AS PRE-EXISTING DISCONTINUITIES (SEE C8.4.1).

Figure C8.1—Microscopic Intrusions

in the form of either microscopic undercut or slag intrusions, or both. Normal inspection methods cannot detect these discontinuities, which in any case are unavoidable when using existing welding technologies. See References 28, 32 (Ch. 1 and 2) and 33.

In plain material, fatigue life is spent in crack initiation and propagation. In weldments, however, it must be assumed that crack-like discontinuities already exist. Therefore, the fatigue life of welds is spent solely in crack propagation. This, along with residual tensile stresses at or near the yield point, is the essential reason why weldments can endure fewer cycles to fatigue failure than a similarly loaded plain material. See Figure C8.2.

Fatigue life enhancement can be obtained by reconditioning the weld toes. The small pre-existing discontinuities are either removed or the sharp openings dulled (Figure C8.5). Toe grinding and TIG dressing extend fatigue life by restoring a crack initiation phase. Peening, by the introduction of a compressive stress, retards the rate of crack propagation. The resulting weld profile also complements the overall joint resistance to fatigue cracking by reducing the geometric stress concentration. When these pre-existing toe discontinuities are perpendicular to the applied stress, fatigue life enhancement methods are most effective (Figure C8.4). See Reference 32 (Ch. 4).

(1) Profile improvement for round tubular sections shall conform to 2.36.6.6, 2.36.6.7, and the corresponding sections from the Commentary, C2.36.6.6 and

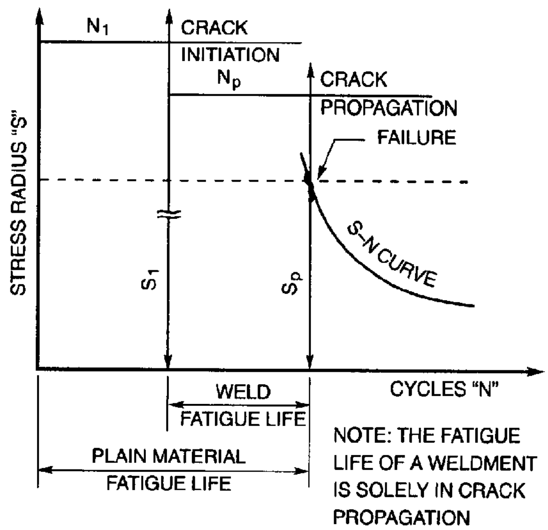


Figure C8.2—Fatigue Life (see C8.4.1)

C2.36.6.7. Acceptable profiles in accordance with Figure 3.10 may be attained by (1) adding a capping layer, (2) grinding the weld surface, and (3) peening the weld toe with a blunt instrument. Figure C2.20 provides precise profile criteria. Fatigue category limitations on weld size or thickness and weld profile shall meet the criteria of Table 2.7, Level I.

(2) Toe grinding shall be done along the centerline of the weld toe for both tubular connections (T, Y, or K) and

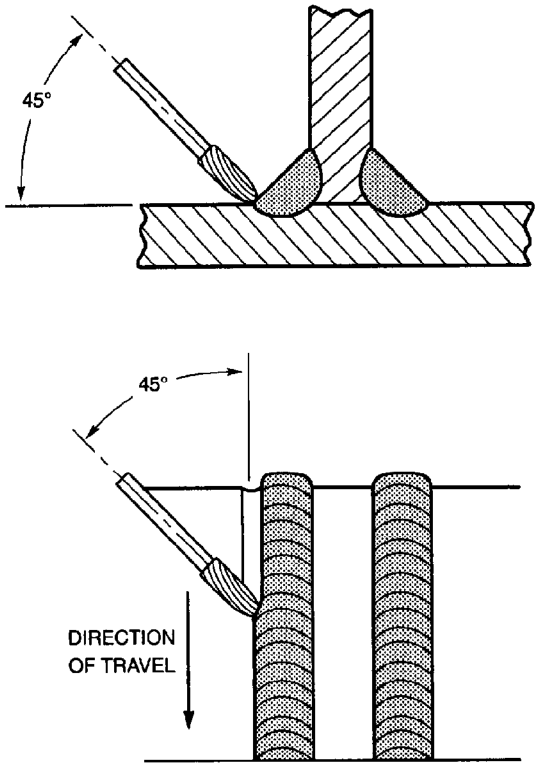


Figure C8.3—Toe Dressing with Burr Grinder (see C8.4.1)

