CASE

1426 S. Polk
Dallas, Texas 75224

214/946-9446

(CITIZENS ASSN. FOR SOUND ENERGY)

May 14, 1984

Docketing and Service Section
Office of the Secretary
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Sir:

Subject: In the Matter of
Application of Texas Utilities
Electric Company, et al. for
An Operating License for
Comanche Peak Steam Electric
Station, Units #1 and #2 (CPSES)
Docket Nos. 50-445-1 and 50-446-1

Affidavit of CASE Witness Jack Doyle

We are attaching the original signed and notarized Affidavit of CASE Witness Jack Doyle.

Please note that Mr. Doyle has included as part of his Affidavit the SUMMARY portion of CASE's 5/14/84 ANSWER TO APPLICANTS' MOTION FOR SUMMARY DISPOSITION OF CERTAIN ALLEGATIONS REGARDING AWS AND ASME CODE PROVISIONS RELATED TO WELDING ISSUES, and the entire CASE'S ANSWER TO APPLICANTS' STATEMENT OF MATERIAL FACTS AS TO WHICH THERE IS NO GENUINE ISSUE. We are also attaching copies of these documents.

Please also note that, as indicated in the attached letter dated 5/14/84 to the Licensing Board and parties in the hearings, Mr. Doyle telephoned me after our pleadings had already been typed, printed, and collated, and stated that he wished to add one additional reference which was inadvertently omitted. Page 9 of CASE'S 5/14/84 ANSWER TO APPLICANTS' MOTION FOR SUMMARY DISPOSITION etc. has been revised and is attached to our 5/14/84 letter. We are also attaching a copy of our letter and the revised page 9.

Sincerely,

CASE (Citizens Association for Sound Energy)

Juanita Ellis

(Mrs.) Juanita Ellis
President

cc: Service List

CASE EXHIBIT 716

TEXAS UTILITIES SERVICES INC.		REV.	ISSUE DATE	PAGE
ENGINEERING GUIDELINE TITLE	COVER SHEET FOR GUIDELINE REVISIONS	4	5-11-82	1 OF 1
SECTION XI WELD CALCULATIONS		APPROVED: John C. Finneran		
		PSE PROJ. ENGR.		

I. INSTRUCTIONS FOR FILING GUIDELINE PAGES

1. Replace the existing sheets 1 thru 7 with the enclosed sheets 1 thru 17.
2. Replace the existing cover sheet, Rev. 3 with this cover sheet, Rev. 4.

II. STATUS OF GUIDELINE PAGES

PAGE	REV	PAGE	REV	PAGE	REV	PAGE	REV	PAGE	REV	PAGE	REV
1	5	10	0								
2	4	11	0								
3 (void 6-8-82)	~~4~~ 0	12	0								
4	4	13	0								
5	4	14	0								
6 (void 6-8-82)	~~6~~ 4	15	0								
7	~~5~~ 6	16	0								
8	~~0~~ 5	17	0								
9	0										

SECTION XI: WELD CALCULATIONS

1.0 GENERAL

This section supplements weld size requirements as addressed in referance "C".

2.0 REFERENCES

A. Design of Welded Structures, Blodgett

B. AISC Handbook (7th Edition)

C. ASME Section III Division 1 1974 Edition with Winter 1974 Addendum.

D. American Welding Society Code D1.1

3.0 PROPERTIES OF WELDS

For analysis of a weld, the weld will be considered as a line.

Some general configurations based upon this assumption with their corresponding properties are indicated in figure 1.

3.1 Weld Size Selection

The calculated weld size is found by determining the actual resultant force on the weld and comparing it to the allowable force for that weld size.

The largest loads are to be used when determining the required weld size.

The allowable stress for linear component support welds shall be in accordance with Table NF-3292.1-1.

The minimum weld based upon structural member thickness is as inidcated in figure 2.

3.2 Skewed Joints

Fillet welds may be used at skewed joints where the angle is equal or greater than 60° but less than or equal to 135°. (Figure 3)

SECTION XI

If a member is to be joined at an angle greater than 30° or less than 60°, a bevel groove weld is to be used. (See Figure 3). The effective throat is indicated in parentheses.

If a member is to be attached at an angle greater than 135°, the member should be machined to yield an angle less that 135° but greater than 60°. (See Figure 3.)

3.3 Welding of Structural Tubes

When two tubes of equal size are welded together, a flare bevel weld should be specified. The effective throat is as shown in Figure 4.

When two tubes of unequal size are welded together, a fillet weld shall be specified in all cases. The effective throat is indicated in Figure 5.

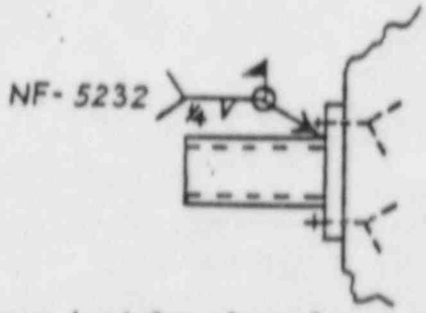
For combined fillet and flare bevel welds the effective throat is as indicated in Figure 6.

3.4 Weld Symbols

Subsection NF weld inspection procedure paragraphs must be specified in the tail of the weld symbol using the following codes:

52 __"A"__ __"B"__

ASME CLASS	"A"
1	1
2 & MC	2
3	3



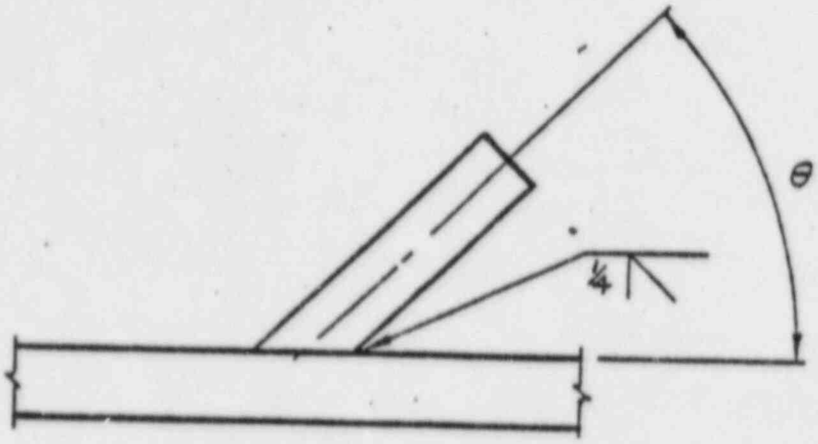
SUPPORT TYPE	"B"
Plate & Shell	1
Linear	2
Component Std.	3

No NF weld symbols are required for class 5 supports or for welds to the pipe.

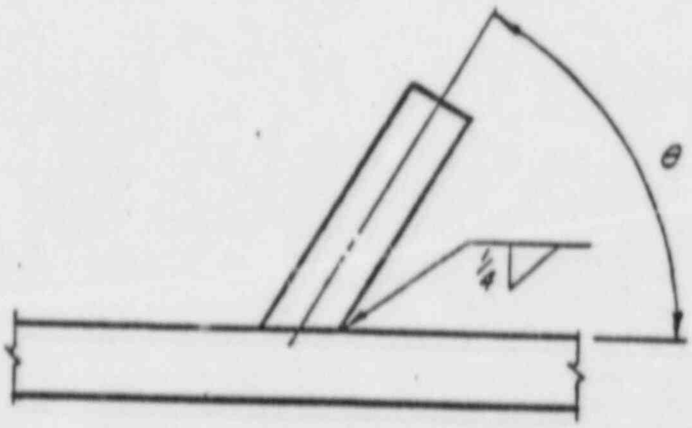
Only welds that connect two plate and shell elements shall be designated as plate and shell.

SECTION XI

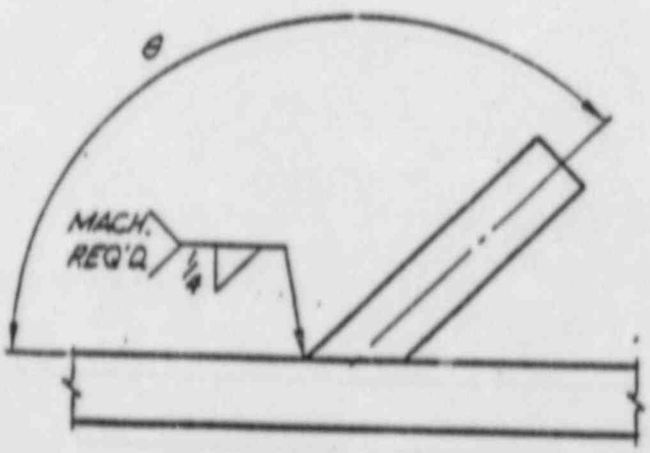
FIGURE 3



$60° > \theta > 30°$



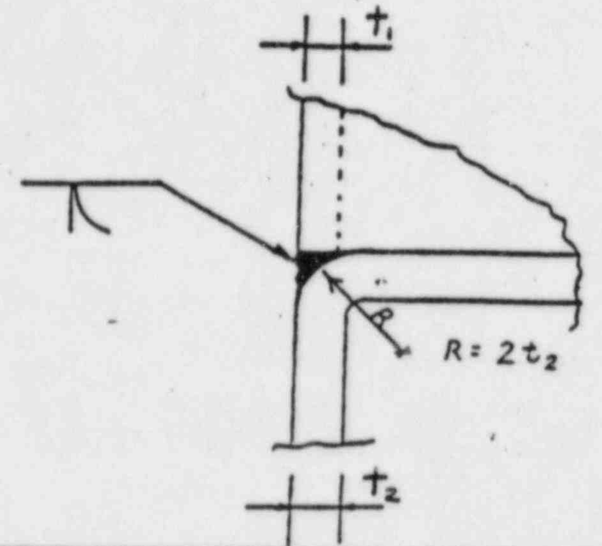
$135° \geq \theta \geq 60°$



$\theta > 135°$

Figure 4

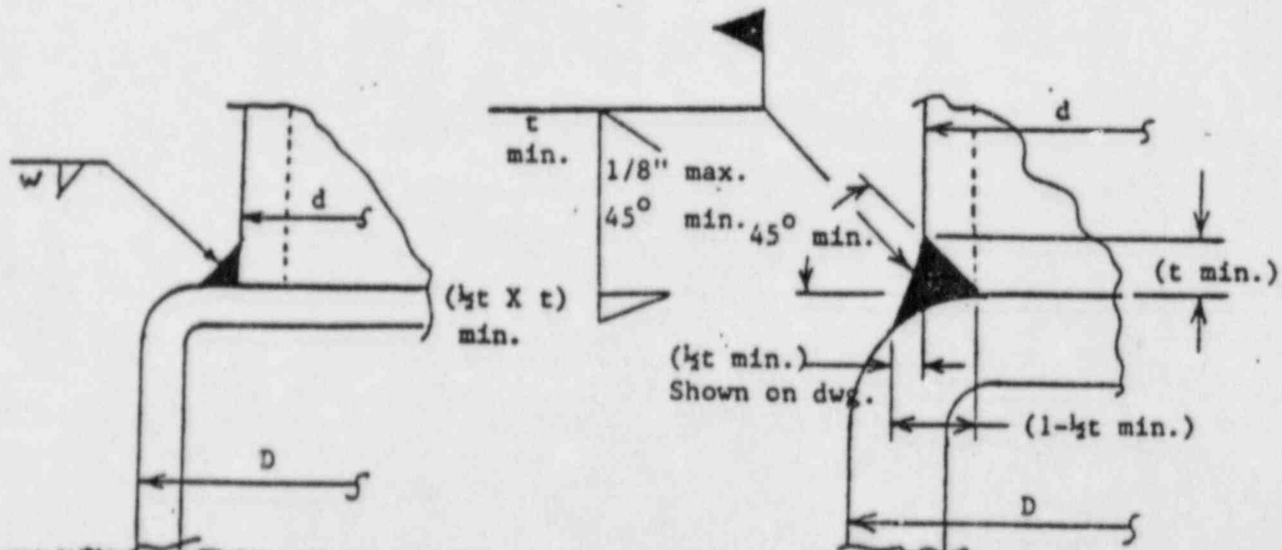
Two Structural Tubes of Equal Size.



Effective throat "te" for design shall be:
te = .625t_2 or t_1
whichever is less.

Figure 5

Two Structural Tubes of Unequal Size



Normal Case

Effective Throat = 0.707 W

To be used only when the ratio of $\frac{d}{D} \leq 0.8$

Special Case

t = Thickness of thinner material

Effective Throat = t

To be used when the ratio of $\frac{d}{D} >$ 0.8 or when calculations dictate an Effective Throat = t. Show the ½t leg dim. on the hgr. dwg.

CASE EXHIBIT 886

Welding Handbook

Sixth Edition

SECTION FOUR

Metals

And

Their Weldability

Edited by Len Griffing
Published in 1972 by AMERICAN WELDING SOCIETY
2501 N.W. 7th Street
Miami, Florida 33125

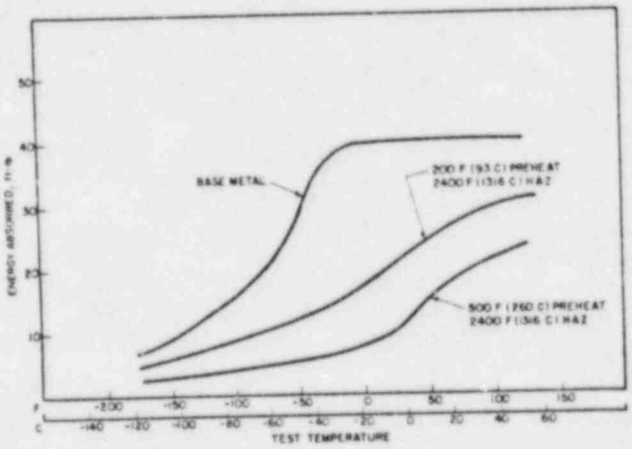


Fig. 63.8.—Effect of weld preheat at 47,000 joules per in. on Charpy V-notch curves for simulated grain-coarsened heat-affected zone in ½-in. thickness of typical A514/517 steel

Welding Technique

The stringer-bead technique, in which weld beads are deposited without appreciable transverse oscillation of the electrode, is preferred for welding quenched and tempered steels. A weave-bead, with its slower travel speed, permits the arc to linger over each portion of the joint and increases the heat input. Furthermore, stringer-bead technique reduces distortion and favors good weld-metal toughness.

Where arc gouging is used, such as removing base metal or previously deposited weld metal at the root of the joint, grinding is usually necessary to clean the surfaces prior to welding. During gouging, the arc should be moved as rapidly as possible, consistent with good gouging practice, to avoid excessive heat input. Gouging with an oxygen-cutting torch should not be done on these steels because of the danger of overheating quenched and tempered steel.

Postweld Heat Treatment

Experience with structures and pressure vessels in service, and information from full-scale tests, show that thermal stress relief is not required to prevent brittle fracture in welded quenched and tempered steels of the types discussed here. In fact, notch-toughness tests have demonstrated that exposure to temperatures in the range of 950 to 1200°F (510 to 694°C) may actually impair the toughness of both the weld metal and heat-affected zone, and that the extent of this impairment is greater with the slow cooling rate that is necessary for stress relief. Also of concern when weldments are given such a heat treatment is that intergranular cracking may occur in the grain-coarsened region of the heat-affected zone. When it does occur, this type of cracking occurs during the early stages of the heat treatment before the high residual stresses from welding have been significantly reduced. The mechanism is one of stress rupture. This type of cracking has been prevented from occurring at the toes of fillet welds by properly contouring the welds to minimize stress concentrations, by peening at the toes of the welds, or by depositing weld metal whose elevated-temperature strength is significantly lower than that of the base metal heat-affected zone.

Stress relief may be required for weldments that must retain dimensional stability during machining, or where stress corrosion may be involved, although neither of these requirements is unique to quenched and tempered steels. The

ANSI/AWS D1.1-82

An American National Standard
Approved by
American National Standards Institute
January 25, 1982

Structural Welding Code—Steel

Sixth Edition

Superseding
AWS D1.1-81

Prepared by
AWS Structural Welding Committee

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Effective January 1, 1982

AMERICAN WELDING SOCIETY, INC.
550 North LeJeune Rd., Miami, FL 33126

Table 2.3.1.4
Effective throats of flare groove welds

Flare-bevel-groove welds		Flare-V-groove welds
	All diam bars	
5/16 R		1/2 R*

Note: R = radius of bar.
*Except 3/8 R for GMAW (except short circuiting transfer) process with bar sizes 1 in. (25.4 mm) diam and over.

Part C
Details of Welded Joints

2.6 Joint Qualification

2.6.1 Joints meeting the following requirements are designated as prequalified:

(1) Conformance with the details specified in 2.7 through 2.10 and 10.13.

(2) Use of one of the following welding processes in accordance with the requirements of Sections 3, 4, and 8, 9, or 10 as applicable: shielded metal arc, submerged arc, gas metal arc (except short circuiting transfer), or flux cored arc welding.

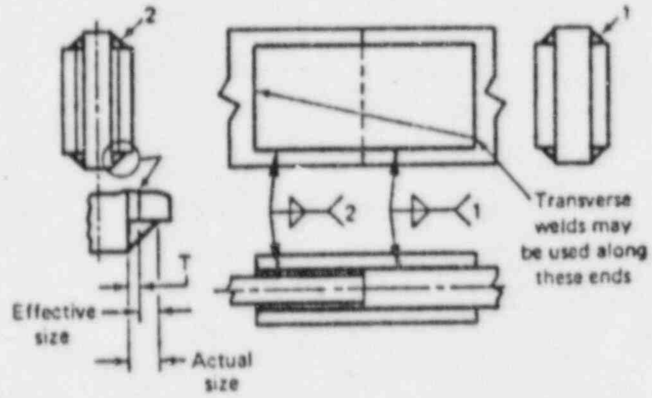
2.6.1.1 Joints meeting these requirements may be used without performing the joint welding procedure qualification tests prescribed in 5.2.

2.6.1.2 The joint welding procedure for all joints welded by short circuiting transfer gas metal arc welding (see Appendix D) shall be qualified by tests prescribed in 5.2.

2.6.2 Joint details may depart from the details prescribed in 2.9 and 2.10 and in 10.13 only if the contractor submits to the Engineer his proposed joints and joint welding procedures and at his own expense demonstrates their adequacy in accordance with the requirements of 5.2 of this Code and their conformance with applicable provisions of Sections 3 and 4.

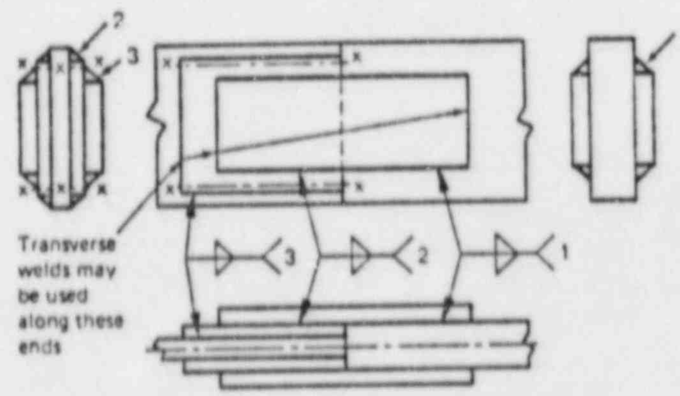
2.7 Details of Fillet Welds

2.7.1 The details of fillet welds made by shielded metal arc, submerged arc, gas metal arc (except short circuiting transfer), or flux cored arc welding to be used without joint welding procedure qualifications are listed in 2.7.1.1 through 2.7.1.5 and detailed in Figs. 2.7.1 and 10.13.5.



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

Fig. 2.4.2–Fillers less than 1/4 in. thick



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

Fig. 2.4.3–Fillers 1/4 in. or thicker

2.7.1.1 The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 2.7.

2.7.1.2 The maximum fillet weld size permitted along edges of material shall be

(1) the thickness of the base metal, for metal less than 1/4 in. (6.4 mm) thick (see Fig. 2.7.1, 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 Fig. 2.7.1, detail B), unless the weld is designated on the drawing to be built out to obtain full throat thickness.

transfer), or flux cored arc welding processes are listed in 2.8.2 through 2.8.8 and 3.3.1 and may be used without performing the joint welding procedure qualification prescribed in 5.2, provided the technique provisions of 4.21 or 4.22, as applicable, are complied with.

2.8.2 The minimum diameter of the hole for a plug weld shall be no less than the thickness of the part containing it plus 5/16 in. (8.0 mm), preferably rounded to the next greater odd 1/16 in. (1.6 mm). The maximum diameter of the hole for a plug weld shall not be greater than 2-1/4 times the depth of filling.

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

2.8.4 The length of the slot for a slot weld shall not exceed ten times the thickness of the part containing it. The width of the slot shall be no less than the thickness of the part containing it plus 5/16 in. (8.0 mm), preferably rounded to the next greater odd 1/16 in. (1.6 mm), nor shall it be greater than 2-1/4 times the depth of filling.

2.8.5 Plug and slot welds are not permitted in quenched and tempered steels.

Table 2.7
Minimum fillet weld size for prequalified joints

Base metal thickness of thicker part jointed (T) in.	mm	Minimum size of fillet weld* in.	mm	
T≤1/4	T≤ 6.4	1/8**	3	Single-pass welds must be used
1/4<T≤1/2	6.4<T≤12.7	3/16	5	
1/2<T≤3/4	12.7<T≤19.0	1/4	6	
3/4<T	19.0<T	5/16	8	

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

**Minimum size for bridge applications is 3/16 in.

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

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

2.8.8 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.

