A PROPOSED
FRACTURE CONTROL PLAN FOR NEW BRIDGES
with
FRACTURE CRITICAL MEMBERS

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Volume I

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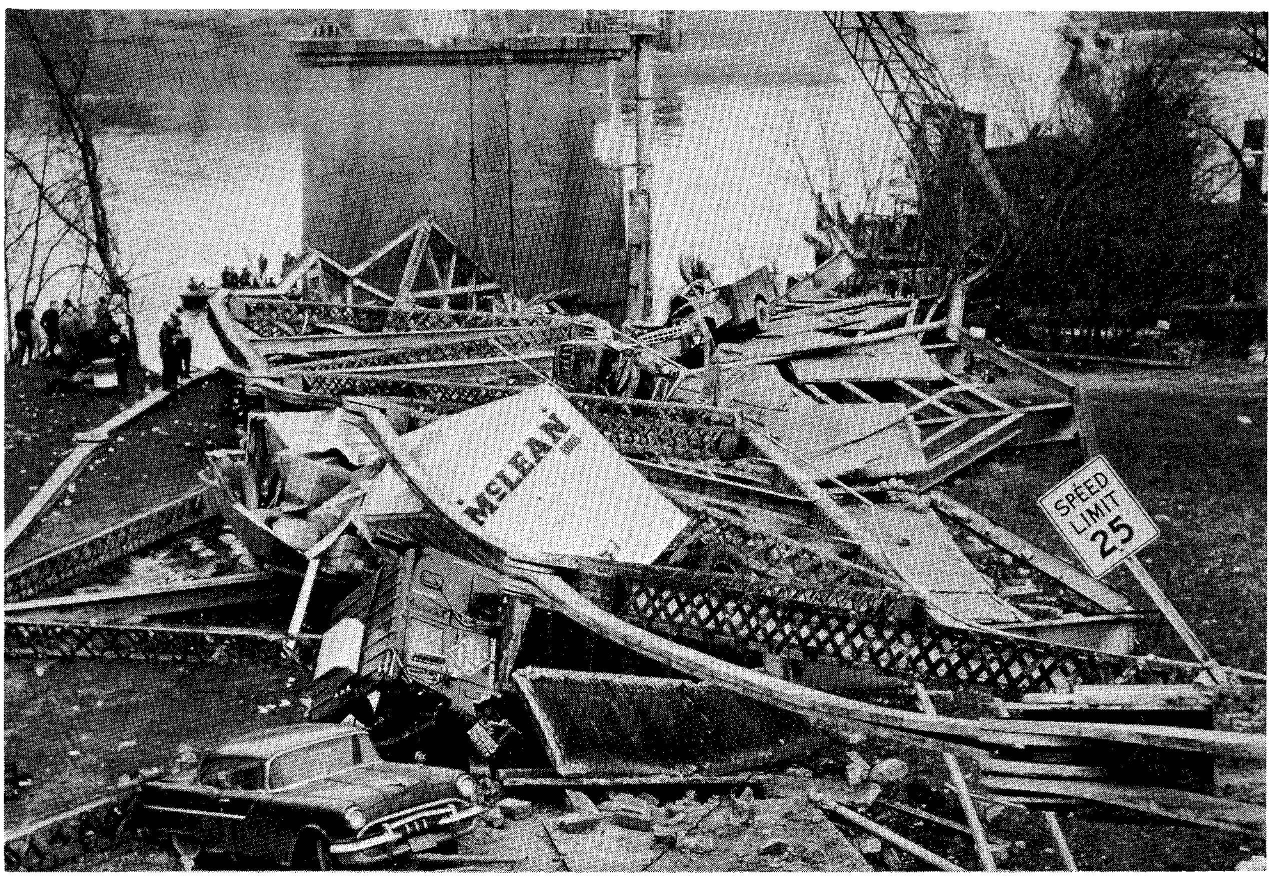

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Requests for these documents and suggestions on the contents of any publications should be addressed to the Federal Highway Administration, Office of Engineering, Bridge Division, HNG-32, Washington, D.C. 20590.

COVER

The cover shows some of the wreckage of the Silver Bridge, an eyebar-chain suspension bridge at Point Pleasant, West Virginia. Eyebars, deck slabs, and collapsed steel trusses can be seen. The bridge was built in 1929, and collasped, killing 46 people, in 1967. The view shown was photographed from the Ohio approach span, looking east.