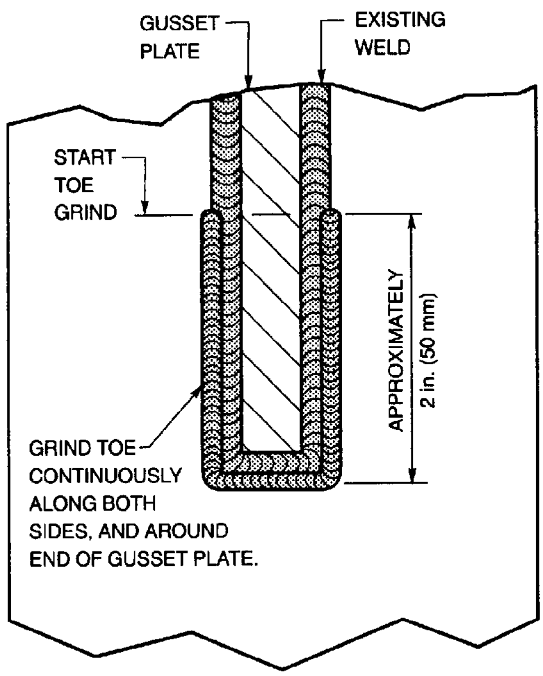


Figure C8.4—Toe Dressing Normal to Stress (see C8.4.1)

nontubular joints. The recommended tools include a high-speed grinder for use with a tungsten carbide burr. The tip radius shall be scaled to the plate thickness according to Table C8.2. These radii are the minimum recommended, larger sizes may prove more beneficial.

Grinding shall be carried out to a minimum depth of 0.03–0.04 in. (0.8–1.0 mm) below the plate surface or approximately 0.02–.03 in. (0.5–0.8 mm) below the deepest undercut to a maximum total depth of 1/16 in. (2 mm) or 5% of the plate thickness, whichever is greater. The axis of the burr shall be at approximately 45° to the main plate, see Figure C8.3. The angle of the burr axis shall be a maximum 45° of the direction of travel to ensure that the grinding marks are nearly perpendicular to the weld toe line (parallel to the direction of stress). The ends of longitudinally stressed welds require special care to be effective (Figure C8.6). The

Table C8.2
Relationship Between Plate Thickness and Burr Radius (see C8.4.1(2))

Plate Thickness (in.)	Plate Thickness (mm)	Burr Radius (mm)
< 0.79	< 20	5
0.79–1.14	20–29	6
1.18–1.54	30–39	8
1.57–1.93	40–49	10
1.97–2.52	50–64	12
2.56–3.11	65–79	16
3.15–3.90	80–99	18
3.94–4.69	100–119	20
4.72–5.87	120–149	25
5.91–7.09	150–180	30

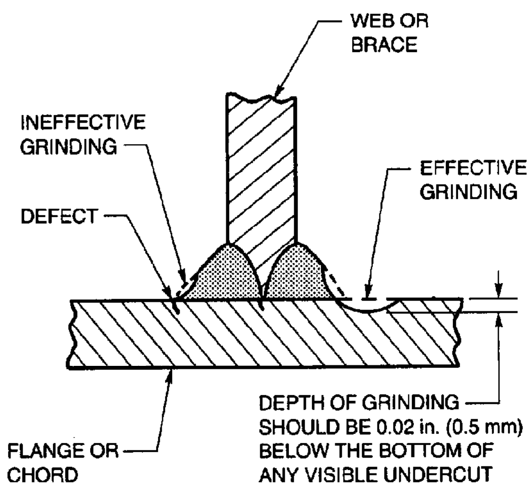


Figure C8.5—Effective Toe Grinding (see C8.4.1)