Legend for Figs. 2.9.1 through 2.10.1

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

Symbols for weld types
- 1–square-groove
- 2–single-V-groove
- 3–double-V-groove
- 4–single-bevel-groove
- 5–double-bevel-groove
- 6–single-U-groove
- 7–double-U-groove
- 8–single-J-groove
- 9–double-J-groove

Symbols for welding processes if not shielded metal arc
- S–submerged arc welding
- G–gas metal arc welding
- F–flux cored arc welding

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

or 5% of the thickness, whichever is smaller, nor leave reinforcement that exceeds 1/32 in. However, all reinforcement must be removed where the weld forms part of a faying or contact surface. Any reinforcement must blend smoothly into the plate surfaces with transition areas free from edge weld undercut. Chipping may be used provided it is followed by grinding. Where surface finishing is required, its roughness value[7] shall not exceed 250 μin. (6.3 μm). Surfaces finished to values of over 125 μin. (3.2 μm) through 250 μin. shall be finished parallel to the direction of primary stress. Surfaces finished to values of 125 μin. or less may be finished in any direction.

3.6.3.1 Ends of butt joints required to be flush shall be finished so as not to reduce the width beyond the detailed width or the actual width furnished, whichever is greater, by more than 1/8 in. (3.2 mm) or so as not to leave reinforcement at each end that exceeds 1/8 in. (3.2 mm). Ends of welds in butt joints shall be faired to adjacent plate or shape edges at a slope not to exceed 1 in 10.

3.6.4 Welds shall be free from overlap.

3.7 Repairs

3.7.1 The removal of weld metal or portions of the base metal may be done by machining, grinding, chipping, oxygen gouging, or air carbon arc gouging. It shall be done in such a manner that the remaining weld metal or base metal is not nicked or undercut. Oxygen gouging shall not be used in quenched and tempered steel. Unacceptable portions of the weld shall be removed without substantial removal of the base metal. Additional weld metal to compensate for any deficiency in size shall be deposited using an electrode preferably smaller than that used for making the original weld, and preferably not more than 5/32 in. (4.0 mm) in diameter. The surfaces shall be cleaned thoroughly before welding.

3.7.2 The contractor has the option of either repairing an unacceptable weld or removing and replacing the entire weld, except as modified by 3.7.4. The repaired or replaced weld shall be retested by the method originally used, and the same technique and quality acceptance criteria shall be applied. If the contractor elects to repair the weld, it shall be corrected as follows:

3.7.2.1 Overlap or Excessive Convexity. Remove excess weld metal.

3.7.2.2 Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting. Prepare surfaces (see 3.11) and deposit additional weld metal.

3.7.2.3 Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion. Remove unacceptable portions (see 3.7.1) and reweld.

3.7.2.4 Cracks in Weld or Base Metal. Ascertain the extent of the crack by use of acid etching, magnetic particle inspection, dye penetrant inspection, or other equally positive means; remove the crack and sound metal 2 in. (50.8 mm) beyond each end of the crack, and reweld.

3.7.3 Members distorted by welding shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heat. The temperature of heated areas as measured by approved methods shall not exceed 1100° F (590° C) for quenched and tempered steel nor 1200° F (650° C) (a dull red color) for other steels. The part to be heated for straightening shall be substantially free of stress and from external forces, except those stresses resulting from the mechanical straightening method used in conjunction with the application of heat.

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

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

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

3.7.7 Restoration of Unacceptable Holes by Welding. When base metal with punched or drilled mislocated holes is to be restored to its original condition by welding, the following requirements shall apply:

(1) Restoration by welding is not recommended unless required for structural reasons.

(2) Holes in material not subject to tensile stress may be restored by welding, provided that weld soundness is verified by either radiographic or ultrasonic inspection to the acceptance criteria for compressive stresses.

(3) Restoration of holes by welding in material subject to tensile stress is prohibited, except when approved by the Engineer and the weld soundness is verified by either radiographic or ultrasonic inspection to the acceptance criteria for tensile stresses.

(4) Prior to restoration of mislocated holes in a production member, a welding procedure specification shall be prepared setting forth the welding procedure, technique, materials, and representative joint geometries to be used for the restoration. Sample welds shall be made following the welding procedures specification. The sample weld in any material shall meet the soundness criteria of (2) or (3) above as applicable. For restoration of mislocated holes in quenched and tempered steel, sufficient additional samples shall be prepared to perform the following mechanical tests:

7. ANSI B46.1, Surface Texture, in microinches (μin.).

No. of tests	Type of test
1	Reduced section tension test
2	Side-bend tests
3	Longitudinal Charpy V-notch tests. (The Charpy V-notch to be located in the heat-affected zone and normal to the section or plate surface.

(5) The welding procedure specification and all test results shall be approved by the Engineer prior to restoration welding on a production member. Production welding shall be done in accordance with the established welding procedure specification and within the limitation of variables set forth in 5.5 of this Code. The Engineer should accept documented evidence of previously satisfactorily tested sample welds.

(6) Weld surfaces shall be finished as specified in 3.6.3.

3.8 Peening

3.8.1 Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking. No peening shall be done on the root or surface layer of the weld or the base metal at the edges of the weld except as provided in 10.7.5(3). Care should be taken to prevent overlapping or cracking of the weld or base metal.

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

3.9 Caulking

Caulking of welds shall not be permitted.

3.10 Arc Strikes

Arc strikes outside the area of permanent welds should be avoided on any base metal. Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and checked to ensure soundness.

3.11 Weld Cleaning

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

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

3.12 Weld Termination

3.12.1 Welds shall be terminated at the end of a joint in a manner that will ensure sound welds. Whenever necessary, this shall be done by use of extension bars and runoff plates.

3.12.2 In building construction, extension bars or runoff plates need not be removed unless required by the Engineer.

3.12.3 In bridge construction, extension bars and runoff plates shall be removed upon completion and cooling of the weld, and the ends of the weld shall be made smooth and flush with the edges of abutting parts.

3.13 Groove Weld Backing

3.13.1 Groove welds made with the use of steel backing shall have the weld metal thoroughly fused with the backing.

3.13.2 Steel backing shall be made continuous for the full length of the weld. All necessary joints in the steel backing shall be complete joint penetration welds in butt joints meeting all the workmanship requirements of Section 3 of this code.

3.13.3 Bridge Structures. On bridge 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.

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

3.13.4 Buildings and Tubular Structures. Steel backing of welds used in buildings or tubular structures need not be removed, unless required by the Engineer.

Table B
Equivalent fillet weld leg size factors for skewed T-joints

Dihedral angle, ψ	60	65	70	75	80	85	90	95
Comparable fillet weld size for same strength	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03
Dihedral angle, ψ	100	105	110	115	120	125	130	135
Comparable fillet weld size for same strength	1.08	1.12	1.16	1.19	1.23	1.25	1.28	1.31

For fillet welds having equal measured legs (w_n), the distance from the root of the joint to the face of the diagrammatic weld (t_n) may be calculated as follows:

For gaps > 1/16 in. and ≤ 3/16 in., use

$$t_n = \frac{w_n - g_n}{2 \sin \frac{\psi}{2}}$$

For gaps < 1/16 in., use

$g_n = 0$ and $t'_n = t_n$

where the measured leg of such fillet weld (w_n) is the perpendicular distance from the surface of the joint to the opposite toe, and (g) is the gap, if any, between parts. See Fig. 2.7.1. Acceptable gaps are defined in 3.3.1.

CASE EXHIBIT 909

Commentary on Structural Welding Code –Steel

Third Edition

Prepared by
AWS Structural Welding Committee

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Foreword

This commentary on AWS D1.1-81, Structural Welding Code—Steel, has been prepared to generate better understanding in the application of the Code to welding in steel construction.

Since the Code is written in the form of a specification, it cannot present background material or discuss the Committee's intent; it is the function of this commentary to fill this need.

Suggestions for application as well as clarification of Code requirements are offered with specific emphasis on new or revised sections that may be less familiar to the user.

Since the publication of the first edition of the Code, the nature of inquiries directed to the American Welding Society and the Structural Welding Committee has indicated that there are some requirements in the Code that are either difficult to understand or not sufficiently specific, and others that appear to be overly conservative.

It should be recognized that the fundamental premise of the Code is to provide general stipulations applicable to any situation and to leave sufficient latitude for the exercise of engineering judgment.

Another point to be recognized is that the Code represents the collective experience of the Committee and while some provisions may seem overly conservative, they have been based on sound engineering practice.

The Committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of many of the Code requirements. Obviously, the size of the commentary had to impose some limitations with respect to the extent of coverage.

This commentary is not intended to provide a historical background of the development of the Code, nor is it intended to provide a detailed resume of the studies and research data reviewed by the Committee in formulating the provisions of the Code.

Generally, the Code does not treat such design considerations as loading and the computation of stresses for the purposes of proportioning the load-carrying members of the structure and their connections. Such considerations are assumed to be covered elsewhere, in a general building code, bridge specification, or similar document. As an exception, the Code does provide allowable stresses in welds, fatigue provisions for welds in bridges and tubular structures, and strength limitations for tubular connections. These provisions are related to particular properties of welded connections.

The Committee has endeavored to produce a useful document suitable in language, form, and coverage for welding in steel construction. The Code provides a means for establishing welding standards for use in design and construction by the owner or his designated representative. The Code incorporates provisions for regulation of welding that are considered necessary for public safety.

The Committee recommends that the owner or owner's representative be guided by this commentary in application of the Code to his welded structure. The commentary is not intended to supplement Code requirements, but only to provide a useful document for interpretation and application of the Code; none of its provisions are binding.

Comments or inquiries pertaining to this commentary or to the Code are welcome. They should be addressed to: Secretary, Structural Welding Committee, American Welding Society.

Preface

It is the intention of the Structural Welding Committee to revise the commentary on an annual basis so that commentary on the changes to the Code can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the Structural Welding Code—Steel with which it is bound.

Changes in the commentary from the first edition have been indicated by a single vertical line that appears in the margin immediately adjacent to the paragraph affected. Changes to tables and figures, as well as new tables or new figures, have not been so indicated.

Commentary on Structural Welding Code—Steel

1. General Provisions

Note: All references to numbered paragraphs, tables, and figures, unless otherwise indicated, refer to paragraphs, tables, or figures in AWS D1.1, Structural Welding Code—Steel. References to paragraphs, tables, or figures in this commentary are prefixed with a C. Hence, Fig. 8.8.5 is in AWS D1.1, while Fig. C8.8.5 is in this commentary.

1.1 Application

The Structural Welding Code, hereinafter referred to as the Code, provides welding requirements for the construction of steel structures. It is intended to be complementary with any general code or specification for design and construction of steel structures.

This Code was specifically written for use in the construction of buildings, bridges, or tubular structures, but its provisions are generally applicable to any steel structure.

When using the Code for other structures, owners, architects, and engineers should recognize that not all of its provisions may be applicable or suitable to their particular structure. However, any modifications of the Code deemed necessary by these authorities should be clearly referenced in the contractual agreement between the owner and the contractor.[1]

1.2 Base Metal[2]

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.

1.3 Welding 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 welding procedures in conjunction with certain related types of joints have been thoroughly tested and have a long record of proven satisfactory performance. These welding procedures and joints are designated as prequalified and may be used without tests or qualification (see 5.1 and 5.2).

Prequalified provisions are given in Section 2, Prequalified Joint Details; Section 3, Workmanship; and Section 4, Technique. Section 4 includes welding procedures, 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 10.

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 procedures on the basis of a successful qualification by the contractor conducted in accordance with the requirements of the Code (see 5.2).

1. As used in this commentary, contractor designates the party responsible for performing the welding under the Code. The term is used collectively to mean contractor, fabricator, erector, manufacturer, etc.

2. Since all steel specifications approved by the Code for use in buildings, bridges, and tubular structures are listed in 10.2, the general provisions for approved base metals will be discussed in C10.2. As an exception, specific provisions applicable only to buildings or bridges are discussed in C8.2 or C9.2 respectively.

2. Design of Welded Connections

2.1.3 The engineer preparing contract design drawings cannot specify the depth of groove (S) without knowing the welding process and the position of welding. The Code is explicit in stipulating that only the effective throat (E) is to be specified on design drawings for partial joint penetration groove welds (2.1.3.1). This allows the contractor to produce the effective throat by assigning a depth of preparation to grooves shown on shop drawings as related to his choice of welding process and position of welding.

The root penetration will generally depend on the angle subtended at the root of the groove in combination with the root opening, the welding position, and the welding process. For joints using bevel- and V-groove welds, these factors determine the relationship between the depth of preparation and the effective throat for prequalified partial joint penetration groove welds.

2.5 Partial Joint Penetration Groove Welds

A partial joint penetration groove weld has an unwelded portion at the root of the weld. This condition may also exist in joints welded from one side without backing, and, therefore, the Code considers them partial joint penetration groove welds except as modified in Section 10 (10.12.4).

The unwelded portions are no more harmful than those in fillet welded joints. These unwelded portions constitute a stress raiser having significance when fatigue loads are applied transversely to the joint. This condition is reflected in the applicable fatigue criteria.

However, when the load is applied longitudinally, there is no appreciable reduction in fatigue strength. Irrespective of the rules governing the service application of these particular grooves, the eccentricity of shrinkage forces in relation to the center of gravity of the material will result in angular distortion on cooling after welding. This same eccentricity will also tend to cause rotation in transfer of axial load transversely across the joint. Therefore, means must be applied to restrain or preclude such rotation, both during fabrication and in service.

2.7.1 Minimum Fillet Weld Sizes for Prequalified Joints. The Code specifies the minimum fillet weld size and requires that this size be made in a single pass. This provision is intended to ensure sufficient heat input in order to reduce the possibility of cracking in either the heat-affected zone or weld metal, especially in a restrained joint. The minimum size applies if it is greater than the size required to carry design stresses.

The intent of Table 2.7 is further clarified as follows: Base metal thickness of 3/4 in. (19 mm) and under are exempt from preheat in accordance with Table 4.2. 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 a provided by the minimum fillet size required by Table 2.7.

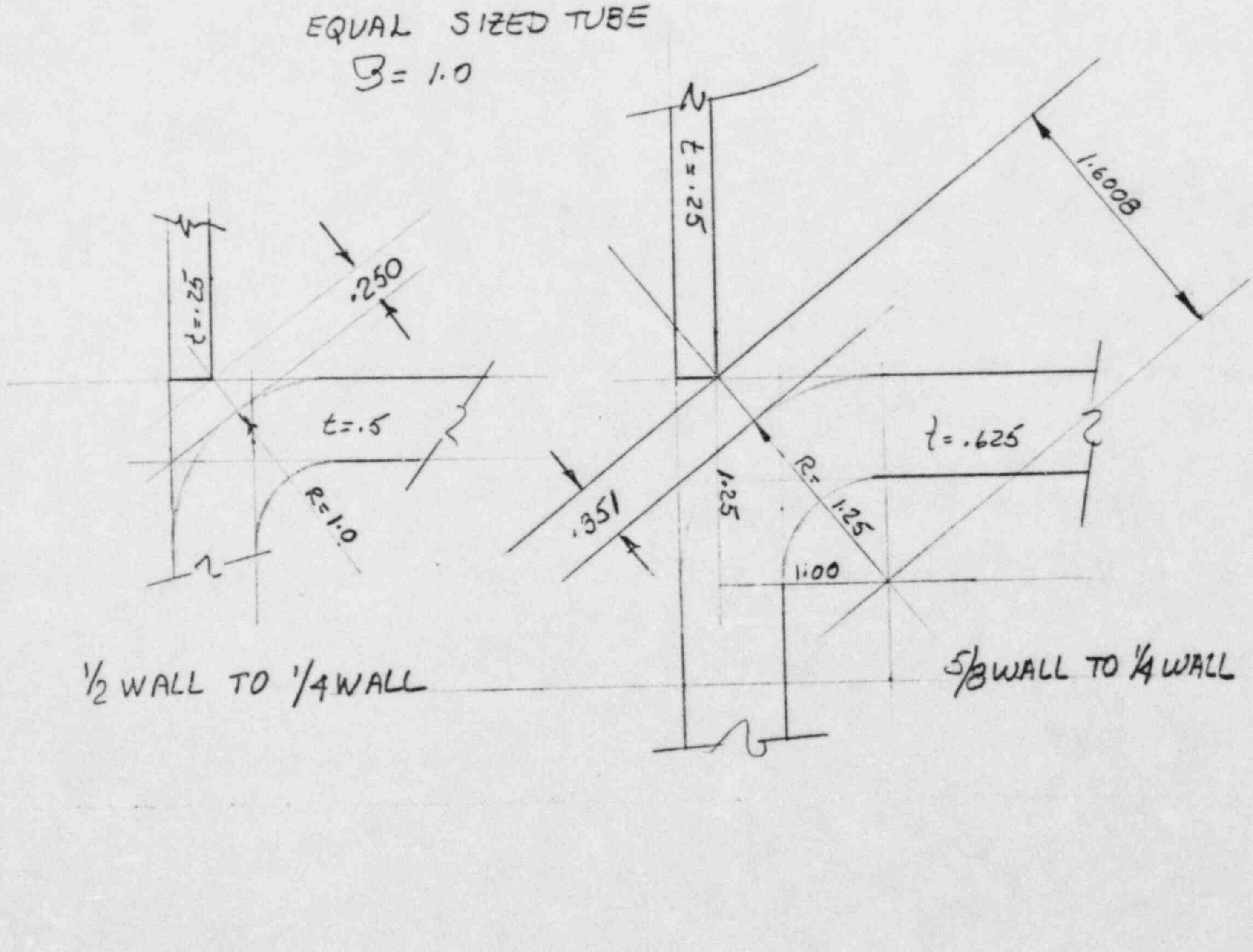
2.8 Plug Welds and Slot Welds

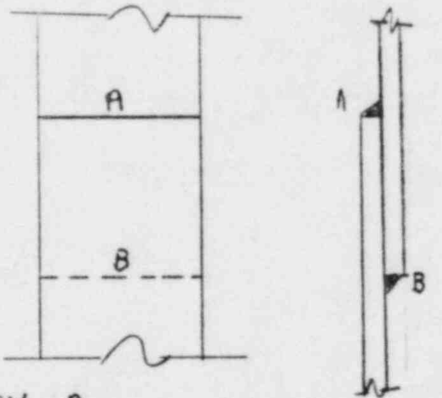
Plug and slot welds conforming to the dimensional requirements of 2.8, welded by techniques prescribed in Appendix A, and using materials approved by 8.2, 9.2, or 10.2, are considered prequalified and may be used without performing joint welding procedure qualification tests.

2.9.4–2.10.5 Corner Joint Details. 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 Fig. C2.9.4.

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 Figs. 2.9.1 and 2.10.1. 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 Fig. C2.9.4, 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).

CASE EXHIBIT 910





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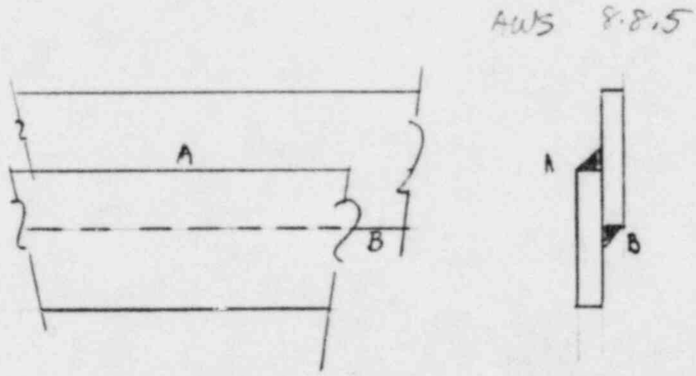

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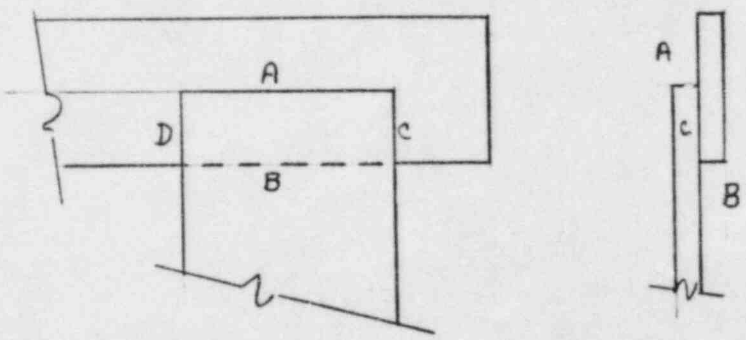

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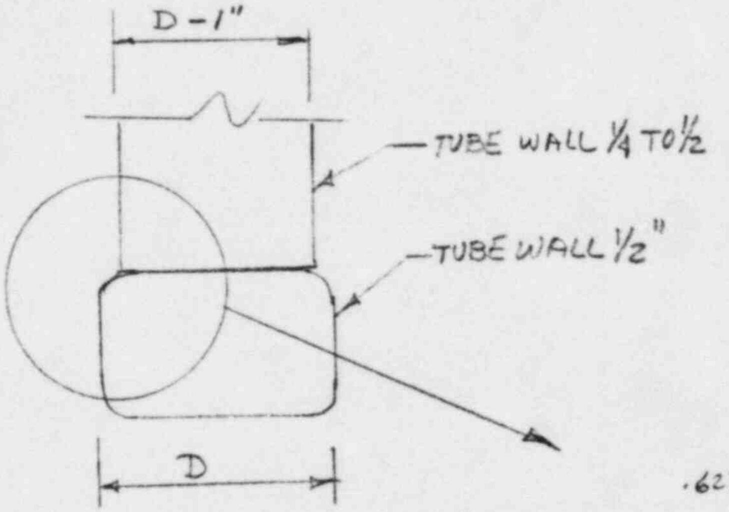

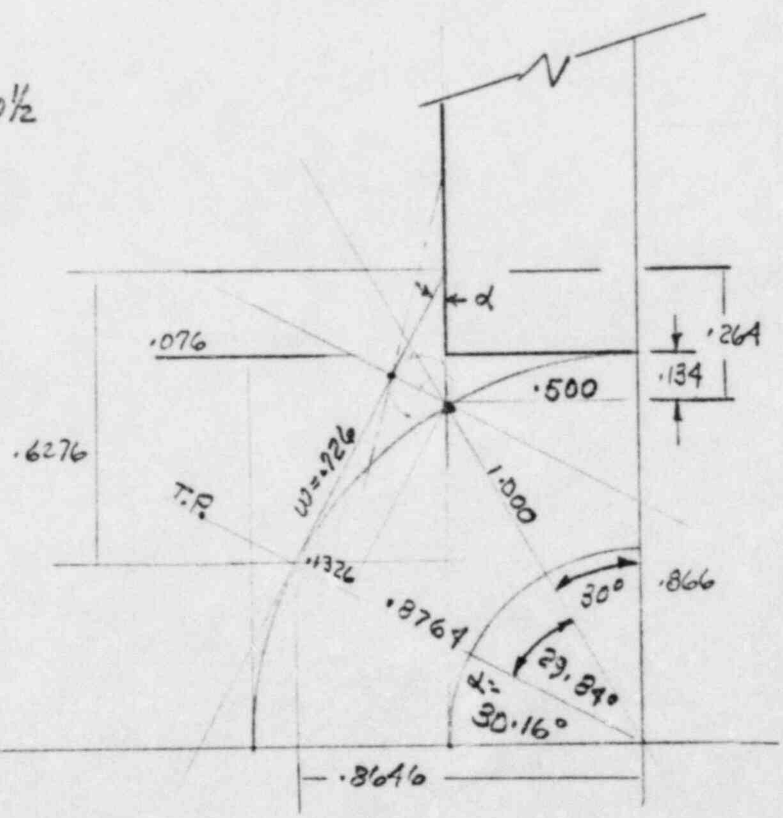

CASE EXHIBIT 950

DESIGN OF WELDED STRUCTURES

BY

Omer W. Blodgett

THE JAMES F. LINCOLN ARC WELDING FOUNDATION
CLEVELAND, OHIO

Progress Through Study

preferred analysis listed. Sulphur content of these steels is usually below 0.035%, although the specification limits permit as much as 0.050%.