DIGEST
of the
FRACTURE CONTROL PLAN FOR NEW BRIDGES
with
FRACTURE CRITICAL MEMBERS

by
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Volume I

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PREFACE

The following is a digest of the American Welding Society (AWS) Structural Welding Code, as amended, for fracture-critical members. With the amendments, this is far more than a welding code; it is in fact a fracture control plan encompassing design, materials specification, and inspection, as well as detailed welding requirements. As a digest, the following is not sufficient in itself; a revision of AWS D1.1 in its entirety as it applies to bridges is available for application to fracture critical members (FCMs). See Volume II.

The amended code constitutes a modification of the following publications:

(1) the American Welding Society (AWS) Structural Welding Code AWS D1.1-75, as revised,

(2) the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Welding of Structural Steel Highway Bridges, Second Edition, 1977,

(3) the AASHTO Standard Specifications for Highway Bridges, 12th Edition, 1977,

(4) the AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1, Specifications, 11th Edition, 1974.

The modifications supersede the above documents. With the exception of Section 1-General Provisions, the paragraph, table and figure numbers used correspond to the numbers in AWS D1.1-75. Section 9-Design of New Bridges of AWS D1.1 has been deleted and those provisions of Section 9 deemed relevant to FCMs have been incorporated in the appropriate sections of this code.

Revision of the Code was deemed necessary as a result of several instances of weld cracking and brittle fracture in major bridges in the last decade. Moreover, fabrication shop inspections and the welding associated with service failures has revealed many instances of unsatisfactory workmanship and quality control. In the interest of public safety, where fracture critical members are used, it is imperative that more strigent controls be exercised.

Some engineers, examining the fracture control plan with economics in mind, will conclude that fracture-critical members no longer should be used in bridge design. This may well be a valid conclusion if we can not regain control over the quality of workmanship required for FCMs at all stages of fabrication. However, there is no easy solution to the overall problem because certain details commonly used in bridges are fracture critical, i.e., not all fracture-critical details can be readily abandoned.

FRACTURE-CONTROL PLAN

1. GENERAL PROVISIONS*

1.1 SCOPE. This fracture control plan:

1.1.1 assigns responsibility for specifying which, if any, steel structural components fall in the category of "fracture critical", (par. 1.3.1);

1.1.2 requires American Institute of Steel Construction (AISC) Quality Certification, or other suitable certification of the fabricator to assure that girders containing "fracture-critical" members are fabricated by plants with personnel, organization, experience, procedures, knowledge, and equipment capable of producing quality workmanship (par. 1.4.1);

1.1.3 requires that all Welding Inspectors be qualified under the provisions of the American Welding Society (AWS Qualification and Certification Program, or other suitable demonstration of competence to assure that "fracture critical" members are in compliance with this control plan (par. 6.1.2);

1.1.4 requires American Society of Nondestructive Testing (ASNT Level-II and Level-III personnel on the staff of both the fabricator and the Engineer for the inspection of "fracture critical" members (par. 6.1.3);

1.1.5 requires that the designer have overall responsibility for implementation of this fracture-control plan, both in fabrication and in erection (par. 1.3);

1.1.6 requires that the designer review the shop drawings, the weld-procedure-qualification testing, the weld-procedure specifications and the qualifications of the shop welding inspectors (par. 1.3.2 and 1.3.3);

1.1.7 requires that the designer specify the methods to be used in non-destructive inspection and the specific joints to be inspected (par. 1.3.4);

1.1.8 provides for Quality Assurance (QA) as a prerogative of the Engineer (par. 6.1.1), with QA verification based on reexamination of selected welds (par. 6.1.1.1);

1.1.9 specifies the use of more strigent preheat/interpass temperatures (par. 4.2.2) and provides for 450°F postheat in weld repair (par. 4.2.3);

1.1.10 requires more strigent weld-procedure qualification testing (par. 5.6 and 5.12);

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*With the exception of Section 1 - General Provisions, the paragraph numbers correspond to AWS D1.1, as amended.