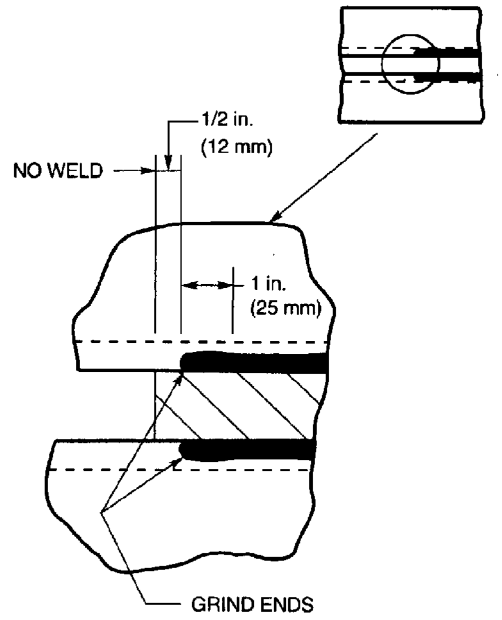


Figure C8.6—End Grinding (see C8.4.1(2))

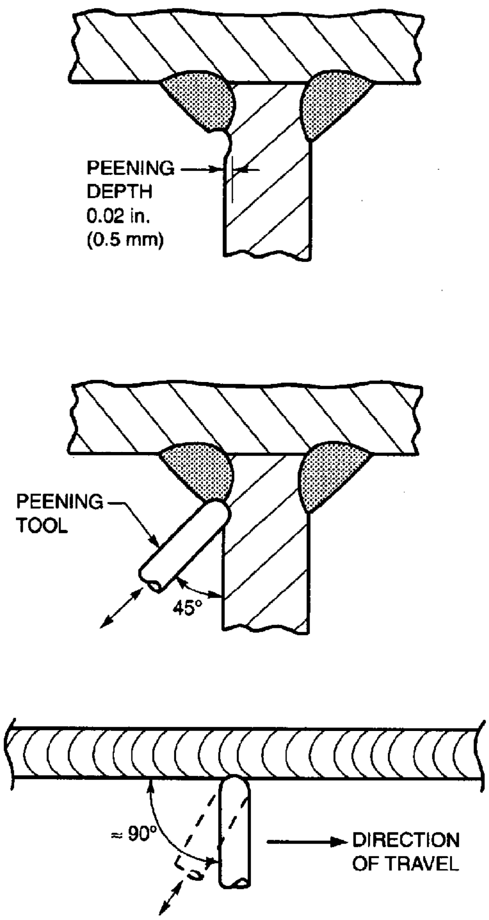


Figure C8.7—Hammer Peening (see C8.4.1(3))

(Courtesy of S. Maddox, IIW, Com. XIII)

finishing pass should be light to obtain a good surface finish. Check visually and with MT or PT for any remaining undercut or other discontinuities. See References 28, 29, 32 (Ch. 2), 34, and 37.

(3) Hammer peening applies to steels with yield strengths up to 115 ksi (800 MPa) and thicknesses not less than 3/8 in. (10 mm). Steel hammer bits shall have approximately hemispherical tips with diameters between 1/4 in. and 1/2 in. (6 mm and 12 mm). The indentation shall be centered on the weld toe so that metal on each side (both weld metal and base metal) is deformed, resulting in a smooth surface free from obvious individual blows. The hammer should be held at 45° to the plate surface and approximately perpendicular to the direction of travel. The indentation in mild steel (yield strength up to 36 ksi (250 MPa)) should be approximately 0.02 in. (0.5 mm); in medium-strength steel (yield strength between 36 ksi and 65 ksi (250 and 450 MPa)) 0.01 in. (0.25 mm); and in high-strength steel (yield strength between 65 and 115 ksi (450 and 800 MPa)) 0.004 in. (0.1 mm). See Figure C8.7. These depths are roughly equivalent to four peening passes. The weld shall be checked visually and with MT or PT prior to peening. See References 28, 29, 32 (Ch. 2), 34 and 36.

The benefit of hammer peening is derived from the introduction of compressive residual stresses; thus, it is critical to ensure that nothing which will cause stress relief (e.g., postweld heat treatment) be performed after peening. Also, hammer peening should be applied when the joint is "in place" and carrying dead-load.

(4) TIG (GTAW) dressing consists of remelting the existing weld metal to a depth of approximately 1/16 in. (2 mm) along the weld toe without the addition of filler metal. The weld surface shall be free from rust, slag, and mill scale. The tip of the electrode must be kept sharp and clean. The tip shall be located horizontally .02 to 0.06 in. (.5 to 1.5 mm) from the weld toe, see Figure C8.8. Where toughness of the heat-affected zone may create problems, a modified technique using a second tempering pass may be used. See References 28, 32 (Ch. 2 & 4) and 35.