Continued progress is being made in metallurgical control of steel, as well as in the development of welding processes, electrodes and fluxes. This tends to broaden the range of "weldability" with respect to steel analysis.

The six basic ASTM-specification construction steels usually do not require special precautions or special procedures.

However, when welding the thi er plates in even these steels the increased rigidity and restraint and the drastic quench effect makes the use of the proper procedure vitally important. In addition, thick plates usually have higher carbon content.

We also have an increase in the use of higher strength low alloy steels and the heat treated very high yield strength steels. These steels have some elements in their chemistry that exceed the ideal analysis. Table 1. for high speed welding.

Frequently pre-planned and proven welding procedures are required to assure the production of crack-free welds when joining thicker plates or the oy steels. These procedures usually call for one or a of the following:

1. Proper bead shape and joint configuration.
2. Minimized penetration to prevent dilution of the weld metal with the alloy elements in the plate.
3. Preheating, controlled interpass temperature and sometimes even controlled heat input from the welding procedure to retard the cooling rate and reduce shrinkage stresses.

3. BASE PROCEDURE ON ACTUAL ANALYSIS

Published standard production welding procedures generally apply to normal welding conditions and the more common, "preferred analysis" mild steels.

When a steel's specification analysis falls outside the preferred analysis, the user often adopts a special welding procedure based on the *extremes* of the material's chemical content "allowed" by the steel's specification. However, since the chemistry of a specific heat of steel may run far below the top limit of the "allowables", a special procedure may not be required, or may require only a slight change from standard procedures and thereby minimize any increase in welding cost.

TABLE 1—Preferred Analysis Of Carbon Steel for Good Weldability

Element		Normal Range, %	Steel Exceeding Any One of the Following Percentages Will Probably Require Extra Care
Carbon	C	.06 - .25	.35
Manganese	Mn	.35 - .80	1.40
Silicon	Si	.10 max	.30
Sulphur	S	.035 max	.050
Phosphorus	P	.030 max	.040

For optimum economy and quality, under either favorable or adverse conditions, the welding procedure for joining any type of steel should be based on the steel's *actual* chemistry rather than the *maximum* alloy content allowed by the specification. This is because a mill's average production normally runs considerably under the maximum limits set by the specification.

Usually a Mill Test Report is available which gives the *specific* analysis of any given heat of steel. Once this information is obtained, a welding procedure can be set that will assure the production of crack-free welds at the lowest possible cost.

4. WELD QUALITY

The main objective of any welding procedure is to join the pieces as required with the most efficient weld possible and at the least possible cost. "As required" means the weld's size and quality must be consistent with the service requirements. Excessive precautions to obtain unnecessary quality, beyond that needed to meet service requirements, serve no practical purpose and can be expensive.

Because it greatly increases cost without any benefit, inspection should not request the correction of slight undercut or minor radiographic defects such as limited scattered porosity and slag inclusions, unless thorough study shows such defects cannot be tolerated because of specific service requirements.

Why Welds Crack and How to Prevent It

5. WELD CRACKS

A crack in a weld, however, is never minor and cannot be condoned. Good design and proper welding procedure will prevent these cracking problems:

1. weld cracks occurring during welding,
2. cracking in the heat affected zone of the base metal,
3. welded joints failing in service.

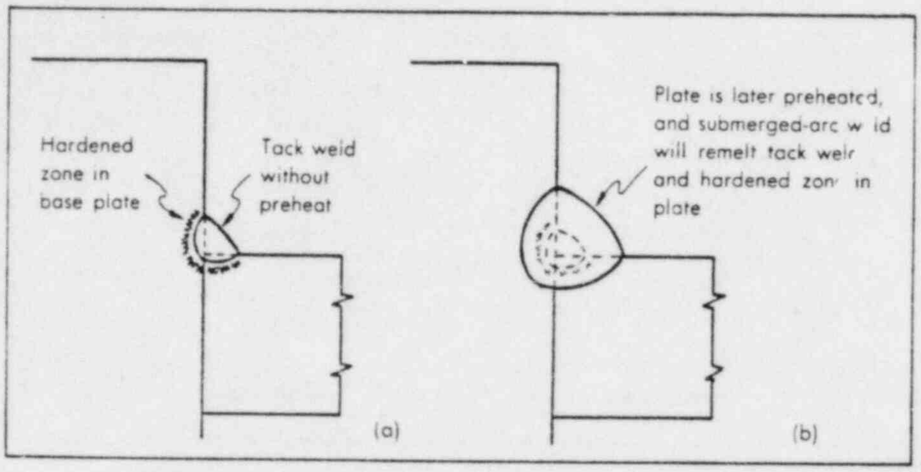

FIGURE 1

Factors that Affect Weld Cracking During Welding

1. *Joint Restraint* that causes high stresses in the weld.

2. *Bead Shape* of the deposited weld. As the hot weld cools, it tends to shrink. A convex bead has sufficient material in the throat to satisfy the demands of the biaxial pull. However, a concave bead may result in high tensile stresses across the weld surface from toe to toe. These stresses frequently are high enough to rupture the surface of the weld causing a longitudinal crack.

An excessively penetrated weld with its depth greater than its width under conditions of high restraint may cause internal cracks.

Both of these types of cracking are greatly aggravated by high sulphur or phosphorus content in the base plate.

3. *Carbon and Alloy Content* of the base metal. The higher the carbon and alloy content of the base metal, the greater the possible reduction in ductility of the weld metal through admixture. This contributes appreciably to weld cracking.

4. *Hydrogen Pickup* in the weld deposit from the electrode coating, moisture in the joint, and contaminants on the surface of the base metal.

5. *Rapid Cooling Rate* which increases the effect of items 3 and 4.

Factors that Affect Cracking in the Heat-Affected Zone

1. *High carbon or alloy content* which increases hardenability and loss of ductility in the heat-affected zone. (Underbead cracking does not occur in non-hardenable steel.)

2. *Hydrogen embrittlement* of the fusion zone through migration of hydrogen liberated from the weld metal.

3. *Rate of cooling* which controls items 1 and 2.

Factors that Affect Welded Joints Failing in Service

Welds do not usually "crack" in service but may "break" because the weld was of insufficient size to fulfill service requirements. Two other factors would be:

1. Notch toughness,* which would affect the breaking of welds or plate when subjected to high impact loading at extremely low temperatures.

2. Fatigue cracking* due to a notch effect from poor joint geometry. This occurs under service conditions of unusually severe stress reversals.

Items to Control

1. *Bead Shape.* Deposit beads having proper bead surface (i.e. slightly convex) and also having the proper width-to-depth ratio. This is most critical in the case of single pass welds or the root pass of a multiple pass weld.

2. *Joint Restraint.* Design weldments and structure to keep restraint problems to a minimum.

3. *Carbon and Alloy Content.* Select the correct grade and quality of steel for a given application, through familiarity with the mill analysis and the cost of welding. This will ensure balancing weld cost and steel price using that steel which will develop the lowest possible overall cost. Further, this approach will usually avoid use of inferior welding quality steels that have excessively high percentages of those elements that always adversely affect weld quality—sulphur and phosphorus.

Avoid excessive admixture. This can be accomplished through procedure changes which reduce penetration (different electrodes, lower currents, changing

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* Neither notch toughness nor fatigue cracking are discussed here. See Section 2.1, "Properties of Materials," Section 2.8, "Designing for Impact Loads, and Section 2.9, "Designing for Fatigue Loads."

polarity, or improving joint design such as replacing a square edge butt weld with a bevel joint.)

4. *Hydrogen Pickup.* Select low-hydrogen welding materials.

5. *Heat Input.* Control total heat input. This may include preheat, welding heat, heating between weld passes to control interpass temperature and post heating to control cooling rate. Control of heat input lowers the shrinkage stresses and retards the cooling rate helping to prevent excessive hardening in the heat-affected zone, two primary causes of cracking.

6. TACK WELDS

The American Welding Society's Building Code and Bridge Specifications both require any tack welds that will be incorporated into the final joint, to be made under the same quality requirements, including preheat, as the final welds.

However, this does not recognize the deep penetration characteristics of some welding processes, for example, submerged-arc. If the initial tack welds are relatively small compared to the first submerged-arc weld pass, they will be entirely remelted along with the adjacent heat-affected area in the plate.

In this case, no preheat should be required for small single pass tack welds unless the plates are so thick and restrained that the tack welds are breaking. See Figure 1. If the tack welds are breaking, the corrective measures previously listed relating to bead shape and weld throat should be applied with preheating called for as a last resort. It is always a good idea to use low-hydrogen welding materials for tack welding plates over 1 in. thick.

7. THINNER PLATE

Welds that join thinner plates rarely show a tendency to crack. The heat input during welding and lack of mass of the thinner plate create a relatively slow cooling rate. This, plus the reduced internal stresses resulting from a good weld throat to plate thickness ratio and the fact that the thinner plate is less rigid and can flex as the weld cools and shrinks, controls the factors that induce cracking. Cracking is almost never a factor on thinner plate unless unusually high in carbon or alloy content.

8. THICK PLATES

In the steel mill, all steel plates and rolled sections undergo a rather slow rate of cooling after being rolled while red hot. The red hot thick sections, because of their greater mass, cool more slowly than thin sections. For a given carbon and alloy content, slower cooling from the critical temperature results in a slightly lower strength.

For the normal thicknesses, the mill has no difficulty in meeting the minimum yield strength required. However, in extremely thick mill sections, because of their slower cooling, the carbon or alloy content might have to be increased slightly in order to meet the required yield strength.

Since a weld cools faster on a thick plate than on

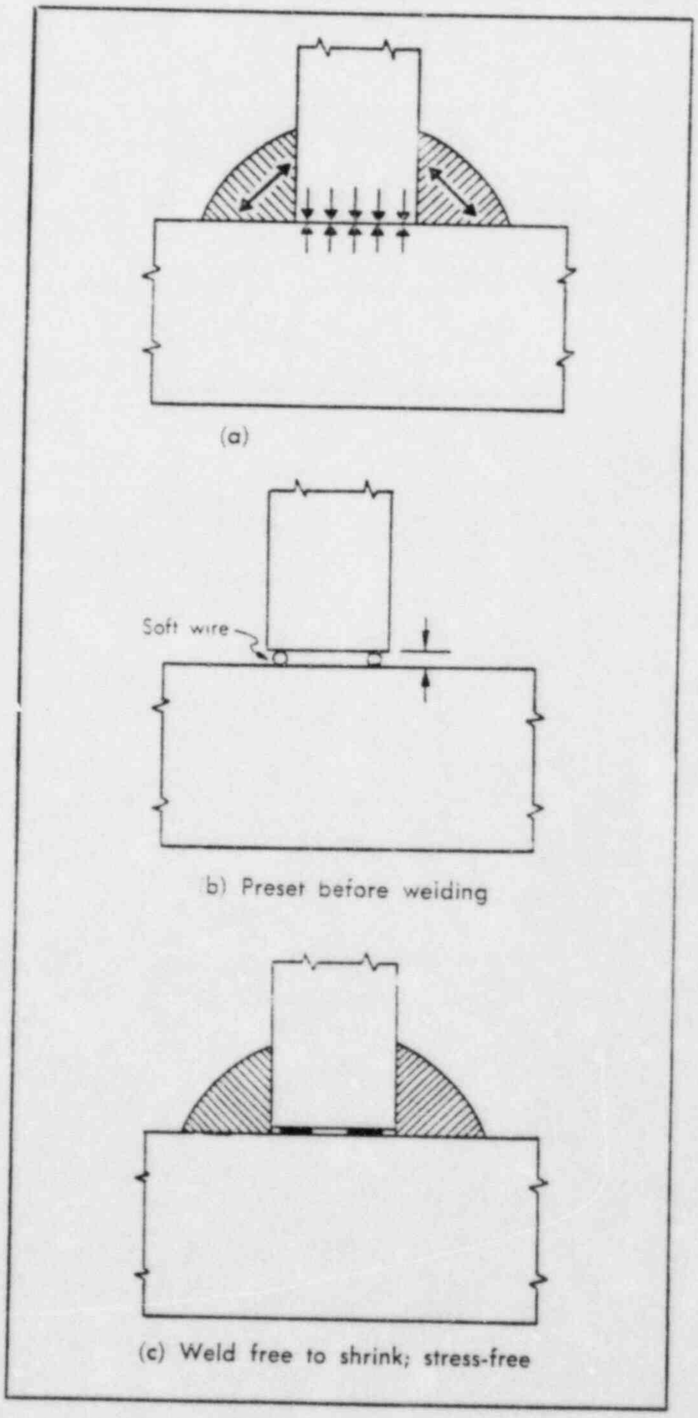

FIGURE 2

a thinner plate, and since the thicker plate will probably have a slightly higher carbon or alloy content, welds on thick plate (because of admixture and fast cooling) will have higher strengths but lower ductility than those made on thinner plate. Special welding procedures may be required for joining thick plate (especially for the first or root pass), and preheating may be necessary. The object is to decrease the weld's rate of cooling so as to increase its ductility.

In addition to improving ductility, preheating thick plates tends to lower the shrinkage stresses that develop because of excessive restraint.

Because of its expense, preheating should be selectively specified, however. For example, fillet welds joining a thin web to a thick flange plate may not require as much preheat as does a butt weld joining two highly restrained thick plates.

On thick plates with large welds, if there is metal-to-metal contact prior to welding, there is no possibility of plate movement. As the welds cool and contract, all the shrinkage stress must be taken up in the weld, Figure 2(a). In cases of severe restraint, this may cause the weld to crack, especially in the first pass on either side of the plate.

By allowing a small gap between the plates, the plates can "move in" slightly as the weld shrinks. This reduces the transverse stresses in the weld. See Figures 2(b) and 2(c). Heavy plates should always have a minimum of 1/32" gap between them, if possible 1/16".

This small gap can be obtained by means of:

1. Insertion of spacers, made of soft steel wire between the plates. The soft wire will flatten out as the weld shrinks. If copper wire is used, care should be taken that it does not mix with the weld metal.

2. A deliberately rough flame-cut edge. The small peaks of the cut edge keep the plates apart, yet can squash out as the weld shrinks.

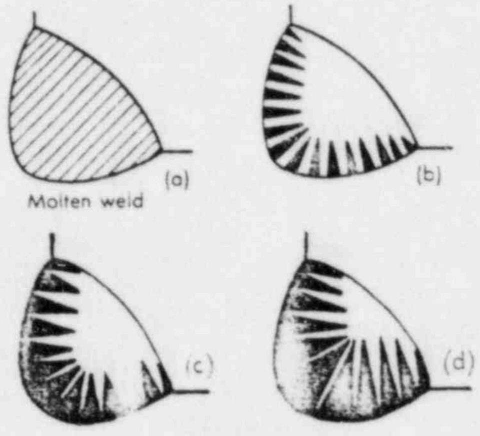

FIGURE 3

3. Upsetting the edge of the plate with a heavy center punch. This acts similar to the rough flame-cut edge.

The plates will usually be tight together after the weld has cooled.

Fillet Welds

The above discussion of metal-to-metal contact and shrinkage stresses especially applies to fillet welds. A slight gap between plates will help assure crack-free fillet welds.

Bead shape is another important factor that affects fillet weld cracking. Freezing of the molten weld, Figure 3(a), due to the quenching effect of the plates commences along the sides of the joint (b) where the cold mass of the heavy plate instantly draws the heat out of the molten weld metal and progresses uniformly inward (c) until the weld is completely solid (d). Notice that the last material to freeze lies in a plane along the centerline of the weld.

To all external appearances, the concave weld (a) in Figure 4 would seem to be larger than the convex weld (b). However, a check of the cross-

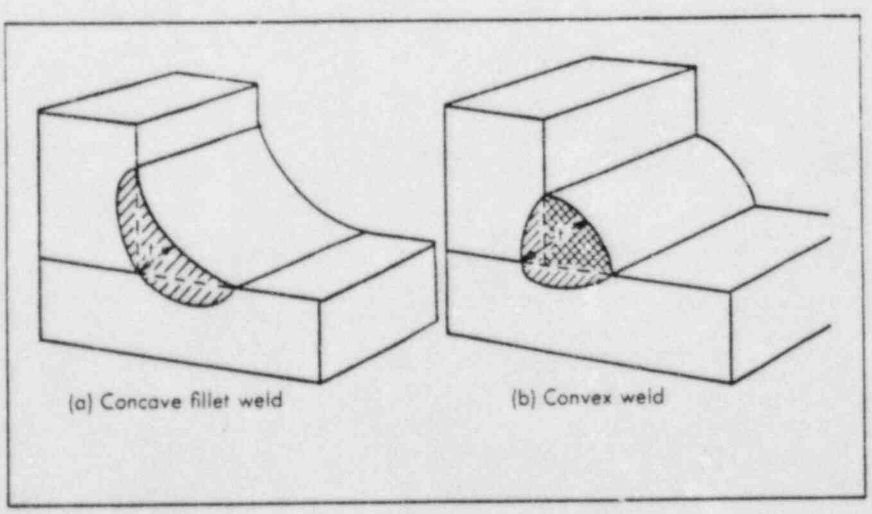

FIGURE 4

section may show the concave weld to have less penetration and a smaller throat (t) than first thought; therefore, the convex weld may actually be stronger even though it may have less deposited metal (darker cross-section).

Designers originally favored the concave fillet weld because it seemed to offer a smoother path for the flow of stress. However, experience has shown that single-pass fillet welds of this shape have a greater tendency to crack upon cooling, which unfortunately usually outweighs the effect of improved stress distribution. This is especially true with steels that require special welding procedures.

When a concave fillet weld cools and shrinks, its outer face is stressed in tension, Figure 5(a). If a surface shrinkage crack should occur, it can usually be avoided by changing to a convex fillet (b). Here the

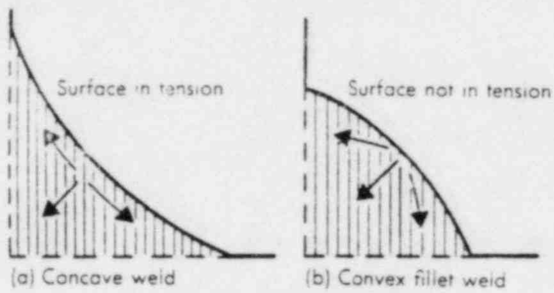

FIGURE 5

weld can shrink, while cooling, without stressing the outer face in tension and should not crack. For multiple-pass fillet welds, the convex bead shape usually applies only to the first pass.

For this reason, when concave welds are desired for special design considerations, such as stress flow, they should be made in two or more passes—the first slightly convex, and the other passes built up to form a concave fillet weld.

9. GROOVE WELDS

On heavy plate, it is usually the first (or root) pass of a groove weld that requires special precautions. This is especially true of the root weld on the back side of a double Vee joint because of the added restraint from the weld on the front side. The weld tends to shrink in all directions as it cools, but is restrained by the plate. Not only are tensile shrinkage stresses set up within the weld, but the weld frequently undergoes plastic yielding to accommodate this shrinkage.