1.1.11 makes provision for testing production-welding procedures by use of extended run-off plates (par. 4.1.1.4);

1.1.12 permits the substitution of production-weld-procedure testing for weld-procedure-qualification testing under 5.2 at the discretion of the Engineer (par. 4.1.1.5);

1.1.13 requires more strigent controls in repair welding (par. 3.7);

1.1.14 specifies more strigent control over welding consumables (par. 4.1.2.4, 4.9, 4.12, 4.13, 4.16, and 4.18);

1.1.15 prohibits the use of "active" submerged-arc-welding fluxes in groove welds and fillet welds with more than three (3) passes (par. 4.1.1.1);

1.1.16 prohibits the use of incomplete-penetration groove welds and fillet welds in tension components where the joint is transverse to the applied stress (par. 2.5);

1.1.17 makes provision for weld-procedure-qualification toughness testing of fillet welds where the fillets are to be used in lieu of complete-pentration groove welds transverse to the applied stress (par. 4.1.1.2.7, 5.10.3.4 and 5.12.1.7);

1.1.18 provides for E399 testing in groove-weld procedure qualification, as an alternative to Charpy testing (par. 4.1.1.2.1);

1.1.19 permits local stress relief of groove-weld butt-, T-, and corner-joints when Charpy V-notch impact tests of weld metal fail to meet the specified toughness at the LAST (par. 4.1.1.2.4);

1.1.20 specifies fracture toughness values for weld metal and base metal based on the concept of through-thickness yielding, where the specified toughness values are a function of plate (and weld) thickness and yield strength (par. 1.5.4 and 4.1.1.2);

1.1.21 limits thickness to 3 inches in a plate with yield strength up to 90 ksi, and 2 inches in plate over 90 ksi (par. 1.5.3);

1.1.22 requires that fracture testing be done no higher than the lowest anticipated service temperature (the LAST), where the LAST is based on a first percentile minimum temperature for the geographical location of the structure (par. 1.5.4.1);

1.1.23 provides for a nil-ductility transition (NDT) temperature 30°F below the lowest anticipated service temperature (LAST) based on "no-break" performance 20°F below the LAST (par. 1.5.4);

1.1.24 prohibits field welding of FCMs (par. 2.15.6.9).

1.2 Definitions.

1.2.1 Fracture critical members (FCMs) are those tension components whose failure would be expected to result in the collapse of the structure.

1.2.2 Tension components of a structure consist of pure tension members and those portions of a flexural member that are subject to tension stress. The connecting welds in any attachment joined to a tension component of a FCM shall be considered part of the tension component and, therefore, shall be considered fracture critical.

1.3 Design and Review Responsibilities. The designer has full responsibility for suitability of the design of the structure for its intended purpose, including the selection of materials, weld details, and methods and locations for nondestructive inspection.

1.3.1 The prime responsibility for determining which, if any, structural components fall in the FCM category shall rest with the designer.

The designer shall evaluate his design to determine the location of FCMs. The location of all members or components deemed "fracture critical" by the designer shall be clearly delineated on the contract plans. The designer shall review the shop drawings involving FCMs to assure that they show the location and extent of FCMs. A note on the first page of the contract plans shall state whether there are or are not FCMs.

1.3.2 The designer shall have a welding engineer review the contract plans and shop drawings for weld-joint design, the weld-procedure qualification and the weld-procedure specifications to assure conformance with the AWS/AASHTO Structural Welding Code, as amended herein. The welding Engineer shall verify the qualifications of the contractor's welding inspectors, and supervise the Quality Assurance welding inspection.

1.3.3 The designer shall verify the proper and sufficient implementation of this control plan for fracture-critical members. In addition to specifying which, if any, members are fracture critical, the designer shall verify compliance with this fracture-control plan at all stages of fabrication and erection.

1.3.4 All groove welds in tension-components and all attachment groove welds contiguous to tension components shall be nondestructively inspected as specified in Section 6, as amended, and the welds shall be qualified by testing in accordance with Section 5, as amended.

The designer shall designate on the contract plans those welds which are to be ultrasonically tested (UT), radiographically tested (RT), magnetic-particle (MP) tested, eddy-current (EC) tested, and/or dye-penetrant (DP) tested. The specific welds to be nondestructively tested shall be designated with one or combination of the following symbols: DP, EC, MP, RT and UT. All welds shall be visually inspected.