(5) Toe grinding followed by hammer peening inhibits fatigue crack initiation and the rate of crack propagation. Thus, for critical joints, this combined treatment offers su-

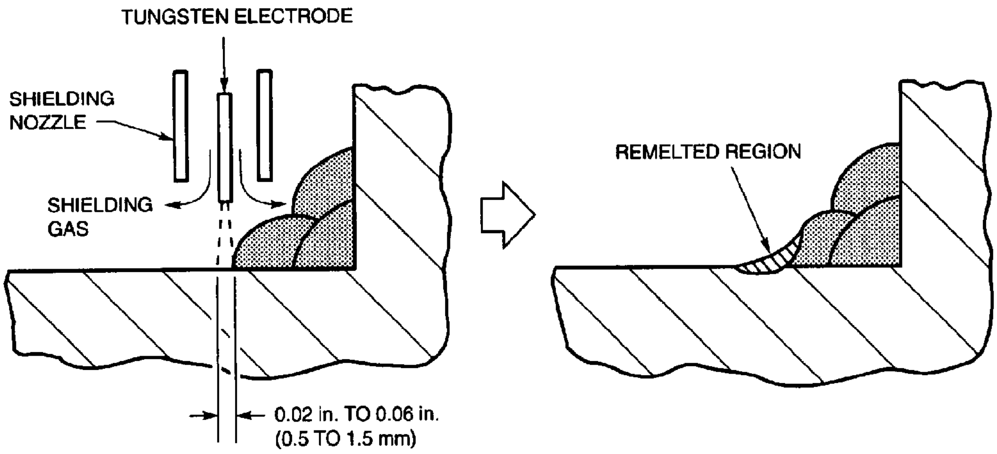


Figure C8.8—Toe Remelting (see C8.4.1(4))

(Courtesy of P. Haagensen, IIW, Com. XIII)

perior resistance to fatigue failure. The weld surface shall be checked visually and by MT for surface discontinuities prior to peening. During peening operations, visually check after each pass. See References 30, 31 and 34.

C8.4.2 Stress Range Increase. The allowable stress range for cyclically loaded connections may be increased by a factor of 1.3 along the S-N design curve, which is equivalent to a factor of 2.2 on cycle life, for an S/N slope of approximately 1/3, when toe grinding, hammer peening, or TIG dressing is used. However, the effect of toe grinding and hammer peening is cumulative. A factor of 1.5 on the stress range may be allowed at high cycles ($N = 10^7$), but reduced to a factor of 1.0 (no benefit) at low cycles ($N = 10^4$). For nontubular joints, the improvement factor should not exceed the highest as-welded fatigue design category.

Tubular sections for T-, K-, and Y-joints are discussed in 2.36.6.6 and 2.36.6.7. See References 28, 29, 30, 32, 34, 35 and 36.

Note: Current research at Lehigh University on beams with welded cover plates suggests that this joint does not respond to enhancement techniques (especially hammer peening) as well as previous testing had indicated.

C8.5 Workmanship and Technique

C8.5.2 Member Discontinuities. Welding or applying heat to steel in the presence of existing cracks can result in crack propagation because of the stress levels that may exist at the crack tip. As a result, it is strongly recommended that any crack-like discontinuities be removed prior to applying heat or welding. This can be accomplished by drilling a hole at the termination of the crack or by grinding. References 23 and 26 provide guidance for repairing many commonly observed conditions. Procedures for repairing existing welds must also conform to the specified provision 5.26 for repairing new welds.

C8.5.4 Base Metal of Insufficient Thickness. Corrosion or wear with resultant section loss may reduce the thickness of the parts below that required to provide adequate weld size. Building up the edge of the thin section may be performed by welding, provided the thickness of the overall section is adequate to carry the load.

Corrosion or wear may reduce the thickness of parts below that required to support the load. Similarly, increased loads may require additional member thickness. Increasing member thickness by facing with weld metal would generally be ineffective except for small, localized regions. Reinforcement of the member by the use of additional plates or similar attachments is preferred.

C8.5.5 Heat Straightening. Heat straightening of steel members requires the sequencing of various heating patterns. Literature (References 1, 8, 9, 13, 14, 15, 16, 17, and 18) exists that provides guidance as to the mechanics of heat straightening. The actual process remains one of operator experience.