Some idea of the possible locked-in stress and plastic flow of the weld may be seen in Figure 6. Imagine the plate to be cut near the joint, allowing the weld to freely shrink (dotted lines). Then pull the plates back to the original rigid position that they would normally be in during and after welding (solid lines). This necessitates a stretching of the weld.

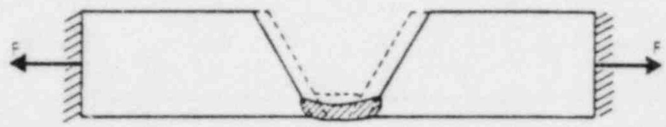

FIGURE 6

In actual practice all of this stretch or yielding can occur only in the weld, since the plate cannot move and the weld has the least thickness of the joint. Most of this yielding takes place while the weld is hot and has lower strength and ductility. If, at this time, the internal stress exceeds the physical properties of the weld, a crack occurs which is usually down the centerline of the weld.

The problem is enhanced by the fact that the first (or root) bead usually picks up additional carbon or alloy by admixture with the base metal. The root bead thus is less ductile than subsequent beads.

A concave bead surface in a groove weld creates the same tendency for surface cracking as described for fillet welds, Figure 7. This tendency is further increased with lower ductility.

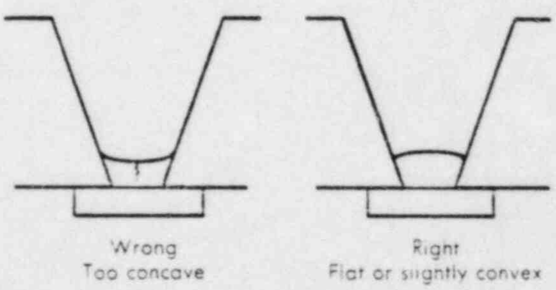

FIGURE 7

Increasing the throat dimension of the root pass will help to prevent cracking; use electrodes or procedures that develop a convex bead shape. Low hydrogen welding materials are sometimes useful and finally preheat can be specified. Obviously preheating should be adopted as a last resort since it will cause the greatest increase in weld cost.

The problem of centerline cracking can even occur in the succeeding passes of a multiple pass weld if the passes are excessively wide or concave. Corrective measures call for a procedure that specifies a narrower slightly convex bead shape, making the completed weld two or more beads wide, side by side, Figure 8.

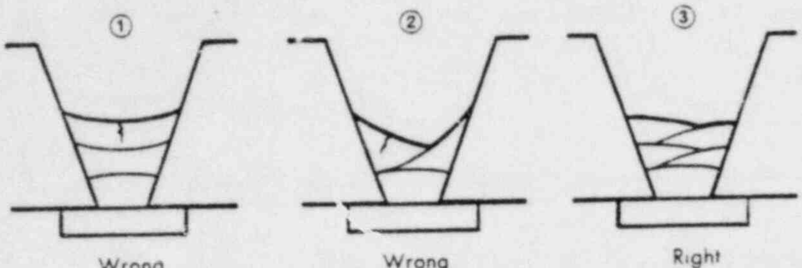

FIGURE 8

10. INTERNAL CRACKS AND WELD WIDTH TO DEPTH OF FUSION RATIO

Where a cracking problem exists due to joint restraint, material chemistry or both, the crack usually appears at the weld's face. In some situations, however, an internal crack can occur which won't reach the weld's face. This type of crack usually stems from the misuse of a welding process that can achieve deep penetration, or poor joint design.

The freezing action for butt and groove welds is the same as that illustrated for fillet welds. Freezing starts along the weld surface adjacent to the cold base metal, and finishes at the centerline of the weld. If, however, the weld depth of fusion is much greater than width of the face, the weld's surface may freeze in advance of its center. Now the shrinkage forces will act on the still hot center or core of the bead which could cause a centerline crack along its length without this crack extending to the weld's face, Figure 9(a).

Internal cracks can also result with improper joint design or preparation. Figure 9(b) illustrates the results of combining thick plate, a deep penetrating welding process, and a 45° included angle.

A small bevel on the second pass side of the double-V-groove weld, Figure 9(c), and arc gouging a groove too deep for its width, led to the internal crack illustrated.

Internal cracks can also occur on fillet welds if the depth of fusion is sufficiently greater than the face width of the bead, Figure 9(d).

Although internal cracks are most serious since they cannot be detected with visual inspection methods, a few preventive measures can assure their elimination. Limiting the penetration and the volume of weld metal deposited per pass through speed and amperage control and using a joint design which sets reasonable depth of fusion requirements are both steps in the right direction.

In all cases, however, the critical factor that helps control internal cracks is the ratio of weld width to depth. Experience shows that the weld width to depth of fusion ratio can range from a minimum of 1 to 1 to a maximum of 1.4 to 1.

$$\frac{\text{Width of Weld}}{\text{Depth of Fusion}} = 1 \text{ to } 1.4$$

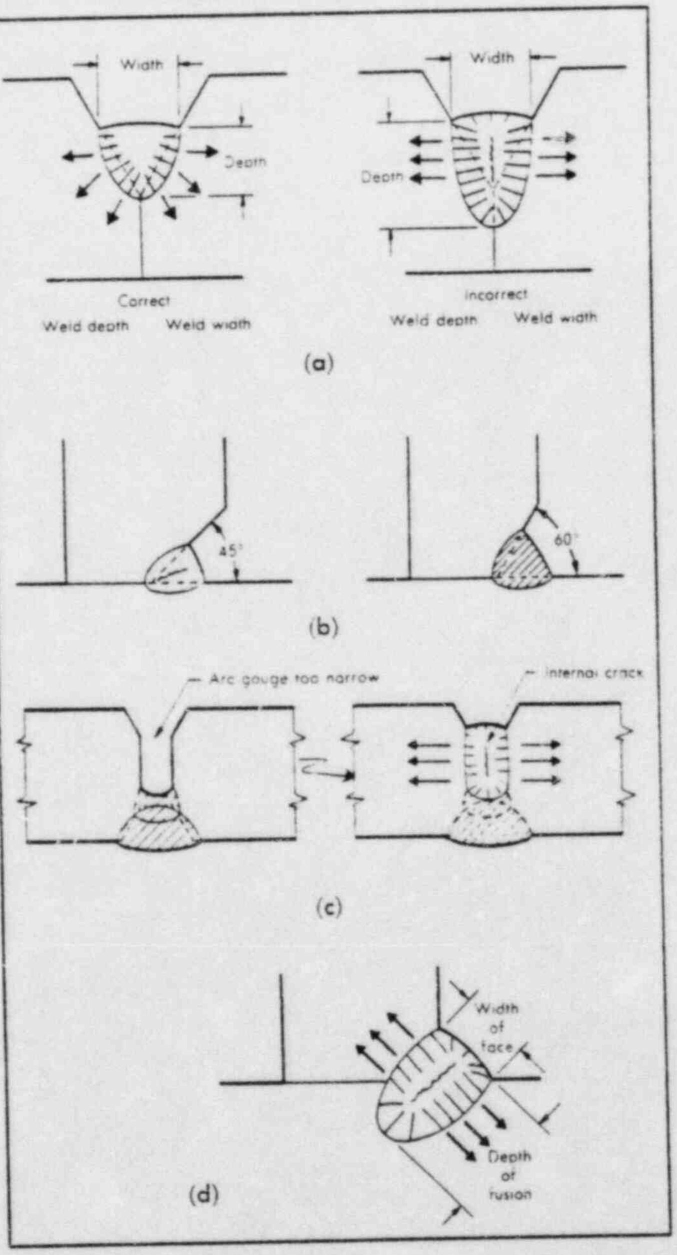

FIGURE 9

11. UNDERBEAD CRACKING

Underbead cracking is not a problem with the controlled analysis low carbon steels. This problem if it occurs is in the heat-affected zone of the base metal. It can become a factor with thick plate as the carbon or alloy content of the steel increases. As an exampl this can occur with the heat treatable very hig strength, high carbon low alloy steels like 4140 or 6150. The construction alloy steels which have over 100,000 psi tensile strength and are heat treated before welding, also can experience underbead cracking in thick plates. When armour plate was used, underbead cracking (toe cracks) was a problem. The point is that the problem is only important on hardena le steels.

Low-hydrogen processes should be used to join these materials since one cause of underbead cracking is hydrogen embrittlement in the heat-affected zone. Hydrogen in the welding arc, either from the electrode coating or from wet or dirty plate surfaces, will tend be partially absorbed into the droplets of weld metal being deposited and absorbed into the molten metal beneath the arc.

As the welding arc progresses along the plate, the deposited hot weld metal (which has now solidified) and the adjacent base metal heated by the weld above the transformation temperature are both austenitic at this elevated temperature, and have a high solubility for hydrogen. Fortunately, a considerable amount of hydrogen escapes through the weld's surface into the air; however, a small amount may diffuse back through the weld into the adjacent base metal. (The rate of diffusion decreases with decreasing temperature.)

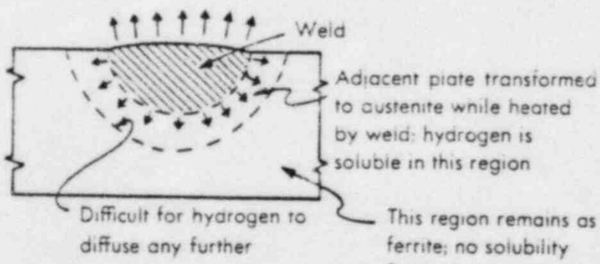

FIGURE 10

Beyond the boundary of the heat-affected zone, the base metal is in the form of ferrite, which has practically no solubility for hydrogen. This ferrite boundary becomes an imaginary fence, and the hydrogen tends to pile up here, going no farther. See Figure 10.

Upon further cooling, the heat-affected area transforms back to ferrite with almost no solubility for hydrogen. Any hydrogen present tends to separate out between the crystal lattice and builds up pressure. This pressure, when combined with shrinkage stresses and any hardening effect of the steel's chemistry, may cause tiny cracks. Since weld metal is usually of a lower carbon than the base plate, this trouble occurs mainly just beyond the weld along the austenite-ferrite boundary and is called "underbead cracking" See Figure 11. If some of these cracks appear on the plate surface adjacent to the weld, they are called "toe cracks". Slower cooling by welding slower and preheating allows hydrogen to escape and helps control this problem.

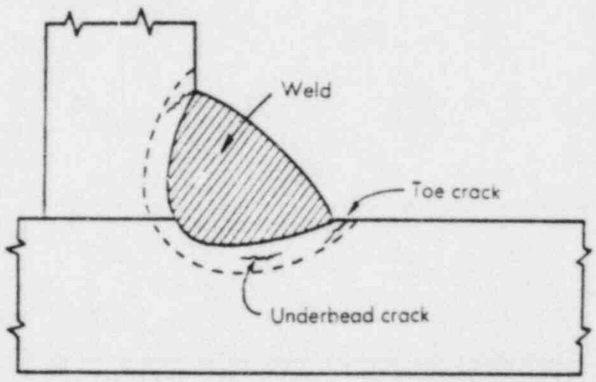

FIGURE 11

The use of low-hydrogen welding materials eliminates the major source of hydrogen and usually eliminates underbead cracking.

12. SUMMARY ON CRACKING

The first requirement of any welded joint is to be crack-free. Cracking may occur in either the weld metal or the heat-affected zone of the base plates.

Most steels can be welded in the average plate thickness without worrying about weld cracking.

As plate thickness increases, and as the carbon and alloying content increase, weld cracks and underbead cracks may become problems and require special precautions for their control.

This necessitates in order of importance: a) good welding procedure, especially in respect to bead shape, control of admixture, b) reducing rigidity by intentional spacing of plates, c) use of low-hydrogen welding materials, and d) controlled cooling rate, including welding current and travel speed, and if needed control of preheat and interpass temperature.

Why Preheat and How to Determine Correct Preheat Temperature

13. WHEN AND WHY TO PREHEAT

Preheating, while not always necessary, is used for one of the following reasons:

1. To reduce shrinkage stresses in the weld and adjacent base metal; especially important in highly restrained joints.

2. To provide a slower rate of cooling through the critical temperature range (about 1800° F to 1330° F) preventing excessive hardening and lowered ductility in both weld and heat-affected area of the base plate.

3. To provide a slower rate of cooling through the 400°F range, allowing more time for any hydrogen that is present to diffuse away from the weld and adjacent plate to avoid underbead cracking.

4. To increase the allowable critical rate of cooling below which there will be no underbead cracking. Thus, with the welding procedure held constant, a higher initial plate temperature increases the maximum safe rate of cooling while slowing down the actual rate of cooling. This tends to make the heat input from the welding process less critical.

Cottrell and Bradstreet* show the following critical cooling rates (R_{cr}) for a given steel at 572°F (300°C) using low-hydrogen electrode in order to prevent underbead cracking for various preheats to be:

T_o (°F)	R_{cr} (°F/sec)
−58	6.8 — 9.9
68	8.6 — 11.7
212	21.6 — 37.8

5. To increase the notch toughness in the weld zone.

6. To lower the transition temperature of the weld and adjacent base metal.

Normally, not much preheat is required to prevent underbead cracking. This is held to a minimum when low-hydrogen welding materials are used. Higher preheat temperature might be required for some other reason, e.g. a highly restrained joint between very thick plates, or a high alloy content.

Preheating makes other factors less critical, but since it invariably increases the cost of welding, it cannot be indulged in unnecessarily.

* Cottrell and Bradstreet, "Effect of Preheat on Weldability", BRITISH WELDING JOURNAL, July 1955, p. 309.

14. AWS MINIMUM REQUIREMENTS

The AWS has set up minimum preheat and interpass requirements given in Table 2.

These minimum preheat requirements may need to be adjusted, according to welding heat input, specific steel chemistry, the joint geometry, and other factors.

TABLE 1—AWS Minimum Initial and Interpass Temperatures[1,2] (1966)

Thickness of Thickest Part at Point of Welding (inches)	Welding Process: Shielded Metal-Arc Welding with Other than Low-Hydrogen Electrodes A36[3], A7[3], A373[3]	Welding Process: Shielded Metal-Arc Welding with Low-Hydrogen Electrodes and Submerged Arc Welding A36[4], A7[4], A373[4], A441[4] A242[5] Weldable Grade
To ¾, incl.	none[3]	none[6]
Over ¾ to 1½, incl.	150°F	70°F
Over 1½ to 2½, incl.	225°F	150°F
Over 2½	300°F	225°F

[1] Welding shall not be done when the ambient temperature is lower than 0°F.
[2] When the base metal is below the temperature listed for the welding process being used and the thickness of material being welded, it shall be preheated for both tack welding and welding in such manner that the surfaces of the parts on which weld metal is being deposited are at or above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 inches, both laterally and in advance of the welding. Preheat temperature shall not exceed 400°F. (Interpass temperature is not subject to a maximum limit.)
[3] Using E60XX or E70XX electrodes other than the low-hydrogen types.
[4] Using E60XX or E70XX low-hydrogen electrodes (EXX15, -16, -18, -28) or Grade SAW-1 or SAW-2.
[5] Using only E70XX low-hydrogen electrodes (E7015, E7016, E7018, E7028) or Grade SAW-2.
[6] When the base metal temperature is below 32°F, preheat the base metal to at least 72°F.

15. HEAT INPUT DURING WELDING

One factor that would reduce preheat requirements is the use of greater welding heat input; for example, the welding heat input for vertical welding with weave passes at an arc speed of 3 in./min. is greater than that of horizontal welding with stringer beads at 6 in./min. The heat input (J) for a specific welding procedure can be determined using the formula:

$$J = \frac{E\ I\ 60}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

J = Heat input in Joules/in. or watt-sec/in.
E = Arc voltage in volts
I = Welding current in amps
V = Arc speed in in./min

Since all of the welding heat input at the arc does not enter the plate, the following heat efficiencies are suggested for use with this formula and subsequent formulas, charts or nomographs:

75-80% manual welding

90-100% submerged arc welding

Most preheat and interpass temperature recommendations are set up for manual welding where there is a relatively low heat input. For example, a current of 200 amps and a speed of 6 in./min. would produce a welding heat input of about 48,000 joules/in. or watt-sec./in., assuming an efficiency of 80 percent. Yet, it might be necessary to weld a 12-gauge sheet to this plate in the vertical down position with 180 amps and a speed of 22 in./min. This would reduce the welding heat input to 9800 joules/in. If this were a thick plate, it would indicate the need, with this second procedure, for more preheat, although existing preheat tables do not recognize the effect of different welding heat inputs.

On the other hand, some downward adjustment in preheat from the value listed in the preheat tables should be made for standard welding procedures which provide a much greater welding heat input. We are considering here a stable heat-flow condition after some welding has progressed.

This does not consider the more severe cooling conditions at the moment welding commences. Undoubtedly, some initial heat could be supplied to a localized area at the start of the weld on thick plate. The question now becomes how much, if any, preheat is needed for the remaining length of joint.

For example, it is standard practice today to use submerged-arc automatic welding to build up columns and girders from heavy plate. One method of fabrication uses a single-arc, submerged-arc automatic weld at 850 amps and a speed of 20 in./min. (for a ⅜" fillet weld), with the girder positioned for flat welding. This would provide a heat input of 86,000 joules/in. An alternate method positions the girder with its web vertical so that both welds are made simultaneously in the horizontal position, and uses two sets of tandem arcs (each set with two welding heads); the heat input from each arc would be 73,600 joules/in.—a total of 147,000 joules/in. of weld for each fillet. Because of the resulting lower cooling rate, less preheat should be required once the weld has been started. This may be a considerable advantage for the comfort of welding operators, especially when welding inside large box girders.

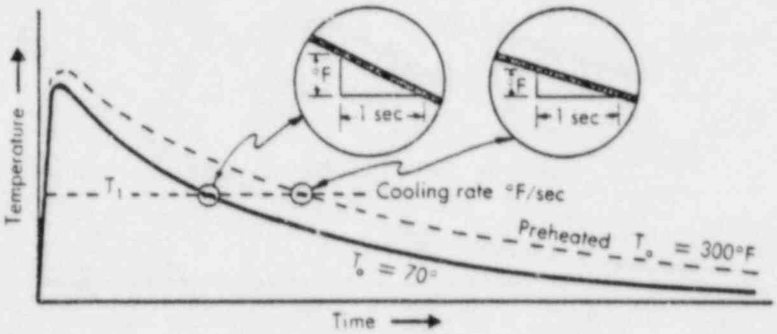

FIGURE 12

16. COOLING RATE

When a weld is made, the weld and adjacent plate cool very rapidly. The rate of cooling depends *first* on the combination of initial plate temperature (T_o) (including effects of preheat or interpass temperature) and the welding heat input (J), and *secondly*, on the plate's capacity to absorb this heat in terms of plate thickness and joint geometry.

Figure 12 illustrates the temperatures in the heat-affected zone of the plate as the welding arc passes by. Under a given set of conditions, the cooling rate will vary as represented by the changing slopes of both curves.

For a particular chemistry, at a given temperature level (T_1) there is a critical cooling rate (R_{cr}) which should not be exceeded in order to avoid underbead cracking. This temperature level is in the range of 400°F to 750°F. American investigators tend to use a higher value such as 750°, while English and Canadian investigators favor a lower value such as 300°C, or 572°F. In this discussion, we have placed this temperature level (T_1) at 572°F.

The investigation of cooling rates has been based largely on two extreme conditions, which have been developed mathematically.* These are:

1. The *thin plate*, in which the combination of

heat input and plate size permit assuming the temperature to be uniform throughout the thickness at any point; in other words, heat flows transversely in only two axes. See Figure 13.

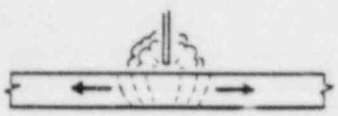

FIGURE 13

thin plate

$$R = K_1 \left(\frac{t}{J}\right)^2 (T_1 - T_o)^3 \qquad \ldots\ldots\ldots\ldots (2)$$

2. The *thick plate*, in which the combination of heat input and plate size permit assuming the bottom surface of the plate does not increase in temperature; in other words, heat flows transversely in three axes. See Figure 14.

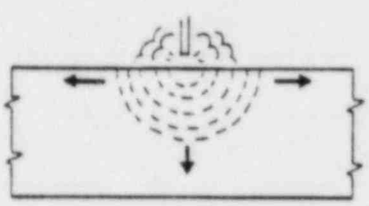

FIGURE 14

thick plate

$$R = \frac{K_2}{J}(T_1 - T_o)^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:

R = cooling rate at temperature (T_1), °F/sec

T_1 = temperature at which cooling rate is considered, 572°F

T_o = initial plate temperature or preheat temperature when preheating is used, °F

K = thermal conductivity (the BTU loss per hour per square foot of surface divided by the temperature gradient of °F per foot of thickness.)

(K = 25.9 for mild steel at 572°F)

K_1 = constant, representing K, ρ, C at T_1

(K_1 = 161.48 for mild steel at 572°F)

K_2 = constant, representing K at T_1

(K_2 = 5.961 for mild steel at 572°F)

ρ = density, lbs/ft³

(ρ = 489.6 lbs/ft³ for mild steel)

C = specific heat, BTU/lb/°F

(C = .136 BTU/lb/°F for mild steel)

t = actual plate thickness, in.