1.4 Fabricator Qualification Certification.

1.4.1 Structural steel fabricators shall be certified under the AISC Quality Certification Program, Category III, Major Steel Bridges, or other suitable program as determined by the Engineer before they are eligible to fabricate fracture-critical members.

1.5 Base Metal.

1.5.1 Steel types. The base metals to be used in FCMs are the carbon and low-alloy steels commonly used in the fabrication of steel structures including but not necessarily limited to the following ASTM types:

A36
A441
A572 grades 42, 45, and 50
A588
A514
A517

Whatever the steel used, it must be qualified by test using the procedures specified in Section 5 of the AWS/AASHTO Welding Code, as amended.

1.5.3 Plate thickness shall be limited to three (3) inches for yield strengths up to 90 ksi. With yield strengths greater than 90 ksi, the thickness shall be limited to two (2) inches.

1.5.4 Plate toughness. All plate used in FCMs shall be furnished to the Charpy V-notch (CVN) impact values specified in Table 1.5.4.

When retesting fails to produce 80 percent shear fracture as an indicator of upper-shelf performance (see footnote (a) of Table 1.5.4), the steel used in FCMs shall have a nil-ductility transition temperature (NDTT) at least 30^{o}F below the LAST.

The NDTT shall be determined in accordance with ASTM E208 with the following modification; in plate 1 1/2-inches thick and thicker, the drop-weight test specimens shall be positioned so as to test the midthickness of the plate, i.e., the crack-starter weld bead shall be deposited in the plane of the plate midthickness.

The NDT test requirement will be satisfied by "no-break" performance in triplicate specimens tested at a temperature corresponding to the LAST minus 20^{o}F. The "no-break" NDT performance criterion is described in ASTM E208-69 paragraph 15.1.

1.5.4.1 Lowest anticipated service temperature (the LAST). The LAST shall be based on the isoline in Figure 1.5.4.1 nearest the geographical location of the structure.

1.5.4.2 Impact-machine proof testing. In accord with ASTM E23, Charpy machines used in testing plate (and welds) of FCMs shall be proof tested with standarized specimens every six (6) months. Documentation based on the AMMRC report of evaluation shall be submitted to the Engineer prior to testing.

TABLE 1.5.4

CHARPY-IMPACT REQUIREMENT[a] for FRACTURE CRITICAL MEMBERS

YIELD[b] STRENGTH (ksi)	MINIMUM CVN-IMPACT (ft-lb)[c] AT THE LAST[d] FOR SPECIFIED THICKNESS RANGES (in.)		
	up to 2	over 2 to 2 1/2	over 2 1/2 to 3
from 36 to 60	25	30	35
over 60 to 70	30	35	40
over 70 to 80	35	40	45
over 80 to 90	40	45	50
over 90 to 100	45	(e)	(e)
over 100 to 110	50	(e)	(e)
over 110 to 120	55	(e)	(e)

NOTES: (a) The CVN-impact testing shall be "P" (plate) frequency testing; when more than one flange or web is stripped from a larger plate, only the larger plate need be tested. The Charpy test pieces shall be coded with respect to heat/plate number and that code shall be recorded on the mill-test report of the steel supplier with the test result. The fracture appearance at the LAST shall be no less than 80 percent shear (see ASTM A370-75, Section 23.2.2.1). If the fracture appearance in any one specimen is less than 80 percent shear (fibrous), a retest shall be made and the fracture appearance of each of the three retest specimens shall equal or exceed the 80 percent shear requirement. If the retest specimens fail to meet the fracture-appearance, ASTM E208 testing is required.

(b) The yield strength is the value given in the certified MILL TEST REPORT.

(c) Average of three (3) tests. If the energy value for more than one of the three test specimens is below the minimum average requirement, or if the energy value for one of the three specimens is less than 75 percent of the specified minimum average requirement, a retest shall be made and the energy value obtained from each of the three retest specimens shall equal or exceed the specified minimum average requirement.

(d) The lowest anticipated service temperature (the LAST) shall be based on the isoline in Figure 1.5.4.1 nearest the geographical location of the structure.

(e) Plate in excess of 2-inch thick shall not be used in FCMs when the yield strength exceeds 90 ksi.