Limits (including significant safety factors) are placed on the temperature to which steel can be heated to avoid possible metallurgical changes in the steel when it subsequently cools down to an ambient temperature. The chemistry and prior tempering of the steel dictates the critical temperature.

Rapid cooling of steel from elevated temperatures down to about 600°F (315°C) is not recommended because undesirable metallurgical transformations can occur. See 5.8 for a more detailed discussion of this subject.

Reference 20 (AASHTO Div. II, section 11.4.12.2.3) also considers 600°F (315°C) as the critical temperature. Furthermore, Reference 21 shows that at this temperature, the moduli of elasticity and yield point of steel are not significantly reduced from that of steel at ambient temperature.

Cooling rates suggested in other parts of the general specification for the appropriate grade and thickness of steel are recommended. A water mist, wet rags, or forced air is considered to be accelerated cooling and may only be used when the steel temperature is below 600°F (315°C).

C8.5.6 Welding Sequence. Welding procedures should be adjusted so that the total heat input per unit length of the weld for a given thickness and geometry of the material will maintain the temperature isotherms relatively narrow and minor in relation to the cross section of the stress-carrying member.

C8.6 Quality

The Engineer determines the level of inspection and nondestructive testing as appropriate for the job conditions. It is recommended that the contract document requirements be made compatible with section 6 of this code.

Examination of rivets and bolts affected by the heat induced by welding or straightening should be considered.

References

1. Blodgett, O. W. *Design of Welded Structures,* 12th Printing. Cleveland, OH: The James F. Lincoln Arc Welding Foundation, 1982.
2. Ricker, D. T. "Field welding to existing steel structures." *Engineering Journal* 25(1): Chicago, IL. American Institute of Steel Construction 1988.
3. American Welding Society. *Welding Handbook, Volume 4.* Miami, FL: American Welding Society, 1982.
4. Lincoln Arc Welding. *The Procedure Handbook of Arc Welding,* 12th Ed. Cleveland, OH: The James F. Lincoln Arc Welding Foundation, June 1973.
5. Jefferson, T. B. and Woods, G. *Metals and How to Weld Them,* 2nd Ed. Cleveland, OH: W. E. Publications, The James F. Lincoln Arc Welding Foundation, 1972.
6. American Welding Society, *Guide for Welding Iron Castings,* ANSI/AWS D11.2-89. Miami, FL: American Welding Society, 1989.
7. Nagaraja Rao, N. R. and Tall, L. "Columns reinforced under load." *Welding Journal,* Vol. 42, Research Supplement 177-s, April 1963.
8. Shanafelt, G. O. and Horn, W. B. "Guidelines for evaluation and repair of damaged steel bridge members." *Report No. 271.* Washington, DC: National Cooperative Highway Research Program, Transportation Research Board, June 1984.
9. Tide, R. H. R. "Basic considerations when reinforcing existing steel structures." *Conference Proceedings, National Engineering Conference and Conference of Operating Personnel, New Orleans, LA.* Chicago, IL: American Institute of Steel Construction, April 1987.
10. Tide, R. H. R. "Effects of fabrication on local stress conditions." *Conference Proceedings, ASCE Seventh Structures and Pacific Rim Engineering Conference, San Francisco, CA.* New York, NY: American Society of Civil Engineers, May 1989.
11. Marzouk, H. and Mohan, S. "Strengthening of wide-flange columns under load." *Canadian Journal of Civil Engineering* 17(5), October 1990. Ottawa, Ontario, Canada: Canadian Society of Civil Engineers.
12. Tide, R. H. R. "Reinforcing steel members and the Effects of Welding." *Engineering Journal* 27(4): 1990.

13. Stitt, J. R. "Distortion control during welding of large structures." *Paper 844B, Air Transport and Space Meeting.* New York, NY: Society of Automotive Engineers, Inc. and American Society of Mechanical Engineers, April 1964.

14. Holt, Richard E. "Primary concepts of flame bending." *Welding Journal,* June 1971.

15. United States Steel Corporation. *Fabrication Aids for Continuously Heat-Curved Girders,* ADUSS 88-5538-01. Pittsburgh, PA: United States Steel Corporation, April 1972.

16. Stewart, J. P. *Flame Straightening Technology,* LaSalle, QUE, 1981.

17. Roeder, C. W. "Experimental study of heat induced deformation." *Journal of Structural Engineering* 112(ST10) 1986. New York, NY: American Society of Civil Engineers.