J = welding heat input (formula 1)

Unfortunately, there is no clear definition of what is a "thin plate" and what is a "thick plate" relative to cooling rate. The actual condition often lies somewhere between these two extremes, and for this reason a certain amount of judgment is needed. For example, welding on a 1" plate with submerged arc at a current of 1000 amps and a speed of 10 in./min. would approach a "thin plate" condition; yet manual welding vertically down on a ¾" plate at a current of 120 amps and a speed of 12 in./min. would approach a "thick plate" condition.

In Figure 15, these two basic formulas are plotted for a given set of conditions: heat input (J), and preheat and interpass temperature (T_o).

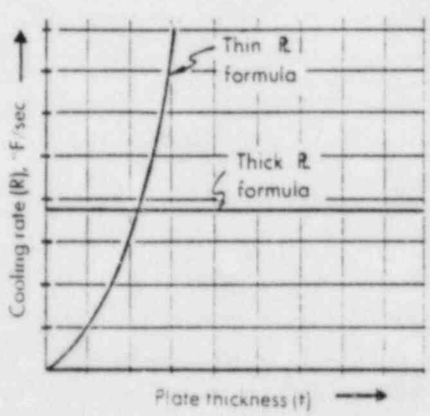

FIGURE 15

The formula for a "thin plate" recognizes the effect of plate thickness (t); and the resulting cooling rate (R) increases rapidly as the square of the plate thickness. When the cooling rate characteristics of a thick plate are studied, however, it soon becomes apparent that for a given welding procedure and an initial temperature, increasing the plate thickness beyond a certain dimension will not cause further change in the rate of cooling. For this reason, the formula for "thick plate"—Formula No. 3—does not include actual plate thickness (t) and the value of (R) does not vary with thickness but remains constant for a given

* D. Rosenthal, "Mathematical Theory of Heat Distribution During Cutting and Welding", WELDING JOURNAL, May 1941, p. 220-s.

heat input, preheat and interpass temperature. For a given heat input, the cooling rate indicated by the "thick plate" formula is the maximum (R_m) that can occur regardless of the plate thickness.

At any given plate thickness the lower cooling rate value is the more nearly correct. Using the two curves of Figure 15 as a limit and a guide, a new curve (solid line) has been drawn in Figure 16.

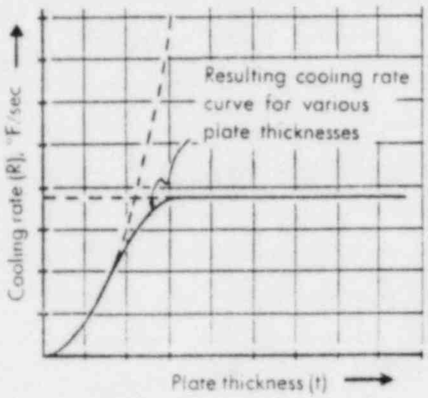

FIGURE 16

Notice, Figure 16, that the upper half of the variable part of this curve is almost a perfect reversal of the lower half, and the lower half belongs to the curve for the "thin plate". Therefore, the curved portions will be expressed mathematically as—

lower portion

$$R = 161.48 \left(\frac{t}{J}\right)^2 (572 - T_o)^3 \quad \dots\dots\dots (4)$$

upper portion

$$R = 5.961 \frac{(572 - T_o)^2}{J} \left(- 27.09\, t^2 \frac{(572 - T_o)}{J} + 14.72\, t \sqrt{\frac{572 - T_o}{J}} - 1 \right) \quad \dots\dots (5)$$

If a welding procedure for a given plate thickness lies in the lower portion of the curve, it is easy to solve directly for the required preheat (T_o) using formula (4); however, this would be very difficult for the upper portion using formula (5).

The chart is further limited in use since it only covers a single value of preheat and heat input. Therefore, to expand the application of this approach, we will put both formulas (4) and (5) into more usable non-dimension formulas (6) and (7). This calls for inclusion of the maximum effective plate thickness (t_{me}), and the corresponding maximum effective preheat ($T_{o/me}$) for this thickness.

lower portion

$$\frac{t}{t_{me}} = \sqrt{\frac{1}{2}\left(\frac{T_1 - T_{o/me}}{T_1 - T_o}\right)^3} \quad \dots\dots\dots\dots\dots (6)$$

upper portion

$$\frac{t}{t_{me}} = \sqrt{\frac{T_1 - T_{o/me}}{T_1 - T_o}} \left(1 - \frac{1}{\sqrt{2}} \sqrt{1 - \left(\frac{T_1 - T_{o/me}}{T_1 - T_o}\right)^2} \right) \quad \dots\dots (7)$$

where:

t = actual thickness of the plate, in.

t_{me} = maximum effective plate for given values of (J) and (R)

$$t_{me} = .4246 \sqrt[4]{\frac{J}{R}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots (8)$$

T_1 = elevated temperature at which cooling rate is considered (572°F)

T_o = preheat temperature for given values of (J), (R), and (t), °F

$T_{o/me}$ = maximum effective preheat temperature for a given value of (J) and (R), °F

$$T_1 - T_{o/me} = \sqrt{\frac{R\,J}{5.961}} \quad \dots\dots\dots\dots\dots\dots\dots (9)$$

Formulas (6) and (7) produced the curve shown in Figure 17. This can be used to determine T_o the required preheat temperature.

17. BI-THERMAL VS. TRI-THERMAL HEAT FLOW

This work is based upon bi-thermal heat flow where the heat has two avenues for escape; for example, a conventional butt joint consisting of two plates, Figure 18(a).

Tri-thermal heat flow has three avenues for escape, an example is a tee joint made of three plates, Figure 18(b).

Where tri-thermal heat flow condition exists, the above work should be modified either by:

1. Using ⅔ of the actual heat input (J), or
2. Adjusting the plate thickness (t) to allow for the extra plate by using ½ of the sum of three thicknesses.

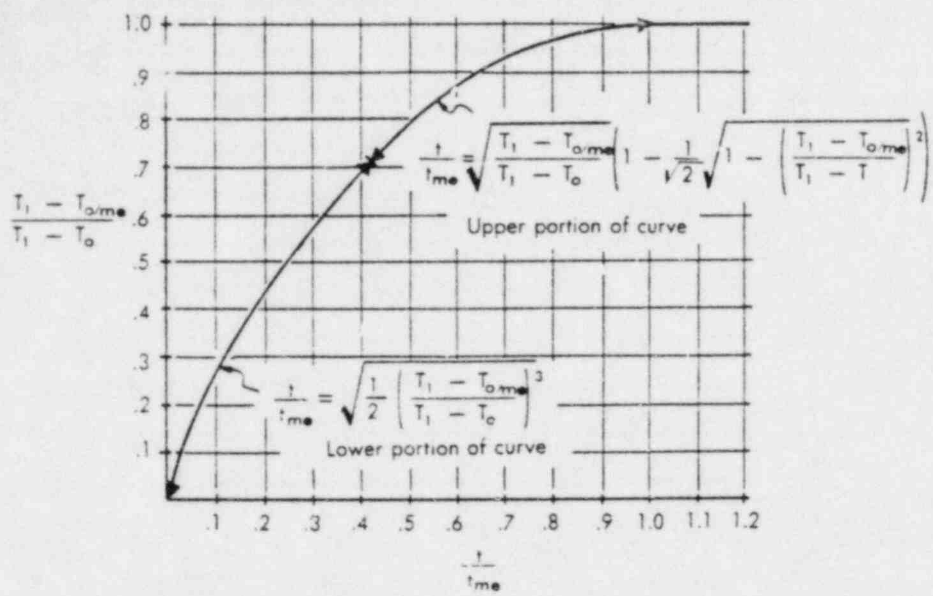

FIGURE 17

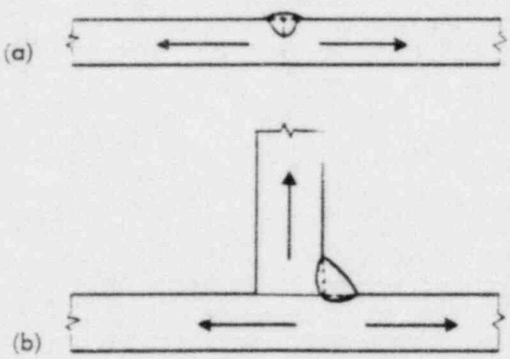

FIGURE 18

18. CARBON EQUIVALENT

As a result of recent experiments and studies, it is possible to simplify the relationship of all chemical elements in a steel to the occurrence of underbead cracking. The simplification is expressed in a single formula known as the carbon equivalent. This formula expresses the influence of each element relative to that of carbon.

Investigators* have shown a definite relationship in the percent of underbead cracking to the carbon equivalent. Figure 19 shows a 1" thick test plate on which a single bead was deposited using ⅛" E6010 electrode at 100 amps, 25 v, reversed polarity, at 10 in./min. The chart, Figure 20, shows the percentage of underbead cracking for different carbon equivalents that occurred with this test. A deposit made with low-hydrogen E6015 electrodes on a specimen of this thickness did not have underbead cracks. The AWS E6015 electrode is comparable to today's E7018. The results were plotted, Figure 20, to give curves for three different preheat temperatures (T_o).

K. Winterton* has listed 14 different carbon equivalent formulas and recommended the following:

$$C_{eq} = C\% + \frac{Mn\%}{6} + \frac{Ni\%}{20} + \frac{Cr\%}{10} - \frac{Mo\%}{50} - \frac{V\%}{10} + \frac{Cu\%}{40} \quad (10)$$

This formula is applicable to the low-carbon low-alloy steels for construction and machinery manufacturing.

19. COOLING RATE AND CARBON EQUIVALENT

Although not too well defined, for a given analysis of steel there is a maximum rate at which the weld and adjacent plate may be cooled without underbead cracking occurring.

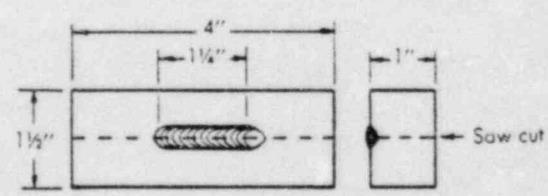

FIGURE 19

* Stout and Doty, "Weldability of Steels", Welding Research Council, 1953, p. 150; Williams, Roach, Martin and Voldrich, "Weldability of Carbon-Manganese Steels", WELDING JOURNAL, July 1949, p. 311-s.

* K. Winterton, "Weldability Prediction from Steel Composition to Avoid Heat-Affected Zone Cracking", WELDING JOURNAL, June 1961, p. 253-s.

The higher the carbon equivalent, the lower will be this critical (allowable) cooling rate. Thus, the higher the steel's carbon equivalent, the more important becomes the use of low-hydrogen welding and preheating.

Cottrell and Bradstreet* have used a type of Reeve Restraint test, called the CTS (Controlled Thermal Severity) test. For any given steel, three thicknesses are tested — ¼, ½, and 1". Each test requires

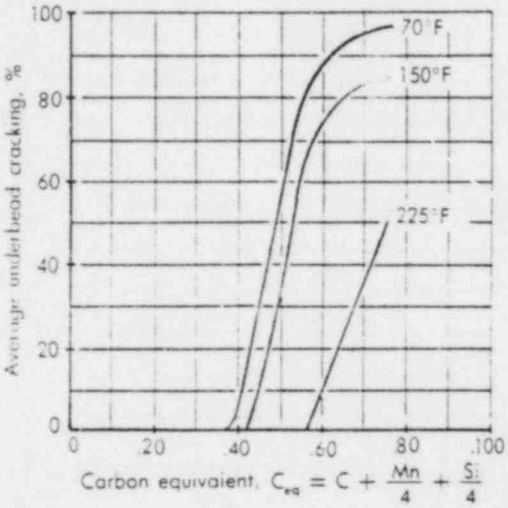

FIGURE 20

two fillet welds—one a bi-thermal weld (two avenues for heat to escape), the other a tri-thermal weld (three avenues for heat to escape). This gives a total of 6 different values for TSN (Thermal Severity Number), and for the given welding heat input (about 32,000 joules/in.) produces 6 different cooling rates. It is then observed at what cooling rate cracking does or does not occur, and the subsequent welding procedure is adjusted so this critical cooling rate will not be exceeded.

Both of these men have produced tables in which relative weldability has been expressed along with the critical cooling rate. More recently, Bradstreet** has tied in this relative weldability with carbon equivalent. By working back through this information, the carbon equivalent—critical cooling rate curve shown in Figure 21 has been produced to use as a guide in case the CTS test on the particular steel is not made. This curve may be expressed by the following formula:

$$R_{cr} = \frac{6.598}{C_{eq} - .3074} - 16.26 \quad \ldots\ldots\ldots\ldots(11)$$

This is the critical cooling rate at T_1 — 572°F.

The critical cooling rate (R_{cr}) can be determined by a) actual test of the particular steel to see what cooling rate will not cause cracking, or b) using formula (11) based upon Canadian investigations.

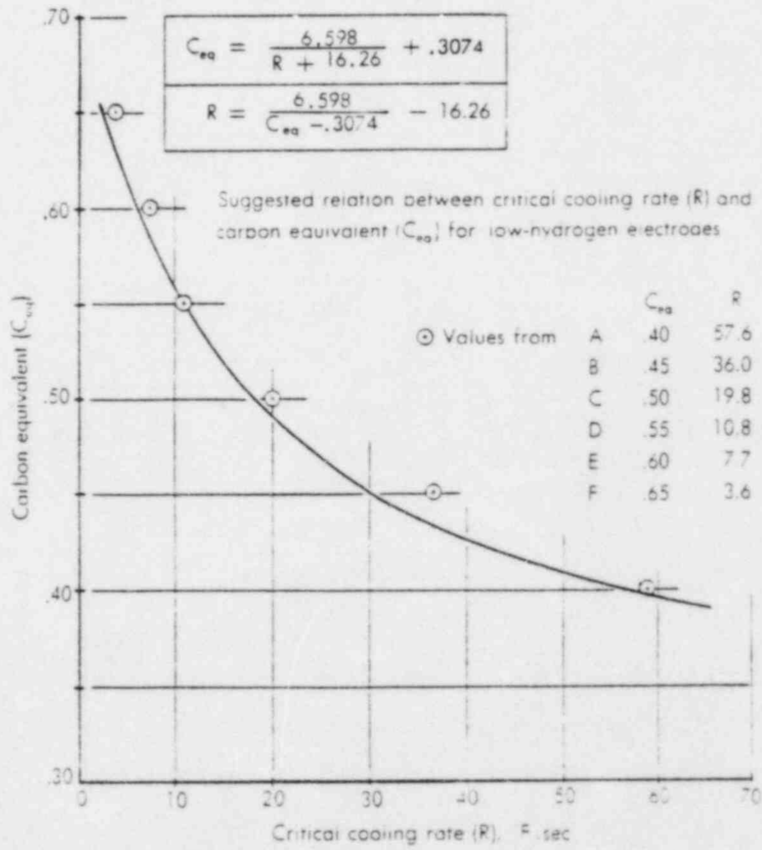

FIGURE 21

20. FINDING REQUIRED PREHEAT TEMPERATURE

To calculate the required preheat temperature (T_o) that will produce the required cooling rate (R) for a given heat input (J) and plate thickness (t), the following mathematical computations must be made:

a) Determine from formula (9) the value of (T_1 — $T_o/_{me}$).

b) Determine from formula (8) the value of (t_{me}).

c) From this (b) determine (t/t_{me}).

d) From the chart, Figure 17, using (c) read the value for

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* C. L. M. Cottrell, "Controlled Thermal Severity Cracking Test Simulates Practical Welded Joints", WELDING JOURNAL, June 1953, p. 257-s; Cottrell and Bradstreet, "A Method for Calculating the Effect of Preheat on Weldability", BRITISH WELDING JOURNAL, July 1955, p. 305; Cottrell and Bradstreet, "Calculating Preheat Temperatures to Prevent Hard Zone Cracking in Low Alloy Steels", BRITISH WELDING JOURNAL, July 1955, p. 310.

** B. J. Bradstreet, "Methods to Establish Procedures for Welding Low Alloy Steels", ENGINEERING JOURNAL (Engineering Institute of Canada), November 1963.

$$\left(\frac{T_1 - T_o/_{me}}{T_1 - T_o}\right)$$

e) Knowing this value (d) and the value of $(T_1 - T_o/_{me})$ from item (a), determine the required preheat temeprature (T_o).

An easier and faster method for determining the required preheat uses the nomograph, Figure 22. This nomograph is actually two nomographs superimposed upon each other. The first nomograph (subscript a) will provide a value for $\left(\frac{T_1 - T_o/_{me}}{T_1 - T_o}\right)$. The second nomograph (subscript b) will provide the required preheat and interpass temperature (T_o).

A set of eight graphs, Figure 23, will also provide this same information.

Example Using Chart (Fig. 17)

Given:

$J = 20.000 \frac{\text{watt-sec}}{\text{inch}}$

$R = 25\ ^\circ F/sec$

$t = 1.0''$

find required preheat temperature (T_o):

a) Determine $T_1 - T_o/_{me} = \sqrt{\frac{R\ J}{5.961}}$

$= \sqrt{\frac{(25)\ (20{,}000)}{5.961}}$

$= 289.6^\circ F$

b) Determine $t_{me} = .42457 \sqrt[4]{\frac{J}{R}}$

$= .42457 \sqrt[4]{\frac{20.000}{25}}$

$= 2.26''$

c) Determine relative thickness: $\frac{t}{t_{me}} = \frac{1''}{2.26''}$

$= .4429$

d) From chart, Figure 17, read relative preheat temperature: $\frac{T_1 - T_o/_{me}}{T_1 - T_o} = .73$

e) Therefore: $T_1 - T_o = \frac{T_1 - T_o/_{me}}{.73} = \frac{289.6}{.73}$

$= 396.7$

$572 - T_o = 396.7$

or $T_o = \underline{175.3}\ ^\circ F$

Example Using Nomograph (Fig. 22)

Given: $J = 20.000 \frac{\text{watt-sec}}{\text{inch}}$

$R = 25\ ^\circ F/sec$

$t = 1.0''$

find preheat temperature (T_o):

1st nomograph

(1) $R = 25\ ^\circ F/sec$

(2a) $J = 20{,}000 \frac{\text{watt-sec}}{\text{inch}}$

(3a) Read $t_{me} = 2.26''$

Use this number as a pivot point

(4a) $t = 1.0''$

(5a) Read $\% \frac{T_1 - T_o/_{me}}{T_1 - T_o} = 73\%$

2nd nomograph

(1) $R = 25\ ^\circ F/sec$

(2b) $J = 20{,}000 \frac{\text{watt-sec}}{\text{inch}}$

(3b) Read $T_o/_{me} = 282\ ^\circ F$

Use this number as a pivot point

(4b) $\% \frac{T_1 - T_o/_{me}}{T_1 - T_o} = 73\%$ (from 1st nomograph)

(5b) Read $T_o = 175\ ^\circ F$

21. OTHER POINTS OF CONSIDERATION

Test data has indicated that thin plates result in slightly higher cooling rates than calculated. It is believed this is because thin plates have a relatively greater surface area for heat loss per volume than thick plates.

Normally, in the investigation of a groove weld, the pass completing the joint is considered rather than the root pass. This is because the face pass usually has a slightly higher cooling rate due to the larger cross-section of the joint (assuming the same interpass temperature).

There is some indication that fillet welds have slightly higher cooling rates than the bead-on-plate welds used in the investigative work. This is because the 90° intersection of the two plates presents a larger area of contact with the weld, therefore absorbing heat at a slightly greater rate. A groove weld similarly would offer a larger area of plate contact with the weld than a bead-on-plate weld.

CASE EXHIBIT 971

AWS D1.1-75

Structural Welding Code

Prepared by
AWS Structural Welding Committee

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors, June 16, 1975

AMERICAN WELDING SOCIETY, INC.
2501 N.W. 7th Street, Miami, Fla. 33125

4. Technique

Part A General

4.1 Filler Metal Requirements

4.1.1 The electrode, electrode-flux combination, or grade of weld metal for making complete joint penetration butt welds shall be in accordance with Table 4.1.1.

4.1.2 The electrode, electrode-flux combination, or grade of weld metal for complete joint penetration or partial joint penetration groove welds and for fillet welds may be of a lower strength than required for complete joint penetration butt welds provided the weld metal meets the stress requirements (see 8.4, 9.3, or 10.4, whichever is applicable).

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

4.1.4 For exposed, bare, unpainted applications of ASTM A242 and A588 steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode, electrode-flux combination, or grade of weld metal shall be in accordance with Table 4.1.4. In multiple pass welds, the weld metal may be deposited so that at least two layers on all exposed surfaces and edges are deposited with one of the filler metals listed in Table 4.1.4, provided the underlying layers are deposited with one of the filler metals specified in Table 4.1.1.

4.1.5 For single pass welding, other than electroslag or electrogas, of exposed, bare, unpainted applications of ASTM A242 and A588 steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the following variation from Table 4.1.4 may be made:

4.1.5.1 Shielded Metal Arc Welding. Single pass fillet welds up to 1/4 in. (6.4 mm) maximum and 1/4 in. groove welds made with a single pass or single pass each side may be made using an E70XX low-hydrogen electrode.

4.1.5.2 Submerged Arc Welding. Single pass fillet welds up to 5/16 in. (8.0 mm) maximum and groove welds made with a single pass or single pass each side may be made using an F7X-EXXX electrode-flux combination.

4.1.5.3 Gas Metal Arc Welding. Single pass fillet welds up to 5/16 in. (8.0 mm) maximum and groove welds made with a single pass or single pass each side may be made using an E70S-X electrode.

4.1.5.4 Flux Cored Arc Welding. Single pass fillet welds up to 5/16 in. (8.0 mm) maximum and groove welds made with a single pass or single pass each side may be made using an E70T-X electrode.