FIGURE 1.5.4.1 - ISOLINES FOR FIRST-PERCENTILE MINIMUM TEMPERATURES, the basis for determining the lowest anticipated service temperature (LAST) for fracture critical members (FCMs).

2. DESIGN OF WELDED CONNECTIONS

2.1 General. For FCMs, there are requirements which supersede those presently specified in the AWS/AASHTO Structural Welding Code Section 2. The following is a digest of AWS D1.1, as amended.

Drawings. The term "drawings" refers to plans, the design and detail drawings contained in the contract plans, shop working drawings, and erection plans. No welds shall be made in or on FCMs that are not shown on the drawings.

2.1.1.1 Shop drawings shall show the location, type, size and extent of all welds. The joint design details shall conform to AWS/AASHTO Section 2 paragraphs 2.9.1, 2.10.11, 2.11.1, 2.12.1, 2.13.1 and 2.14.1, as amended.

2.1.1.2 Erection plans shall show the location, type, size and extent of all field welds. The erection plans shall be approved by the Engineer in writing prior to any field welding. The erection plans shall clearly distinguish between shop and field welds. The term "field weld" refers to any weld, including temporary attachments for purposes of erection, done off the premises of the fabricator's shop.

2.1.1.3 Railroads shall be prohibited from welding temporary attachments for shipping purposes.

2.5 Partial Joint Penetration Welds. Partial-penetration welds subject to tension normal to the longitudinal axis of the weld including both groove and fillet welds shall not be used in FCMs, except under 4.1.1.2.7.

Holes or slots in members or components to permit passage of another member or component through the member or component shall not be welded to seal or otherwise close the hole or slot.

2.6 Joint Qualification.

2.6.1 Joint design configurations that are in conformance with the details specified in AWS D1.1 Figures 2.9.1 through 2.9.14, inclusive are prequalified for FCMs except as restricted under 2.5.

2.8 Allowable Stresses. (see AWS D1.1-75, 9.3 through 9.6)

2.8.2.1 Fatigue categories D and E shall not be used in FCMs.

2.15 Structural Details. (see AWS D1.1-75, 9.12)

2.15.6 Prohibited types of joints and welds. The joints and welds listed in the following paragraphs are prohibited:

2.15.6.1 Butt joints not fully welded throughout their cross section.

2.15.6.2 Groove welds made from one side only

(1) without backing,

(2) with backing other than steel

These prohibitions for groove welds made from one side only shall not apply to (1) secondary or non-stress carrying members, for shoes, etc., where such welds are not contiguous to an FCM, and (2) corner- and T-joints parallel to the applied stress between components of built-up members designed primarily for axial stress.

2.15.6.3 Intermittent groove welds.

2.15.6.4 Intermittent fillet welds.

2.15.6.5 Bevel-grooves and J-grooves in butt joints for other than horizontal positions (see Figures 2.9.1 and 2.13.1).

2.15.6.6 Partial-penetration fillet welds and groove-weld butt-, T- and corner-joints perpendicular to the applied stress.

2.15.6.7 For joints perpendicular to the applied stress, welds with backing bars left in place and backing fillet welds outside the groove weld.

2.15.6.8 Any temporary weld made in the steel mill, in fabrication, in transportation and/or in erection not shown on the drawings.

2.15.8 <u>Welds in combination with rivets and/or bolts</u>. (see AWS D1.1, 9.14)

2.15.8.2 Bolts used in assembly may be left in place if their removal is not specified. If bolts are removed or mislocated, the holes shall be corrected under 3.7.4.

2.15.8.3 In the design of attachments to FCMs, to the maximum extent possible, connection of the attachment (stringers, gussets, etc.) shall be a bolted connection.

2.15.8.4 Field welding of FCMs shall be eliminated in so far as possible; in the field the preferred connection is a bolted connection.

2.15.12 <u>Girders and beams</u>. (see AWS D1.1-75, 9.21)

2.15.12.3 <u>Stiffeners</u>. If stiffeners are used on only one side of the web, they shall be welded to the compression flange.

Stiffener-to-web connections perpendicular to the applied stress in a pure tension member shall be a complete-penetration groove-weld T-joint, except as provided under 4.1.1.2.7.