18. Avent, R. R. "Heat straightening of steel; from Art to Science." *Conference Proceedings, National Steel Construction Conference, Miami Beach, FL.* Chicago, IL: American Institute of Steel Construction, June 1988.

19. American Society of Civil Engineers. *Plastic Design in Steel, a Guide and Commentary.* New York, NY: ASCE, 1971.

20. American Association of State Highway and Transportation Officials. *Standard Specifications for Highway Bridges,* 15th Edition. Washington, DC: AASHTO, 1992:

21. United States Steel Corporation. *Steel Design Manual,* ADUSS 27-3400-04. Pittsburgh, PA: United States Steel Corporation, January 1981.

22. Jarosch, K. H. and Bowman, M.D. "Tension butt joints with bolts and welds in combination." *Engineering Journal* 23(1) 1986.

23. Fisher, J. W. *Fatigue and Fracture in Steel Bridges.* New York, NY: John Wiley and Sons, Inc., 1984.

24. Fisher, J. W. *Bridge Fatigue Guide—Design and Details.* Chicago, IL: American Institute of Steel Construction, 1977.

25. *Welding in the World.* "Recommendations for repairs and or strengthening of steel structures," 26(11/12), Great Britain.

26. Haagensen, P. J. "Improving the fatigue performance of welded joints," *Proceedings, International Conference on Offshore Welded Structures.* London, England, November 1982.

27. Maddox, S. J. *Aspects of the Improvement in Fatigue Strength of Fillet Welds by Peening.* Cambridge, England: The Welding Institute, 1985.

28. Maddox, S. J., *Fatigue Strength of Welded Structures,* Second Edition. Abington Publishing, 1992.

29. Haagensen, P. J. IIW DOC. XIII-WG2-22-93, *Repair Methods and Life Extension,* 1993.

30. Haagensen, P. J. *The Effect of Grinding and Peening on the Fatigue Strength of Welded T-Joints.* IIW Doc. XIII-1510-93. 1993.

31. Haagensen, P. J., *Life Extension and Repair by Grinding and Peening,* IIW Doc. XIII-1511-93, 1993.

32. The Welding Institute. *Improving the Fatigue Performance of Welded Joints.* Cambridge, England: The Welding Institute, 1983.

    Maddox, S. J., Chapter 1 "An introduction to the fatigue of welded joints"

    Booth, G. S., Chapter 2 "A review of fatigue strength improvement techniques"

    Woodley, C. C, Chapter 4 "Practical applications of weld toe grinding"

    Haagensen, P. J., Chapter 5 "Effect of TIG dressing on fatigue performance and hardness of steel weldments"

33. Maddox, S. J. "International efforts on fatigue of welded construction." *Welding & Metal Fabrication,* December 1992.

34. Commission IIW Working Group 2—Improvement Techniques, *Proposed IIW Specification for Weld Toe Improvement by Hammer Peening or Burr Grinding,* 1993.

35. Takenouchi et. al. *Fatigue Performances of Repairing Welds with TIG-Dressing for Fatigue Damaged Highway Bridges,* IIW Doc. XIII-1509-93. Japan, 1993.

36. Welsch, W. "Peening improves fatigue life." *Welding Design & Fabrication,* September 1990.

37. Connect, No. 12, The Welding Institute, Cambridge, England, (from AWS *Welding Journal,* February 12, 1991).

38. CETIM/Centre Technique Des Industries Mecaniques. *Improving the Fatigue Strength of Welded Joints by TIG or Plasma Dressing.* IIW Doc. XIII-WG2-10-91, 1991.

Annex CXI

Guidelines on Alternative Methods for Determining Preheat

CXI1 Preheat—Background Review and Discussion

CXI1.1 General Observations. The probability of hydrogen cracking depends on a number of factors. Some of these can be classes as global (e.g., chemical composition and thickness) and can therefore be defined, while others which are local factors (e.g., the details of the weld root geometry, or local segregation of certain chemical elements) cannot be defined.

In some cases, these factors may dominate, and this makes it virtually impossible to predict in any rational manner the precise preheating conditions that are necessary to avoid hydrogen cracking. These situations must be recognized from experience and conservative procedures adopted. However, in the majority of cases, it is possible with present day knowledge of the hydrogen cracking phenomenon to predict a preheat and other welding procedure details to avoid hydrogen cracking that will be effective in the majority of cases without being overly conservative.