4.1.6 For electroslag and electrogas welding of exposed, bare, unpainted applications of ASTM A242 and A588 steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the mechanical properties of the weld metal shall meet the requirements of Table 4.20 and the chemical composition requirements of Table 4.1.4.

4.2 Preheat and Interpass Temperature Requirements

With the exclusion of stud welding (see 4.28.7) and electroslag and electrogas welding (see 4.24.5), the minimum preheat and interpass temperatures shall be in accordance with Table 4.2 for the welding process being used and for the higher strength steel being welded. Welding shall not be done when the ambient temperature is lower than 0 °F (−18 °C). (Zero °F does not mean the ambient environmental temperature but the temperature in the immediate vicinity of the weld.

Table 4.1.4—Filler metal requirements for exposed bare applications of ASTM A242 and A588 steel

WELDING PROCESS		
Shielded metal arc	Submerged arc	Gas metal arc or Flux cored arc[2,4]
AWS A5.5	AWS A5.23	
E8016 or 18-C[1,2]	F7X-EXXX-W[2,3]	
E8016 or 18-B1[2]	F7X-EXXX-B1[2,3]	62 ksi min YP
E8016 or 18-B2[2]	F7X-EXXX-B2[2,3]	(430 MPa)
E8015 or 18-B21[2]		72 ksi min TS
E8016 or 18-C1	F7X-EXXX-Ni1[3]	(495 MPa)
E8016 or 18-C2	F7X-EXXX-Ni2[3]	Elon. 18% min
E8016 or 18-C3	F7X-EXXX-Ni3[3]	

1. Deposited weld metal shall have the following chemical composition: C, max %, 0.12; Mn, %, 0.50/1.30; P, max %, 0.03; S, max %, 0.04; Si, %, 0.35/0.80; Cu, %, 0.30/0.75; Ni, %, 0.40/0.80; Cr, %, 0.45/0.70.
2. Deposited weld metal shall have a minimum impact strength of Charpy V-Notch 20 ft lb (27.1 J) at 0 °F (−18 °C) (only applied to bridges).
3. Use of some type filler metal having next higher mechanical properties as listed in AWS specification is permitted.
4. Deposited weld metal shall have a chemical composition the same as that for any one of the weld metals in this table for the shielded metal arc welding process.

Table 4.1.1—Matching filler metal requirements

STEEL SPECIFICATION REQUIREMENTS					FILLER METAL REQUIREMENTS				
Steel Specification[1,2]	Minimum yield point ksi	Minimum yield point MPa	Tensile strength range ksi	Tensile strength range MPa	Electrode Specification[3,4]	Minimum yield point ksi	Minimum yield point MPa	Tensile strength range ksi	Tensile strength range MPa
ASTM A36[5]	36	250	58-80	345-550					
ASTM A53 Grade B	35	240	60 min	415 min	SMAW				
ASTM A106 Grade B	35	240	60 min	415 min	AWS A5.1 or A5.5				
ASTM A131 Grades A, B, C, CS, D, E	32	220	58-71	400-490	E60XX or	50	345	67 min	460
ASTM A139 Grade B	35	240	60 min	415 min	E70XX	57	395	77 min-	530
ASTM A381 Grade Y35	35	240	60 min	415 min					
ASTM A500 Grade A	33/39	230/270	45 min	310 min	SAW				
Grade B	42/46	290/320	58 min	400 min	AWS A5.17 or A5.23				
ASTM A501	36	250	58 min	400 min	F6X-EXXX or	50	345	62-80	425-550
ASTM A516 Grade 55	30	205	55-65	380-450	F7X-EXXX	60	415	70-95	485-655
Grade 60	32	220	60-72	415-495	GMAW				
ASTM A524 Grade I	35	240	60-85	415-585	AWS A5.18				
Grade II	30	205	55-80	380-550					
ASTM A529	42	290	60-85	415-495	E70S-X or	60	415	72 min	495
ASTM A570 Grade D	40	275	55 min	380 min	E70U-1	60	415	72 min	495
Grade E	42	290	58 min	400 min	FCAW				
ASTM A573 Grade 65	35	240	65-77	450-530	AWS A5.20				
ASTM A709 Grade 36[5]	36	250	58-80	345-550	E60T-X	50	345	62 min	425
API 5L Grade B	35	240	60	415	E70T-X	60	415	72 min	495
API 5LX Grade 42	42	290	60	415	(Except -2 & -3)				
ABS Grades A, B, D, CS, DS			58-71	400-490					
Grade E[6]			58-71	400-490					
ASTM A131 Grades AH32, DH32, EH32	45.5	315	68-85	470-585					
Grades AH36, DH36, EH36	51	350	71-90	490-620					
ASTM A242[6]	42-50	290-345	63-70min	435-485					
ASTM A441	42-50	290-345	63-70min	450-530					
ASTM A516 Grade 65	35	240	65-77	450-530					
Grade 70	38	260	70-85	485-585	SMAW				
ASTM A537 Class 1[7]	50	345	70-90	485-620	AWS A5.1 or A5.5				
ASTM A572 Grade 42	42	290	60 min	415 min	E70XX	57	395	77 min	530
Grade 45	45	310	60 min	415 min					
Grade 50	50	345	65 min	450 min	SAW				
Grade 55	55	380	70 min	485 min	AWS A5.17 or A5.23				
ASTM A588[6] (4 in. and under)	50	345	70 min	485 min	F7X-EXXX	60	415	70-95	485-655
ASTM A595 Grade A	55	380	65 min	450 min	GMAW				
Grade B and C	60	415	70 min	485 min	AWS A5.18				
ASTM A606	45	310	65 min	450 min	E70S-X or	60	415	72 min	495
ASTM A607 Grade 45	45	310	60 min	415 min	E70U-1	60	415	72 min	495
Grade 50	50	345	65 min	450 min					
Grade 55	55	380	70 min	485 min	FCAW				
ASTM A618	50	345	70 min	485 min	AWS A5.20				
ASTM A633 Grade A, B[6]	42	290	63-83	435-570	E70T-X	60	415	72 min	495
Grade C, D	50	345	70-90	485-620	(Except -2 & -3)				
(2-1/2 in. and under)									
ASTM A709 Grade 50	50	345	65 min	450 min					
Grade 50W	50	345	70 min	485 min					
API 2H	42	290	62-80	430-550					
ABS Grades AH32, DH32, EH32	45.5	315	71-90	560-620					
Grades AH36, DH36, EH36[6]	51	350	71-90	560-620					
					SMAW AWS A5.5 E80XX[7]	67	460	72 min	495
ASTM A572 Grade 60	60	415	75 min	515 min	SAW AWS A5.23 F8X-EXXX[7]	68	470	80-100	550-690
Grade 65	65	450	80 min	550 min					
ASTM A537 Class 2[3]	60	415	80-100	550-690	GMAW Grade E80S[7]	65	450	80 min	550
ASTM A633 Grade E[6]	60	415	80-100	550-690					
					FCAW Grade E80T[7]	68	470	80-95	550-655
					SMAW AWS A5.5 E100XX[7]	87	600	100 min	690
ASTM 514 (over 2-1/2 in. [63 mm])	90	620	105-135	725-930	SAW AWS A5.23 F10X-EXXX[7]	88	605	100-130	690-895
ASTM A709 Grades 100, 100W (2-1/2 to 4 in. [63 to 102 mm])	90	620	100-130	690-390	GMAW Grade E100S[7]	90		100 min	690
					FCAW Grade E100T[7]	88	605	100-115	690-790
					SMAW AWS A5.5 E110XX[7]	97	670	110 min	760
ASTM A514 (2-1/2 in. [63 mm] and under)	100	690	115-135	795-930	SAW AWS A5.23 F11X-EXXX[7]	98	675	110-130	760-895
ASTM A517	100	690	115-135	795-930	GMAW Grade E110S[7]	98	675	110 min	760
ASTM A709 Grades 100, 100W (2-1/2 in. [63 mm] and under)	100	690	110-130	760-895					
					FCAW Grade E110T[7]	98	675	110-125	760-860

[1] In joints involving base metals of two different yield points or strengths, filler metal electrodes applicable to the lower strength base metal may be used,[a] except that if the higher strength base metal requires low hydrogen electrodes, they shall be used.

[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 per cent vanadium.

[4] See 4.20 for electrogas and electroslag weld metal requirements.

[5] Only low hydrogen electrodes shall be u[illegible] when welding A36 steel more than 1 in. (25.4 mm) thick for bridge applications.

[6] Special welding materials and procedures (e.x., E80XX low alloy electrodes) may be required to match notch toughness of base metal (for applications involving impact loading or low temperature); or, for atmospheric corrosion and weathering characteristics (see 4.1.4).

[7] Low hydrogen classifications only.

[8] Deposited weld metal shall have a minimum impact strength of 20 ft-lbs (27.1J) at 0 °F (–18 °C) when Charpy V-notch specimens are used. This requirement is applicable only to bridges.

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.) When the base metal is below the specified minimum temperature, it shall be preheated so that the parts on which weld metal is being deposited are at or above the specified minimum temperature for a radius equal to the thickness of the part being welded, but not less than 3 in. (76.2 mm) in all directions from the point of welding. Preheat and interpass temperatures must be sufficient to prevent crack formation, and temperatures above the specified minimum may be required for highly restrained welds. In joints involving combinations of base metals, preheat shall be as specified for the higher strength steel being welded.

4.3 Heat Input Control for Quenched and Tempered Steel

When quenched and tempered steels are welded, the heat input shall be restricted in conjunction with the maximum preheat and interpass temperatures required (by reason of base metal thicknesses). The above limitations shall be in strict accordance with the steel producer's recommendations. The use of stringer beads to avoid overheating is strongly recommended. Oxygen gouging of quenched and tempered steels is not permitted.

4.4 Arc Strikes

Arc strikes outside of the area of permanent welds should be avoided on any base metal. Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and checked to ensure soundness.

4.5 Weld Cleaning

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

4.6 Groove Weld Termination

4.6.1 Groove welds shall be terminated at the ends of a joint in a manner that will ensure sound welds. Whenever possible, this shall be done by the use of extension bars or run-off plates.

4.6.2 In building construction, extension bars or run-off plates need not be removed unless required by the Engineer.

4.6.3 In bridge construction, extension bars and run-off plates shall be removed upon completion and cooling of the weld, and the ends of the weld made smooth and flush with the edges of the abutting parts.

4.7 Groove Weld Backing

4.7.1 Groove welds made with the use of steel backing shall have the weld metal thoroughly fused with the backing. On bridge structures, steel backing of welds that are transverse to the direction of computed stress shall be removed and the joint shall be finished smooth or ground. Steel backing of welds that are longitudinal with the direction of stress or are not subject to computed stress need not be removed, unless so specified by the Engineer.

4.7.2 Steel backing of welds used in buildings or tubular structures need not be removed unless required by the Engineer.

4.7.3 Steel backing shall be made continuous for the full length of the weld. All necessary joints in the steel backing shall be complete joint penetration butt welds meeting all workmanship requirements of Section 3 of this code.

4.8 Caulking

Caulking of welds shall not be permitted.

Part B
Shielded Metal Arc Welding

4.9 Electrodes for Shielded Metal Arc Welding

4.9.1 Electrodes for shielded metal arc welding shall conform to the requirements of the latest edition of AWS A5.1, Specification for Mild Steel Covered Arc Welding Electrodes, or to the requirements of AWS A5.5, Specification for Low-Alloy Steel Covered Arc Welding Electrodes.

4.9.2 All electrodes having low hydrogen coverings conforming to AWS A5.1 shall be purchased in hermetically-sealed containers or shall be dried for at least two hours between 450 °F (230 °C) and 500 °F (260 °C) before they are used. Electrodes having low hydrogen coverings conforming to AWS A5.5 shall be

Table 4.2—Minimum preheat and interpass temperature[3, 4]

Steel Specification	Welding Process	Thickness of Thickest Part at Point of Welding in.	mm	Minimum Temperature °F	°C
ASTM A36[2] ASTM A53 Grade B ASTM A106 Grade B ASTM A131 Grades A, B C, CS, D, E ASTM A139 Grade B ASTM A381 Grade Y35 ASTM A500 Grade A Grade B ASTM A501 ASTM A516 Grades 55 & 60 ASTM A524 Grades I & II ASTM A529 ASTM A570 Grades D & E ASTM A573 Grade 65 ASTM A709 Grade 36[2] API 5L Grade B API 5LX Grade 42 ABS Grades A, B, D, CS, DS Grade E	Shielded metal arc welding with other than low hydrogen electrodes	Up to 3/4	19 incl.	None[1]	
		over 3/4 thru 1-1/2	19 38 incl.	150	66
		over 1-1/2 thru 2-1/2	38 64	225	107
		over 2-1/2	64	300	150
ASTM A36[2] ASTM A53 Grade B ASTM A106 Grade B ASTM A131 Grades A, B, C, CS, D, E AH 32 & 36 DH 32 & 36 EH 32 & 36 ASTM A139 Grade B ASTM A242 ASTM A381 Grade Y35 ASTM A441 ASTM A500 Grade A Grade B ASTM A501 ASTM A516 Grades 55 & 60 65 & 70 ASTM A524 Grade I & II ASTM A529 ASTM A537 Classes 1 & 2 ASTM A570 Grades D & E ASTM A572 Grades 42, 45 50, 55 ASTM A573 Grade 65 ASTM A588 ASTM A595 Grades A, B, C ASTM A606 ASTM A607 Grades 45, 50, 55 ASTM A618 ASTM A633 Grades A, B Grades C, D ASTM A709 Grades 36, 50, 50W API 5L Grade B API 5LX Grade 42 API Spec. 2H ABS Grades AH 32 & 36 DH 32 & 36 EH 32 & 36 ABS Grades A, B, D, CS, DS Grade E	Shielded metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Up to 3/4	19 incl.	None[1]	
		over 3/4 thru 1-1/2	19 38 incl.	50	10
		over 1-1/2 thru 2-1/2	38 64 incl.	150	66
		over 2-1/2	64	225	107
ASTM A572 Grades 55, 60, 65 ASTM A633 Grade E	Shielded metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Up to 3/4	19 incl.	50	10
		over 3/4 thru 1-1/2	19 38 incl.	150	66
		over 1-1/2 thru 2-1/2	38 64 incl.	225	107
		over 2-1/2	64	300	150
ASTM A514 over 2-1/2 in. ASTM A517 ASTM A709 Grades 100 & 100W	Shielded metal arc welding with low hydrogen electrodes, submerged arc welding with carbon or alloy steel wire, neutral flux, gas metal arc welding or flux cored arc welding	Up to 3/4	19 incl.	50	10
		over 3/4 thru 1-1/2	19 38 incl.	125	50
		over 1-1/2 thru 2-1/2	35 64 incl.	175	80
		over 2-1/2	64	225	110
ASTM A514 2-1/2 & under ASTM A709 2-1/2 & under Grades 100 & 100W	Submerged arc welding with carbon steel wire, alloy flux	Up to 3/4	19 incl.	50	10
		over 3/4 thru 1-1/2	19 38 incl.	200	95
		over 1-1/2 thru 2-1/2	38 64 incl.	300	150
		over 2-1/2	64	400	205

[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]Only low-hydrogen electrodes shall be used when welding A36 steel more than 1 in. thick for bridges.

[3]Welding shall not be done when the ambient temperature is lower than 0 °F (−18 °C). When the base metal is below the temperature listed for the welding process being used and the thickness of material being welded, it shall be preheated (except as otherwise provided) in such manner that the surfaces of the parts on which weld metal is being deposited are at or above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 in. (76 mm), both laterally and in advance of the welding. Preheat and interpass temperatures must be sufficient to prevent crack formation. Temperature above the minimum shown may be required for highly restrained welds. For quenched and tempered steel the maximum preheat and interpass temperature shall not exceed 400 °F (205 °C) for thicknesses up to 1-1/2 in. (38.1 mm) inclusive, and 450 °F (230 °C) for greater thicknesses. Heat input when welding quenched and tempered steel shall not exceed the steel producers recommendation.

[4]In joints involving combinations of base metals, preheat shall be as specified for the higher strength steel being welded.

NOTE: Zero °F (−18 °C) 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.

purchased in hermetically-sealed containers or shall be dried at least one hour at temperatures between 700 °F (370 °C) and 800 °F (430 °C) before being used. Electrodes shall be dried prior to use if the hermetically-sealed container shows evidence of damage. Immediately after the opening of the hermetically-sealed container or removal of the electrodes from drying ovens, electrodes shall be stored in ovens held at a temperature of at least 250 °F (120 °C). E70XX electrodes that are not used within four hours, E80XX within two hours, E90XX within one hour, E100XX and E110XX within one-half hour after the opening of the hermetically-sealed container or removal of the electrodes from a drying or storage oven shall be redried before use. Electrodes that have been wet shall not be used.

4.9.3 When requested by the Engineer, the contractor or fabricator shall furnish an electrode manufacturer's certification that the electrode will meet the requirements of the classification.

4.10 Procedures for Shielded Metal Arc Welding

4.10.1 The work shall be positioned for flat position welding whenever practicable.

4.10.2 The classification and size of electrode, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances attending the work.

4.10.3 The maximum diameter of electrodes shall be as follows:

4.10.3.1 5/16 in. (8.0 mm) for all welds made in the flat position, except root passes.

4.10.3.2 1/4 in. (6.4 mm) for horizontal fillet welds.

4.10.3.3 1/4 in. (6.4 mm) for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and with a root opening of 1/4 in. or more.

4.10.3.4 5/32 in. (4.0 mm) for welds made with EXX14 and low-hydrogen electrodes in the vertical and overhead positions.

4.10.3.5 3/16 in. (4.8 mm) for root passes of groove welds and for all other welds not included under 4.10.3.1, 4.10.3.2, 4.10.3.3 and 4.10.3.4 above.

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

4.10.5 The maximum thickness of layers subsequent to the root pass of fillet welds and of all layers of groove welds shall be:

4.10.5.1 1/4 in. (6.4 mm) for root passes of groove welds.

4.10.5.2 1/8 in. (3.2 mm) for subsequent layers of welds made in the flat position.

4.10.5.3 3/16 in. (4.8 mm) for subsequent layers of welds made in the vertical, overhead and horizontal positions.

4.10.6 The maximum size fillet weld which may be made in one pass shall be:

4.10.6.1 3/8 in. (9.5 mm) in the flat position.

4.10.6.2 5/16 in. (8.0 mm) in horizontal or overhead positions.

4.10.6.3 1/2 in. (12.7 mm) in the vertical position.

4.10.7 The progressions for all passes in vertical position welding shall be upwards except that undercut may be repaired vertically downwards when preheat is in accordance with Table 4.2 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 or directions for which the welder is qualified.

4.10.8 Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound metal before welding is started from the second side, except as permitted by 10.13.

Part C
Submerged Arc Welding

4.11 General Requirements

4.11.1 Submerged arc welding 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. Submerged arc welding with multiple electrodes may be used for any groove or fillet weld pass.

4.11.2 The following paragraphs (4.11.3-4.11.8) governing the use of submerged arc welding are suitable for any steel included in 8.2, 9.2, or 10.2 other than those of the quenched and tempered group. Concerning the latter group, it is necessary to comply with the steel producer's recommendation for maximum permissible heat input and preheat combinations. Such considerations must include the additional heat input produced in simultaneous welding on the two sides of a common member.

4.11.3 The diameter of electrodes shall not exceed 1/4 in. (6.4 mm).

CASE EXHIBIT 1,022

Structural Welding Code

Prepared by
AWS Structural Welding Committee

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors, June 16, 1975

AMERICAN WELDING SOCIETY, INC.
2501 N.W. 7th Street, Miami, Fla. 33125

Structural Welding Code

1. General Provisions

1.1 Application

1.1.1 This code covers welding requirements applicable to any type of welded structure. It is to be used in conjunction with any complementary code or specification for the design and construction of steel structures. It is not intended to apply to pressure vessels or pressure piping. Requirements that are essentially common to all structures are covered in Sections 1 through 7 while provisions applying exclusively to buildings (static loading), bridges (dynamic loading), or tubular structures are included in Sections 8, 9, and 10 respectively.

1.1.2 All references to the need for approval shall be interpreted to mean approval by the Building Commissioner,[1] the Engineer,[2] or the duly designated person acting for and in behalf of the owner on all matters within the scope of this code. Hereinafter, the term Engineer will be used, and it is to be construed to mean the Building Commissioner, the Engineer, or the duly designated person who acts for and in behalf of the owner on all matters within the scope of this code.

1.2 Base Metal

The base metals to be welded under this code are carbon and low alloy steels commonly used in the fabrication of steel structures. Steels complying with the specifications listed in 8.2, 9.2, and 10.2, together with special requirements applicable individually to each type of structure, are approved for use with this code. Steels other than those listed in 8.2, 9.2 and 10.2 may be used provided the provisions of 8.2.3, 9.2.4, or 10.2.3 are complied with.

1.3 Welding Processes

1.3.1 Shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW) (except short circuiting transfer), and flux cored arc welding (FCAW) procedures which conform to the provisions of Sections 2, 3, and 4, in addition to Sections 8, 9, or 10, as applicable, shall be deemed as prequalified and are therefore approved for use without performing procedure qualification tests.

1.3.2 Electroslag (ESW) and electrogas[3] welding may be used provided the procedures conform to the applicable provisions of Sections 2, 3, and 4 and the contractor qualifies them in accordance with the requirements of 5.2.