Stiffener-to-web connections perpendicular to the applied stress in flexural members, in locations of tension stress the connections shall be a complete-penetration groove-weld T-joint for one-third (1/3) the depth of the girder but not less than two (2) feet. The remaining 2/3 of the stiffener-to-web connection may be an incomplete penetration fillet weld. For exception, see 4.1.1.2.7.

The groove-weld T-joint welding procedure for welds perpendicular to the applied stress shall be qualified by testing, per 5.2, as amended.

Diaphram and hanger welds involving flange and/or web connections perpendicular to the applied stress shall be a complete-penetration groove-weld T-joint. For exception, see 4.1.1.2.7.

2.15.12.5 Cover plates. Cover plates shall be limited to one on any flange. The maximum thickness of cover plates on a flange shall be no greater than 1-1/2 times the thickness of the flange to which the cover plate is attached. The thickness and width of a cover plate may be varied by butt welding parts of different thickness or width with transitions conforming to the requirements of 2.15.11. Such plates shall be assembled and welds ground flush before attaching to the flange. The width of a cover plate, with recognition of dimensional tolerances allowed by ASTM Specification A6, shall allow suitable space for a fillet weld along each edge of the joint between the flange and the plate cover.

In FCMs, when partial-length cover plates are used, the ends of cover plates shall be in sections where the stress is compression. The ends of the cover plate shall be cut square, and a continuous fillet weld shall be deposited across the end and along both edges of the cover plate or flange to connect the cover plate to the flange. The fillet welds shall not terminate at the corners of the cover plate, but shall be returned continuously full size around the corner for a length equal to twice the weld size where such return can be made in the same plane. Boxing shall be indicated on design and detail drawings.

3. WORKMANSHIP

3.1 General. For FCMs, there are requirements which supersede those presently specified in the AWS/AASHTO Structural Welding Code Section 3. The following is a digest of AWS D1.1, as amended.

3.1.5 Temporary welds, welds to fitting aids, and tack welds not incorporated in a joint shown on the drawings (see 2.1) shall not be used during assembly, for shipment or in erection of FCMs unless detailed on the appropriate drawings and approved by the Engineer in writing.

3.1.6 So-called cosmetic welding shall be treated as a weld repair as specified in 3.7, as amended.

3.7 Weld Repairs. The AWS Structural Welding Code, paragraphs 3.2, 3.7, 4.4 and 5.2 are supplemented by a mandatory requirement that all repairs to base and weld metal be documented giving the details of the type and extent of defects. Weld-repair procedures shall be approved by the Engineer prior to initiating repairs. Repair welding is defined as any welding, including the removal of weld or base metal in preparation for welding as necessary to correct defects in materials or workmanship.

3.7.1 Repair welding may be performed using any of the welding procedures qualified for use in the fabrication of FCMs. All repair welding shall be subject to nondestructive tests as provided herein.

3.7.2 Repair welding which consists solely of the deposition of additional weld beads to compensate for insufficient weld throat or to remove undercut shall not require prior approval of the Engineer providing the deficiency is detected and corrected before the preheat/interpass temperature falls below the specified minimum (see 4.2.2.2).

3.7.3 For noncritical repairs the Contractor may prepare written repair procedures and submit them to the Engineer for prequalification. Pre-approved prequalified procedures may be employed after the Engineer has verified that any given defect to be repaired is as described in the approved procedure. Noncritical repairs which may be prequalified include the following:

A. Gouges in cut edges that are less than 7/16-inches deep.

B. Lamellar discontinuities less than one-inch deep, or with a depth of less than one-half the thickness of the plate cut edge, whichever is less, provided the lamellar defect is not within 6-inches of a tension groove weld. There shall be no visible lamellar discontinuities in the boundaries of tension groove welds. Repair of such discontinuities by the "blocking-off" method will not be authorized.

C. The repair of base metal surfaces when ASTM A20 provides for repair by welding. Repair shall be performed as described in the approved procedure and is subject to 1.5.5.1.

D. First-time excavation and repair from one surface of groove welds and of fillet welds which contain porosity, slag or incomplete fusion provided the excavation does not exceed the following limits:

Weld Length "L"	Total Length of Excavation
Up to 1'-6"	"L" or 10" whichever is less
Over 1'-6" to 3'	1'-0"
Over 3' to 6'	1'-6"
Over 6' to 12'	2'-0"
Over 12' to 24'	3'-0"
Over 24'	3'-0" or 10 percent, whichever is greater

and the depth of the excavation does not exceed 65 percent of the effective throat of the weld as detailed on the Plans.