The preheat levels predicted from such a system must of course be compatible with experience. The requirements should allow fabricators to optimize preheating conditions for the particular set of circumstances with which they are concerned. Thus, rather than calling for a certain preheat for a given steel specification, the alternative guide allows preheats to be based on the chemistry of the plate being welded, as determined from mill reports or analysis. Fabricators may then, through knowledge of the particular set of circumstances they have, be able to use lower preheats and a more economical welding procedure. On the other hand, the requirements should provide better guidance for more critical joints; e.g., high restraint situations that will allow fabricators to undertake adequate precautions.

CXI1.2 Basis of Predicting Preheat. Research has shown that there are the following four basic prerequisites for hydrogen cracking to occur:

(1) susceptible microstructure (hardness may give a rough indication of susceptibility)

(2) appropriate level of diffusible hydrogen

(3) appropriate level of restraint

(4) suitable temperature

One or more of these prerequisites may dominate, but the presence of all is necessary for hydrogen cracking to occur. Practical means to prevent this cracking, such as preheat, are designed to control one or more of these factors.

In the past, two different approaches have been taken for predicting preheat. On the basis of a large number of fillet weld controlled thermal severity (CTS) tests, a method based on critical heat-affected zone hardness has been proposed (References 1 and 2). By controlling the weld cooling rate so that the hardness of heat affected zones does not exceed the critical level, the risk of hydrogen cracking could be removed.

The acceptable critical hardness can be a function of the hydrogen content. This approach does not recognize the effect of preheat on the removal of hydrogen from the weld during cooling; although being recommended in the guide for predicting a minimum energy input for welding without preheat, it tends to be overly conservative when predicting preheat levels.

The second method for predicting preheat is based on the control of hydrogen. Recognizing the effect of the low temperature cooling rate, i.e., cooling rate between 572°F and 212°F (300°C and 100°C), empirical relationships between the critical cooling rate, the chemical composition, and hydrogen content have been determined using high restraint groove weld tests (Reference 3).

More generalized models have been proposed by other researchers (References 4, 5 and 6) using simple hydrogen diffusion models. Hydrogen content is usually included as a logarithmic term. The advantage of this approach is that the composition of the steel and the hydrogen content of the weld can be grouped together in one parameter, which may be considered to represent the susceptibility to hydrogen embrittlement. A relationship then exists between the critical cooling time and this parameter, for a given restraint level. It is possible to index the lines for various restraint levels by reference to large scale tests or experience, and for other types of fillet welds (Reference 7). In developing the method, relations between the specific preheat and the cooling time must be assumed.

It is important to recognize that the preheats predicted from these models depend upon the type of test used to provide the experimental data. The condition usually examined in these tests is that of a single root pass in a butt joint. This is considered the most critical and is used to determine the preheat; but there are situations where it is possible to weld the second pass before the first pass cools down (stove pipe welding for girth welds in pipes), and with these special procedures, the weld can be made with lower preheats that would be predicted. However, for general application, it is considered that the preheat is properly determined by that required to make the root pass. For this reason, energy input does not enter explicitly into this hydrogen control method.

CXI1.3 Scope of Proposed Preheat Requirements. An important feature that is omitted in all of the proposed methods for predicting preheat is weld metal cracking. It is assumed that preheat is determined by heat affected zone cracking (and hence parent metal composition), but in some cases, particularly with modern high strength low alloy steels, the weld metal may be more susceptible. There has been insufficient research on this problem to include it in the present guidelines, and in such cases testing may be necessary.

CXI2 Restraint

CXI2.1 The major problem in determining preheats using the hydrogen control approach is in selecting a value for the restraint. In the guide three restraint levels are considered. The first represents a low restraint and is considered to be independent of thickness. The low restraint corresponds to an intensity of restraint, k, less than 1 000 N/mm/mm and this coincides with the fillet weld results. Many welds in practice would be in this category. The medium restraint is based on a value of k = 150 × plate thickness (in mm) and corresponds to a value covering most of the measured values of restraint that have been reported. The high restraint table is based on k = 400 × plate thickness (in mm) and represents a severe level of restraint. It is noticed that in the medium and higher restraint conditions, the restraint is considered to increase with plate thickness.