1.3.3 Stud welding may be used provided the procedures conform to the applicable provisions of 4.25 through 4.31.

1.4 Definitions

The welding terms used in this code shall be interpreted in accordance with the definitions given in the latest edition of AWS A3.0, Terms and Definitions supplemented by Appendix I of this code.

1.5 Welding Symbols

Welding symbols shall be those shown in the latest edition of AWS A2.4, Symbols for Welding and Nondestructive Testing. 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 and Cutting, published by the American Welding Society.

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.

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[1] The term "Building Commissioner" refers to the official or bureau, by whatever term locally designated, who is delegated to enforce the local building law or specifications or other construction regulations.

[2] The Engineer is the duly designated person who acts for and in behalf of the owner on all matters within the scope of this code.

[3] The term electrogas welding as used in this code refers to either gas metal arc welding-electrogas (GMAW-EG) or flux cored arc welding-electrogas (FCAW-EG) or to both.

2. Design of Welded Connections

Part A General Requirements

2.1 Drawings[4]

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

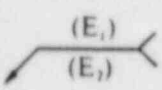
2.1.2 Drawings of those joints or groups of joints in which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted.

2.1.3 Contract design drawings shall specify the effective weld length and, for partial penetration groove welds, the required effective throat, as defined in 2.3 and 10.8. Shop or working drawings shall specify the groove depths (S) applicable for the effective throat (E) required for the welding process and position of welding to be used.

2.1.3.1 It is recommended that contract design drawings show complete joint penetration or partial joint penetration groove weld requirements as follows:

complete joint penetration weld (CP)

The welding symbol without dimensions designates a complete joint penetration weld.



partial joint penetration weld

Where,

E_1 = effective throat, other side

E_2 = effective throat, arrow side

Special groove details shall be specified where required.

[4] The term "drawings" refers to plans, design and detail drawings, and erection plans.

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

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

2.2 Basic Unit Stresses

Basic unit stresses for base metals and for effective areas of weld metal for application to buildings, bridges, and tubular structures shall be as shown in Part B of Sections 8, 9, and 10 respectively.

2.3 Effective Weld Areas, Lengths, and Throats

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

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

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

2.3.1.3 The minimum effective throat of a partial joint penetration groove weld shall be as specified in Table 2.10.3.

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

2.3.2.1 The effective length of a fillet weld shall be the overall length of the full-size fillet, including end returns. No reduction in effective length shall be made for either the start or crater of the weld if the weld is full size throughout its length.

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

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

2.3.2.4 The effective throat shall be the shortest distance from the root to the face of the diagrammatic weld.

2.3.3 Plug and Slot Welds. The effective area, shall be the nominal area of the hole or slot in the plane of the faying surface.

2.3.4 The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the root to the face of the diagrammatic weld minus 1/8 in. (3.2 mm) for any groove detail requiring such deduction (See Appendix B).

Part B Structural Details

2.4 Fillers

2.4.1 Fillers may be used in:

2.4.1.1 Splicing parts of different thicknesses.

2.4.1.2 Connections that, due to existing geometric alignment, must accommodate off-sets to permit simple framing.

2.4.2 A filler 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 (see Fig. 2.4.2).

2.4.3 Any filler 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 as an eccentric load. The welds joining the splice plate or connection material to the filler shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid overstressing the filler along the toe of the weld (see Fig. 2.4.3).

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

Part C Details of Welded Joints

2.6 Joint Qualification

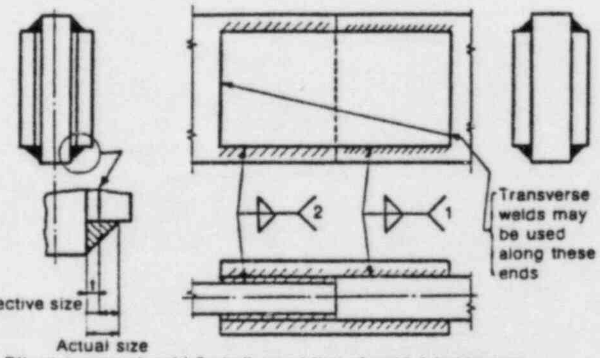
2.6.1 Joints meeting the following requirements are designated as prequalified:

(1) Conformance with the details specified in 2.9 through 2.14 and in 10.13.

(2) Use of one of the following welding processes in accordance with the requirements of Sections 3, 4, and 10 as applicable: shielded metal arc, submerged arc, gas metal arc (except short circuiting transfer) or flux cored arc welding.

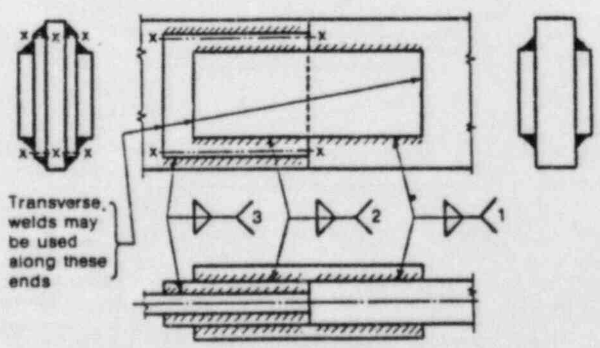
Joints meeting these requirements may be used without performing the joint welding procedure qualification tests prescribed in 5.2.

2.6.1.1 The joint welding procedure for all joints welded by short circuiting transfer gas metal arc welding (see Appendix D) shall be qualified by tests prescribed in 5.2.



Effective area of weld 2 shall equal that of weld 1 but its size shall be its effective size plus the thickness of the filler, t.

Fig. 2.4.2—Fillers less than 1/4 in. thick.



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

Effective area of weld 3 shall at least equal that of weld 1 and there shall be no overstress pf the ends of weld 3 resulting from the eccentricity of the forces acting on the filler.

Fig. 2.4.3—Fillers 1/4 in. or thicker.

2.6.2 Joint details may depart from the details prescribed in 2.9 through 2.14 and in 10.13 only if the contractor submits to the Engineer his proposed joints and joint welding procedures and at his own expense demonstrates their adequacy in accordance with the requirements of 5.2 of this code and their conformance with applicable provisions of Sections 3 and 4.

2.7 Details of Fillet Welds

2.7.1 The details of fillet welds made by shielded metal arc, submerged arc, gas metal arc or flux cored arc welding to be used without joint welding procedure qualification are listed in 2.7.1.1 through 2.7.1.5 and detailed in Figs. 2.7.1 and 10.13.1.3.

2.7.1.1 The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in the following table:

Base Metal Thickness of Thicker Part Joined (T)		Minimum Size of Fillet Weld*		
in.	mm	in.	mm	
T≤1/4	T≤6.4	1/8**	3	single pass welds must be used
1/4<T≤1/2	6.4<T≤12.7	3/16	5	
1/2<T≤3/4	12.7<T≤19.0	1/4	6	
3/4<T	19.0<T	5/16	8	

*Except that the weld size need not exceed the thickness of the thinner part joined. For this exception particular care should be taken to provide sufficient preheat to ensure weld soundness.
**Minimum size for bridge application 3/16 in.

2.7.1.2 The maximum fillet weld size permitted along edges of material shall be:

(1) The thickness of the base metal, for metal less than 1/4 in. (6.4 mm) thick (see Fig. 2.7.1, 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 Fig. 2.7.1, detail B), unless the weld is designated on the drawing to be built out to obtain full throat thickness.

2.7.1.3 Fillet welds in holes, or slots in lap joints, may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the provisions of 2.3.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

2.7.1.4 Fillet welds may be used in skew joints that have an included angle of not less than 60 degrees. (See Fig. 2.7.1, details C and D).

2.7.1.5 The minimum length of an intermittent fillet weld shall be 1-1/2 in. (38.1 mm).

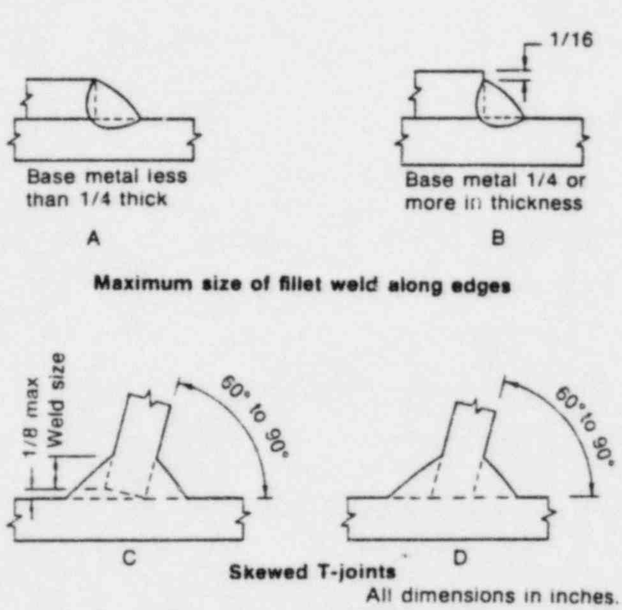


Fig. 2.7.1—Details for fillet welds.

2.8 Plug and Slot Welds[5]

2.8.1 Plug and slot welds in lap joints may be used to transmit shear or to prevent the buckling or separation of lapped parts.

2.8.2 The diameter of the hole for a plug weld shall be no less than the thickness of the part containing it plus 5/16 in. (8.0 mm) preferably rounded to the next greater odd 1/16 in. (1.6 mm). The diameter of the hole for a plug weld shall not be greater than 2-1/4 times the thickness of the weld.

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

2.8.4 The length of the slot for a slot weld shall not exceed ten times the thickness of the weld. The width of the slot shall be no less than the thickness of the part containing it plus 5/16 in. (8.0 mm) preferably rounded to the next greater odd 1/16 in. (1.6 mm) nor shall it be greater than 2-1/4 times the thickness of the weld.

2.8.5 Plug and slot welds are not permitted in quenched and tempered steels.

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

2.8.7 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.

[5]See Appendix A for the technique of making plug and slot welds.

2.8.8 The thickness 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.

2.9 Complete Joint Penetration Groove Welds Made by Shielded Metal Arc Welding

2.9.1 Complete joint penetration groove welds made by shielded metal arc welding in butt, T, and corner joints which may be used without performing the joint welding procedure qualification tests prescribed in 5.2 are detailed in Fig. 2.9.1 and are subject to the the limitations specified in 2.9.2.

2.9.2 Dimensions of groove welds specified on design or detail drawings may vary from the dimensions shown in Fig. 2.9.1 only within the following limits:

2.9.2.1 The specified thickness of base metal is the maximum nominal thickness that may be used.

2.9.2.2 The root face of the joints shall be as dimensioned in Fig. 2.9.1. It may be detailed to exceed the specified dimension by no more than 1/16 in. (1.6 mm). It may not be detailed less than the specified dimension.

2.9.2.3 The root opening of the joints is minimum. It may be detailed to exceed the dimension shown by no more than 1/16 in. (1.6 mm).

2.9.2.4 The groove angle is minimum. It may be detailed to exceed the dimension shown by no more than ten degrees.

2.9.2.5 The radius of J-grooves and U-grooves is minimum. It may be detailed to exceed the dimension shown by no more than 1/8 in. (3.2 mm). U-grooves may be prepared before or after fitting.

2.9.2.6 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.

2.9.3 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.

2.10 Partial Joint Penetration Groove Welds Made by Shielded Metal Arc Welding

2.10.1 Except as provided in 10.13.1.1, groove welds without steel backing, welded from one side, and groove welds welded from both sides but without back gouging are considered partial joint penetration groove welds. Partial joint penetration groove welds made by shielded metal arc welding in butt, T, and corner joints which may be used without performing the joint welding procedure qualification tests prescribed in 5.2 are detailed in Fig. 2.10.1 and are subject to limitations specified in 2.10.2

2.10.2 Dimensions of groove welds specified on design or detail drawings may vary from the dimensions shown in Fig. 2.10.1 only within the following limits:

2.10.2.1 The groove angle is minimum. It may be detailed to exceed the dimension shown by no more than ten degrees.

2.10.2.2 The radius of the U-grooves and J-grooves is minimum. It may be detailed to exceed the dimension shown by no more than 1/8 in. (3.2 mm). -grooves may be prepared before or after fitting.

2.10.2.3 Double-groove welds may have grooves of unequal depth, provided that the weld deposit on each side of the joint conforms to the limitations of Fig. 2.10.1.

2.10.3 The effective throat of partial joint penetration square-, bevel-, and V-groove welds shall be as shown in Table 2.10.3.

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

2.10.4 The minimum root face of the joints shall be 1/8 in. (3.2 mm).

2.10.5 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.

Table 2.10.3—Minimum effective throat for partial joint penetration groove welds

Base metal thickness of thicker part joined, in. (mm)	Minimum effective throat in.	mm
to 1/4 (3.2) incl.	1/8*	3
over 1/4 (3.2) 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

*Minimum size for bridge applications 3/16 in.

Metric (SI) Equivalents for Section 2 Figures

in.	mm	in.	mm
1/32	0.8	2	50.8
1/16	1.6	2-1/8	54.0
1/8	3.2	2-3/8	60.3
3/16	4.8	2-1/2	63.6
1/4	6.4	2-3/4	70.0
3/8	9.5	3	76.2
5/8	15.9	3-1/4	82.6
1/2	12.7	3-5/8	92.1
3/4	19.0	3-3/4	95.2
1	25.4	4	102
1-3/8	34.9	4-3/4	121
1-1/2	38.1	5-1/2	140
1-3/4	44.5	6-1/4	159

Legend for Figs. 2.9.1 through 2.14.1

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

Symbols 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

Symbol for welding processes, if not shielded metal arc

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

3.7 Corrections

3.7.1 The removal of weld metal or portions of the base metal may be done by machining, grinding, chipping, oxygen gouging, or air carbon arc gouging. It shall be done in such a manner that the remaining weld metal or base metal is not nicked or undercut. Oxygen gouging shall not be used in quenched and tempered steel. Unacceptable portions of the weld shall be removed without substantial removal of the base metal. Additional weld metal to compensate for any deficiency in size shall be deposited using an electrode preferably smaller than that used for making the original weld, and preferably not more than 5/32 in. (4.0 mm) in diameter. The surfaces shall be cleaned thoroughly before welding.

3.7.2 The contractor has the option of either repairing an unacceptable weld, or removing and replacing the entire weld, except as modified by 3.7.4. The repaired or replaced weld shall be retested by the method originally used, and the same technique and quality acceptance criteria shall be applied. If the contractor elects to repair the weld, it shall be corrected as follows:

3.7.2.1 **Overlap or Excessive Convexity.** Remove excess weld metal.

3.7.2.2 **Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting.** Prepare surfaces (see 4.5) and deposit additional weld metal.

3.7.2.3 **Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion.** Remove unacceptable portions (see 3.7.1) and reweld.

3.7.2.4 **Cracks in Weld or Base Metal.** Ascertain the extent of the crack by use of acid etching, magnetic particle inspection, or other equally positive means; remove the crack and sound metal 2 in. (50.8 mm) beyond each end of the crack, and reweld.

3.7.3 Members distorted by welding shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heat. The temperature of heated areas as measured by approved methods shall not exceed 1100°F (590°C) for quenched and tempered steel nor 1200°F (650°C) (a dull red color) for other steels. The part to be heated for straightening shall be substantially free of stress and from external forces, except those stresses resulting from the mechanical straightening method used in conjunction with the application of heat.

3.7.4 Approval shall be obtained for such corrections as: repairs to base metal (other than those required by 3.2), repair of major or delayed cracks, or for a revised design to compensate for deficiencies.

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

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

3.8 Peening

Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking. No peening shall be done on the root or surface layer of the weld or in the base metal at the edges of the weld. Care should be taken to prevent overlapping or cracking of the weld or base metal.

3.9 Stress Relief Heat Treatment[12]

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

3.9.1.1 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 (315 °C), the rate of heating[13] shall not be more than 400 °F (220 °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, variation 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.

(3) After a maximum temperature of 1100 °F (590 °C) is reached on quenched and tempered steel, or a mean temperature range between 1100 °F and 1200 °F (650 °C) is reached on other steels, the temperature of the assembly shall be held within the specified limits for one hour per inch of weld

[12] Stress relieving of weldments of quenched and tempered steel is not generally required. 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 of quenched and tempered steel. However, the results of notch toughness tests have shown that postweld heat treatment 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.

[13] 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.

purchased in hermetically-sealed containers or shall be dried at least one hour at temperatures between 700 °F (370 °C) and 800 °F (430 °C) before being used. Electrodes shall be dried prior to use if the hermetically-sealed container shows evidence of damage. Immediately after the opening of the hermetically-sealed container or removal of the electrodes from drying ovens, electrodes shall be stored in ovens held at a temperature of at least 250 °F (120 °C). E70XX electrodes that are not used within four hours, E80XX within two hours, E90XX within one hour, E100XX and E110XX within one-half hour after the opening of the hermetically-sealed container or removal of the electrodes from a drying or storage oven shall be redried before use. Electrodes that have been wet shall not be used.

4.9.3 When requested by the Engineer, the contractor or fabricator shall furnish an electrode manufacturer's certification that the electrode will meet the requirements of the classification.

4.10 Procedures for Shielded Metal Arc Welding

4.10.1 The work shall be positioned for flat position welding whenever practicable.

4.10.2 The classification and size of electrode, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances attending the work.

4.10.3 The maximum diameter of electrodes shall be as follows:

4.10.3.1 5/16 in. (8.0 mm) for all welds made in the flat position, except root passes.

4.10.3.2 1/4 in. (6.4 mm) for horizontal fillet welds.

4.10.3.3 1/4 in. (6.4 mm) for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and with a root opening of 1/4 in. or more.

4.10.3.4 5/32 in. (4.0 mm) for welds made with EXX14 and low-hydrogen electrodes in the vertical and overhead positions.

4.10.3.5 3/16 in. (4.8 mm) for root passes of groove welds and for all other welds not included under 4.10.3.1, 4.10.3.2, 4.10.3.3 and 4.10.3.4 above.

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

4.10.5 The maximum thickness of layers subsequent to the root pass of fillet welds and of all layers of groove welds shall be:

4.10.5.1 1/4 in. (6.4 mm) for root passes of groove welds.

4.10.5.2 1/8 in. (3.2 mm) for subsequent layers of welds made in the flat position.

4.10.5.3 3/16 in. (4.8 mm) for subsequent layers of welds made in the vertical, overhead and horizontal positions.

4.10.6 The maximum size fillet weld which may be made in one pass shall be:

4.10.6.1 3/8 in. (9.5 mm) in the flat position.

4.10.6.2 5/16 in. (8.0 mm) in horizontal or overhead positions.

4.10.6.3 1/2 in. (12.7 mm) in the vertical position.

4.10.7 The progressions for all passes in vertical position welding shall be upwards except that undercut may be repaired vertically downwards when preheat is in accordance with Table 4.2 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 or directions for which the welder is qualified.

4.10.8 Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound metal before welding is started from the second side, except as permitted by 10.13.

Part C
Submerged Arc Welding

4.11 General Requirements

4.11.1 Submerged arc welding 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. Submerged arc welding with multiple electrodes may be used for any groove or fillet weld pass.

4.11.2 The following paragraphs (4.11.3-4.11.8) governing the use of submerged arc welding are suitable for any steel included in 8.2, 9.2, or 10.2 other than those of the quenched and tempered group. Concerning the latter group, it is necessary to comply with the steel producer's recommendation for maximum permissible heat input and preheat combinations. Such considerations must include the additional heat input produced in simultaneous welding on the two sides of a common member.

4.11.3 The diameter of electrodes shall not exceed 1/4 in. (6.4 mm).

cepted. For example, a procedure qualified with a 1 in. (25.4 mm) thick 100 000 psi (690 MPa) yield strength base metal also qualifies for a 3 in. (76.2 mm) thick 90 000 psi (620 MPa) yield strength base metal of the same material specification.

5.5.1.4 Qualification of a welding procedure established with a combination of base metals included in 10.2 of different minimum specified yield strengths, one of which is greater than 50 000 psi (345 MPa) shall qualify the procedure for welding that high yield strength base metal to any other of those base metals having a minimum specified yield strength equal to or less than that of the lower strength base metal used in the test.

5.5.1.5 In preparing the procedure specification the manufacturer or contractor shall report the specific values for the essential variables that are specified in 5.5. The suggested form for showing the information required in the procedure specification is given in Appendix E.

5.5.2 The changes set forth in 5.5.2.1 through 5.5.2.5 shall be considered essential changes in a welding procedure and shall require establishing a new procedure by qualification. When a combination of welding processes is used, the variables applicable to each process shall apply.

5.5.2.1 Shielded Metal Arc Welding

(1) A change increasing filler metal strength level (a change from E70XX to E80XX, for example, but not vice versa).

(2) A change from a low hydrogen type electrode to a non-low hydrogen type of electrode, but not vice versa.

(3) An increase in the diameter of the electrode used, over that called for in the procedure specification.

(4) A change of more than 15 percent above or below the specified mean arc voltage and amperage for each size electrode used.[24]

(5) For a specified groove, a change of more than ±25 percent in the specified number of passes. If the area of the groove is increased, it is also permissible to increase the number of passes in proportion to the increased area.

(6) A change in position in which welding is done as defined in 5.8.

(7) A change in the type of groove (a change from a V- to a U-groove, for example).

(8) A change exceeding tolerances of 2.9, 2.10, or 10.13 in the shape of any one type of groove involving:

(a) A decrease in the included angle of the groove,

(b) A decrease in the root opening of the groove,

(c) An increase in the root face of the groove,

(d) The omission, but not inclusion, of backing material.