CXI2.2 Restraint must be said to have a pronounced effect on the amount of required preheat. The reference to it in the present Table 3.2 of the Code is included in Note 1 under the Table. There it may not fully convey the significance in preheat considerations given to it internationally.

CXI2.3 The Guidelines draw the user's attention to the restraint aspect of welded joints by suggesting three generally described levels. With continuing alertness on the part of users within and outside an industry conducted surveillance program, restraint will eventually be more precisely defined, in terms of actual detail or structural framing situations.

The fact it was impossible to define restraint more explicitly at this time was not taken as sufficiently valid ground not to address restraint, recognize its pronounced influence and provide the presently best available means to accommodate it.

Note: A concerted industry sponsored surveillance program designed for an efficient and rapid exchange of experience so as to permit eventual classification and listing of specific structural details and situations under the three restraint levels, merits full consideration.

Restraint data collected from fabrication and engineering practice could provide grounds for more realistic evaluation of restraint and more reliable determination of preheats following the recommendations of these guidelines.

CXI2.4 The present requirements for welding procedure qualification in structural work, except for some cases of tubular construction, rely on standard test assemblies to "prove" the adequacy of preheat for the same joints as parts of production assemblies. One should be aware that under these circumstances "restraint" is not being considered in the qualification. A shift towards qualification using "joint" simulated test assemblies" would result in a much more reliable indication of performance under service conditions and additionally permit collection of reliable restraint data.

CXI3 Relation Between Energy Input and Fillet Leg Size

Although the heat input to the plate is of prime consideration in regard to cooling rate and potential HAZ hardness, it is often more practical to specify weld size. The relation between energy input and fillet weld size (i.e., leg length) is not unique but depends on process, polarity, and other factors. Some workers have suggested that relationships exist between cooling rate and the total cross-sectional area of fused metal. The latter, however, is difficult to measure and would not be a suitable way of specifying weld sizes in practice.

The weld dimensions and welding conditions have been measured in fillet weld tests and these data used to make plots of leg lengths squared versus energy input. Another source is information derived from the deposition rate data where it has been assumed that all of the metal deposited went into forming an ideal fillet. Where a root opening was present, the leg length was smaller for the same energy input than for the condition of perfect fit-up. The results of these plots are shown in Figure XI-4.

For manual covered electrodes with large quantities of iron powder in the covering, a larger fillet size for the same energy is produced. For submerged arc welding, electrode polarity and electrode extensions have a marked effect, as would be expected. For the normal practical range of welding conditions, a single scatter band can be considered, and a lower bound curve selected as a basis for welding procedure design.

CXI4 Application

CXI4.1 It should be clear that the proposed methods presuppose a good engineering understanding of the concepts involved as well as sound appreciation of the influence of the basic factors and their interplay built into the preheat methodology.

CXI4.2 Engineering judgment must be used in the selection of the applicable hardness curve and a realistic evaluation of the restraint level must be part of the judgment.

CXI4.3 The methods of measuring effective preheat remains an independent matter and requires separate and continuous attention.

CXI4.4 The effectiveness of preheat in preventing cracking will depend significantly on the area preheated and the method used.

Since the objective is to retard the cooling rate to allow the escape of hydrogen, a larger preheated area will stay hot longer and be more effective.

CXI4.5 There appears no need to change the reference in Note 1 under Table 3.2 to preheating within a 3 in. (75 mm) radius from the point of welding, as other work has confirmed the validity of this requirement.

CXI4.6 The methods of preheating (equipment, gases) should be the subject of another investigation with major input from fabricators with the objective to report on their economy and effectiveness.

References

1. British Standards 5135-1974.
2. Coe, F. R. *Welding steels without hydrogen cracking*. Welding Institute of Canada, 1973.
3. Graville, B. A. "Determining requirements for preheat." *Technology Focus*. Welding Institute of Canada, October 1980.
4. Ito, F. and Bessyo, K. *A prediction of welding procedures to avoid HAZ cracking*. IIW document No. IX-631-69.
5. McParlan, M. and Graville, B. A. *Welding Journal* 55 (4): p-92-s. Res. Suppl., April 1976.
6. Suzuki, M. *Cold cracking and its prevention in steel welding*. IIW document No. IXC-1074-78.
7. Tersaki et al., Trans. JWS 10 (1), April 1979.

Index

C

D

G

H

I

J

K

L

M

N

O

P

Q

R

T

U

V

W

X

Y

Z