(9) A decrease of more than 25 °F (13.9 °C) in the minimum specified preheat or interpass temperature.[25]

(10) In vertical welding, a change in the progression specified for any pass from upward to downward or vice versa.

5.5.2.2 Submerged Arc Welding

(1) A change in electrode and flux combination not covered by AWS A5.17 or A5.23.

(2) A change increasing filler metal strength level (from Grade F80 to Grade F90, for example, but not vice versa).

(3) A change in electrode diameter when using an alloy flux.[26]

(4) A change in the number of electrodes used.

(5) A change in the type of current (ac or dc) or polarity when welding quenched and tempered steel or when using an alloy flux.

(6) A change of more than 10 percent above or below the specified mean amperage for each electrode diameter used.[24]

(7) A change of more than 7 percent above or below the specified mean arc voltage for each diameter electrode used.[24]

(8) A change of more than 15 percent above or below the specified mean travel speed.[24]

(9) A change of more than 10 percent or 1/8 in. (3.2 mm), whichever is greater, in the longitudinal spacing of the arcs.

(10) A change of more than 10 percent, or 1/16 in. (1.6 mm) whichever is greater, in the lateral spacing of the arcs.

(11) A change of more than ± 10 deg in the angular position of any parallel electrode.

(12) A change in the angle of electrodes in machine or automatic welding of more than:

(a) ± 3 deg in the direction of travel.

(b) ± 5 deg normal to the direction of travel.

(13) For a specified groove, a change of more than ± 25 percent in the specified number of passes. If the area of the groove is increased, it is also permissible to increase the number of passes in proportion to the increased area.

(14) A change in position in which welding is done as defined in 5.8.

(15) A change in the type of groove (a change from a V- to a U-groove, for example).

(16) A change, exceeding tolerances of 2.11, 2.12,

[24]When welding quenched and tempered steel, any change within the limitation of variables shall not increase the heat input beyond the steel producer's recommendations.

[25]The temperature may fall more than 25 °F below the minimum specified, provided: (1) the provisions of 3.4.7 and Table 4.2 are complied with, and (2) the work shall be at the specified minimum temperature at the time of subsequent welding.

[26]An alloy flux is defined as a flux upon which the alloy content of the weld metal is largely dependent.

8.2.3 When a steel other than those listed in 8.2.1 is approved under the provisions of the general building code and such steel is proposed for welded construction, the weldability of the steel and the procedure for welding it shall be established by qualification in accordance with requirements of 5.2 and such other requirements as prescribed by the Engineer.

8.2.3.1 The responsibility for determining weldability, including the assumption of the additional testing cost involved, is assigned to the party who either specifies a material other than listed in 8.2.1 or who proposes the use of a substitute material not listed in 8.2.1. The fabricator shall have the responsibility of establishing the welding procedure by qualification.

8.2.4 Extension bars, run-off plates, and backing used in welding shall conform to the following requirements:

(1) When used in welding with an approved steel listed in 8.2.1, it may be any of the steels listed in 8.2.1.

(2) When used in welding with a steel qualified in accordance with 8.2.3 it may be:

(a) The steel qualified, or

(b) Any steel listed in 8.2.1.

Spacers used shall be of the same material as the base metal.

8.2.5 The provisions of this code are not intended for use with steels having a minimum specified yield point or yield strength over 100 000 psi (690 MPa).

Part B
Allowable Unit Stresses

8.3 Base Metal Stresses

The base metal stresses shall be those specified in the applicable Building Code.

8.4 Unit Stresses in Welds

8.4.1 Except as modified by 8.5, allowable unit stress in welds shall not exceed those listed in Table 8.4.1.

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

8.5 Increased Unit Stresses

Where the Building Code permits the use of increased unit stresses in the base metal for any reason, a corresponding increase shall be applied to the allowable unit stress for welds.

Part C
Structural Details

8.6 Combinations of Welds

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

8.7 Welds in Combination with Rivets and Bolts

Rivets or bolts used in bearing-type connections shall not be considered as sharing the stress in combination with welds. Welds, if used, shall be provided to carry the entire stress 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 friction-type connection prior to welding may be considered as sharing the stress with the welds.

8.8 Fillet Weld Details

8.8.1 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. (203 mm), unless end transverse welds or intermediate plug or slot welds are used.

8.8.2 Intermittent fillet welds may be used to carry calculated stress.

8.8.3 For lap joints the minimum amount of lap shall be five times the thickness of the thinner part joined but not less than 1 in. (25.4 mm) (see Fig. 8.8.3).

8.8.4 Lap joints in parts carrying axial stress shall be double-fillet welded (see Fig. 8.8.3), except where deflection of the joint is sufficiently restrained to prevent it from opening under load.

Table 8.4.1—Allowable stresses in welds

Type of Weld	Stress in weld[1]		Allowable stress	Required weld strength level[2]
Complete joint penetration groove welds	Tension normal to the effective area		Same as base metal	Matching weld metal must be used. See Table 4.1.1
	Compression normal to the effective area		Same as base metal	Weld metal with a strength level equal to or one classification (10 ksi) less than matching weld metal may be used
	Tension or compression parallel to the axis of the weld		Same as base metal	Weld metal with a strength level equal to or less than matching weld metal may be used
	Shear on the effective area		0.30 nominal tensile strength of weld metal (ksi), except shear stress on base metal shall not exceed 0.40 yield stress of base metal	
Partial joint penetration groove welds	Compression normal to effective area	Joint not designed to bear	0.50 nominal tensile strength of weld metal (ksi), except stress on base metal shall not exceed 0.60 yield stress of base metal	Weld metal with a strength level equal to or less than matching weld metal may be used
		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 weld metal (ksi), except shear stress on base metal shall not exceed 0.40 yield stress of base metal	
	Tension normal to effective area		0.30 nominal tensile strength of weld metal (ksi), except shear stress on base metal shall not exceed 0.60 yield stress of base metal	
Fillet welds	Shear on effective area		0.30 nominal tensile strength of weld metal (ksi), except shear stress on base metal shall not exceed 0.40 yield stress of base metal	Weld metal with a strength level equal to or less than matching 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 weld metal (ksi), except shear stress on base metal shall not exceed 0.40 yield stress of base metal	Weld metal with a strength level equal to or less than matching metal may be used

[1]For definition of effective area, see 2.3.
[2]For matching weld metal, see Table 4.1.1.
[3]Fillet welds 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.

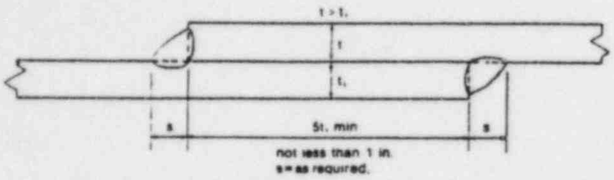


Fig. 8.8.3—Double-fillet-welded lap joint.

8.8.5 Fillet welds deposited on the opposite sides of a common plane of contact between two parts shall be interrupted at the corner common to both welds. (See Fig. 8.8.5).

8.8.6 Boxing (End Returns)

8.8.6.1 Side or end fillet welds terminating at ends or sides, respectively, of parts or members shall, wherever practicable, be returned continuously around the corners for a distance at least twice the nominal size of the weld except as provided in 8.8.5. This provision shall apply to side and top fillet welds connecting brackets, beam seats and similar connections on the plane about which bending moments are computed.

8.8.6.2 End returns shall be indicated on the drawings.

8.9 Eccentricity

In general, adequate provision shall be made for bending stresses due to eccentricty, if any, in the disposition and section of base metal parts and in the location and types of welded joints. 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, T or beams framing into chords of trusses, or similar joints, may be connected with unbalanced fillet welds.

8.10 Transition of Thicknesses or Widths

Tension butt joints in axially aligned primary members or different material thicknesses or widths 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, tapering the wider part, sloping the weld metal, or by any combination of these. (See Fig. 8.10).

8.11 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.

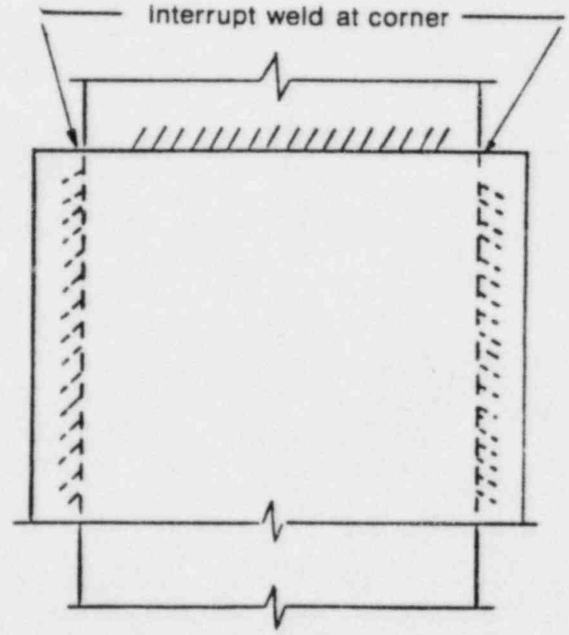


Fig. 8.8.5—Fillet welds on opposite sides of a common plane.

8.12 Connections of Components of Built-Up Members

8.12.1 If two or more plates or rolled shapes are used to build up a member, sufficient stitch welding (of the fillet, plug, or slot type) shall be provided to make the parts act in unison as follows, except where transfer or calculated stress between the parts joined requires closer spacing:

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

8.12.1.2 In built-up compression members, the longitudinal spacing of stitch welds connecting a plate component to other components shall not exceed the plate thickness times $4000/\sqrt{F_y}$ nor shall it exceed 12 in. (305 mm) (F_y = specified minimum yield point in psi of the type of steel being used). The unsupported width of web, cover, or diaphragm plates, between adjacent lines of welds, shall not exceed the plate thickness times $8000 \sqrt{F_y}$. When the unsupported width exceeds this limit, but a portion of its width no greater than $8000/\sqrt{F_y}$ times the thickness would satisfy the stress requirements, the member will be considered acceptable.

8.12.1.3 In built-in tension members, the longitudinal spacing of stitch 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.

8.13.1.3 Web distortions of twice the allowable tolerances of 8.13.1.2 shall be satisfactory when occuring at the end of a girder which has been drilled, or subpunched and reamed; either during assembly or to a template for a field bolted splice; provided, when the splice plates are bolted, the web assumes the proper dimensional tolerances.

8.13.1.4 If architectural considerations require tolerances more restrictive than described in 8.13.1, specific reference must be included in the bid documents.

8.14 Temporary Welds

Temporary welds shall be subject to the same welding procedure requirements as final welds. They shall be removed when required by the Engineer. When they are removed, the surface shall be made flush with the original surface.

8.15 Quality of Welds

8.15.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if it shows that:

8.15.1.1 The weld has no cracks.

8.15.1.2 Thorough fusion exists between weld metal and base metal.

8.15.1.3 All craters are filled to the full cross section of the welds.

8.15.1.4 Weld profiles are in accordance with 3.6.

8.15.1.5 The sum of diameters of piping porosity does not exceed 3/8 in. (9.5 mm) in any linear inch of weld and shall not exceed 3/4 in. (19.0 mm) in any 12 in. (305 mm) length of weld.

8.15.1.6 Fillet welds in any single continuous weld shall be permitted to underrun the nominal fillet size required by 1/16 in. (1.6 mm) without correction provided that the undersize weld does not exceed 10 percent of the length of the weld. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.

8.15.2 Nondestructive Inspection. Welds that are subject to radiographic or magnetic particle testing in addition to visual inspection, shall be unacceptable if the radiograph or magnetic particle inspection shows any of the types of discontinuities given in 8.15.2.1 or 8.15.2.2.

8.15.2.1 Individual discontinuities, having a greatest dimension of 3/32 in. (2.4 mm) or greater, if:

(1) The greatest dimension of a discontinuity is larger than 2/3 of the effective throat, 2/3 the weld size, or 3/4 in. (19.0 mm).

(2) The discontinuity is closer than three times its greatest dimension to the end of a groove weld subject to primary tensile stresses.

(3) A group of such discontinuities is in line such that:

(a) The sum of the greatest dimensions of all such discontinuities is larger than the effective throat or weld size in any length of six times the effective throat or weld size. When the length of the weld being examined is less than six times the effective throat or weld size, the permissible sum of the greatest dimensions shall be proportionally less than the effective throat or weld size.

(b) The space between two such discontinuities which are adjacent is less than three times the greatest dimension of the larger of the discontinuities in the pair being considered.

8.15.2.2 Independent of the requirements of 8.15.2.1, discontinuities having a greatest dimension of less than 3/32 in. (2.4 mm) if the sum of their greatest dimension exceeds 3/8 in. (9.5 mm) in any linear inch of weld.

8.15.3 Welds that are subject to ultrasonic testing, in addition to visual inspection, shall be acceptable if they meet the requirements of Table 8.15.3. Ultrasonically-tested welds are evaluated on the basis of a discontinuity reflecting ultrasound in proportion to its effect on the integrity of the weld.

8.15.4 Welds that are subject to liquid penetrant testing in addition to visual inspection, shall be evaluated on the basis of the requirements for visual inspection.

Part B Allowable Unit Stresses

9.3 Unit Stresses in Welds[31]

Note: The application of these stresses is modified by the requirements of 9.4.

9.3.1 Except as modified by 9.4, 9.5, and 9.6, allowable unit stress in welds shall not exceed those listed in Table 9.3.1.

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

9.4 Fatigue Stress Provisions

The fatigue stress provisions shall, as applicable, comply with the Standard Specifications for Highway Bridges as adopted by the American Association of State Highway and Transportation Officials (AASHTO) or Specification for Steel Railway Bridges of the American Railway Engineering Association (AREA). For bridges subject to cyclic loading, other than highway or railway applications, stress ranges may be obtained from Table 9.4 and Figs. 9.4a and 9.4b for appropriate general condition and cycle life. The cycle life should be determined by the Engineer to meet the planned life requirements of the structure.

9.5 Combined Unit Stresses

In the case of axial stress combined with bending, the allowable unit stress of each kind shall be governed by the requirements of 9.3 and 9.4 and the maximum combined unit stresses calculated therefrom shall be limited in accordance with the requirements of the applicable general specifications.

9.6 Increased Unit Stresses

When the applicable general bridge specification permits the use of increased unit stresses for combination of loads or for secondary or erection stresses, corresponding increases may be applied under this code.

[31] Unless specified in the general specifications, it is recommended that the basic unit shear stress in the net section be 65 percent of the basic allowable stress in tension.

Part C Structural Details

9.7 General

In general, details shall minimize constraint against ductile behavior, avoid undue concentration of welding, and afford ample access for depositing the weld metal.

9.8 Noncontinuous Beams

The connections at the ends of noncontinuous beams shall be designed with flexibility so as to avoid excessive secondary stresses due to bending. Seated connections with a flexible or guiding device to prevent end twisting are recommended.

9.9 Participation of Floor System

Details of the floor system should be so designed as to avoid, in so far as possible, unintended participation in the chord or flange stresses.

9.10 Lap Joints

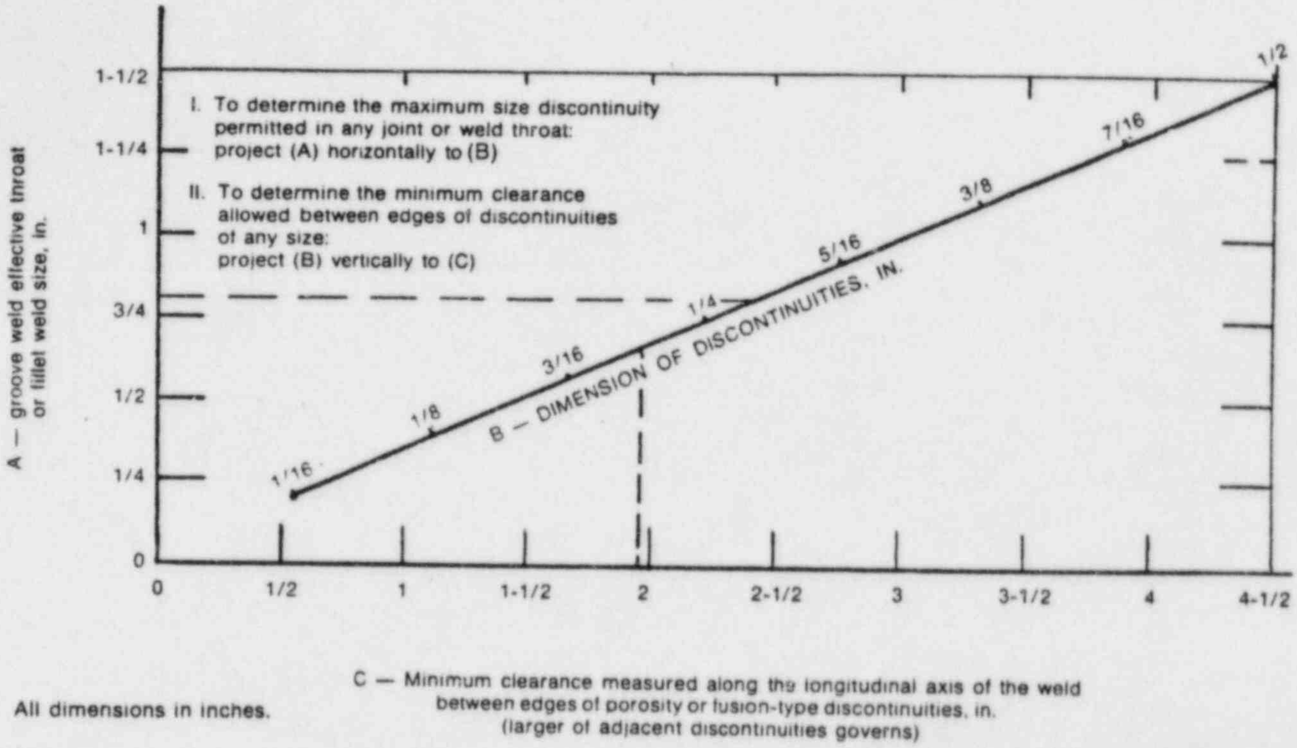
9.10.1 The minimum overlap of parts in stress-carrying lap loints shall be five times the thickness of the thinner part. Unless lateral deflection of the parts is prevented, they shall be connected by at least two transverse lines of fillet, plug or slot welds, or by two or more longtitudinal fillet or slot welds.

9.10.2 If longitudinal fillet welds are used alone in lap joints of end connections, the length of each fillet weld shall be no less than the perpendicular distance between them. 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 welds may be either at the edges of the member or in slots.

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

9.11 Corner and T Joints

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.



Note:
Adjacent discontinuities, spaced less than the minimum spacing required by Fig. 9.25.2.1, shall be measured as one length, equal to the sum of the total length of the discontinuities plus the length of the space between them, and evaluated as a single discontinuity by Fig. 9.25.2.1

Fig. 9.25.2.1—Weld quality requirements for discontinuities occurring in tension welds (limitation of porosity and fusion-type discontinuities).

9.23.1.3 Web distortions of twice the allowable tolerances of 9.23.1.2 shall be satisfactory when occuring at the end of a girder which has been drilled, or subpunched and reamed; either during assembly or to a template for a field bolted splice; provided, when the splice plates are bolted, the web assumes the proper dimensional tolerances.

9.23.1.4 If architectural considerations require tolerances more restrictive than described above, specific reference must be included in the bid documents.

9.24 Temporary Welds

Temporary welds shall be subject to the same welding procedure requirements as the final welds. They shall be removed unless otherwise permitted by the Engineer. When they are removed, the surface shall be made flush with the original surface. There shall be no temporary welds in tension zones of members 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 and shall be made with E70XX low hydrogen electrodes.

9.25 Quality of Welds

9.25.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if it shows that:

9.25.1.1 The weld has no cracks.

9.25.1.2 Thorough fusion exists between weld metal and base metal.

9.25.1.3 All craters are filled to the full cross section of the weld.

9.25.1.4 Weld profiles are in accordance with 3.6.

9.25.1.5 The frequency of piping porosity in fillet welds shall not exceed one in each 4 in. (102 mm) of length and the maximum diameter shall not exceed 3/32 in. (2.4 mm). Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in. (9.5 mm) in any linear inch of weld and shall not exceed 3/4 in. (19.0 mm) in any 12 in. (305 mm) length of weld.

9.25.1.6 A fillet weld in any single continuous weld shall be permitted to underrun the nominal fillet weld size required by 1/16 in. (1.6 mm) without correction, provided that the undersize weld does not exceed 10 percent of the length of the weld. On web-to-flange welds on girders no underrun is permitted at ends for a length equal to twice the width of the flange.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	}{	
	}{	
TEXAS UTILITIES ELECTRIC COMPANY, et al.	}{	Docket Nos. 50-445-1 and 50-446-1
(Comanche Peak Steam Electric Station, Units 1 and 2)	}{	

CERTIFICATE OF SERVICE

By my signature below, I hereby certify that true and correct copies of CASE'S ANSWER TO APPLICANTS' MOTION FOR SUMMARY DISPOSITION OF CERTAIN CASE ALLEGATIONS REGARDING AWS AND ASME CODE PROVISIONS RELATED TO WELDING ISSUES; CASE'S ANSWER TO APPLICANTS' STATEMENT OF MATERIAL FACTS AS TO WHICH THERE IS NO GENUINE ISSUE; AND AFFIDAVIT OF CASE WITNESS JACK DOYLE

have been sent to the names lilsted below this 14th day of May, 1984, by: Express Mail where indicated by * and First Class Mail elsewhere. (Copies of attachments are being sent only to the parties and Docketing & Service)

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