3.7.4 Critical repairs shall be individually approved by the Engineer before repair welding is begun. Critical repairs include the following.

A. Gouges in cut edges 7/16-inches deep or deeper.

B. Repair of lamellar defects not provided for in 3.7.3. Lamellar defects of the type designated W and X in AWS D1.1 Figure 3.2.3.3 shall not be "blocked-off" by welding and will not be permitted in the boundaries of groove welds subject to applied tensile stress.

C. Repair of surface or internal defects in rolled, forged, or cast products except as provided in 3.7.3.

D. Repair of weld defects except as provided in 3.7.3

E. Repair of any cracks including base metal separations such as lamellar tears. One exception will be allowed; viz., first-time excavation and repair of the root pass for "hot" or "restraint" cracking in any given joint.

F. Dimensional corrections requiring weld removal, rewelding or the use of heat and/or force.

G. Any weld correction to compensate for a fabrication error such as improper cutting, punching, drilling, machining, fitting, assembly, etc.

3.7.5 Repair procedures for noncritical and critical repairs shall include dimensioned isometric projections or full-scale plan view, elevation and section drawings to describe the deficiency and proposed method of repair, and to accurately locate the repair within the bridge member. The drawings shall become part of the QC/QA permanent records on each repair in any FCM.

3.7.7G Preheat and interpass temperature shall be given. Quenched-and-tempered (Q&T) steels shall be heated as shown in Table 4.2 except that the MAXIMUM temperatures shall be used whenever this temperature plus the heat input from welding does not exceed the steel manufacturer's recommendations. Steels in the as-rolled, control-rolled or normalized condition with thicknesses up to 1-1/2 inches shall be heated to 350°F minimum. Thicknesses over 1-1/2 inches shall be heated to 450°F minimum. Preheat/interpass and postheat temperatures shall be maintained without interruption until the repair is completed.

3.7.7J Postheat shall be employed and shall continue without interruption from the completion of repair welding to the end of the minimum specified postheat period. Postheat shall be at 450°F for a minimum of one (1) hour for each inch of thickness in the cross section being repair welded. The maintenance of preheat/interpass temperature during repair and postheat shall be continuous operations.

3.7.7M Repair welds shall be nondestructively examined. The testing shall be done according to AWS D1.1 Section 6, as amended. Initial testing may be performed as soon as the weldment has cooled to ambient temperature. Final acceptance of repair welds involving base metal and/or welding consumables with yield strengths up to 90 ksi shall be based on nondestructive examination conducted no sooner than 72 hours after the repair is completed. For base metal and/or welding consumables with yield strength over 90 ksi, the final-acceptance nondestructive examination shall be conducted no sooner than 96 hours after the repair is completed.

3.7.8 The repair-welding-procedure specification shall completely describe the procedure, including the weld technique (stringer beads, width of weave, "buttering", back-stepping, sequence of passes, etc.).

Noncritical repairs should be made using the qualified welding procedure of the joint being repaired or a joint elsewhere in the bridge member. If the volume removed in excavating the defect is too small for automatic welding, shielded metal-arc welding or a semi-automatic qualified welding procedure may be used.

For critical repairs, if the weld-repair procedure is not the same (subject to AWS D1.1 5.5 "limitation of variables") as the qualified welding procedure used in the joint being repaired, the weld-repair procedure shall be subjected to testing as specified in AWS 5.2, as amended.

4. TECHNIQUES

4.1 General. For FCMs, there are requirements which supersede those presently specified in the AWS/AASHTO Structural Welding Code Section 4. The following is a digest of AWS D1.1. as amended.

4.1.1.1 In submerged-arc welding, "active" fluxes shall not be used in groove welds or fillets with over three (3) weld passes.

4.1.1.2 The weld metal of groove welds deposited with the qualified welding procedure shall have Charpy V-notch impact values when tested at the lowest anticipated service temperature (the LAST) as specified in Table 4.1.1.2.

4.1.1.2.1 Groove-weld joints may be qualified by the ASTM E399 Standard Method of Test as an alternative to the Charpy V-notch impact test requirement of Table 4.1.1.2.

The weld metal deposited using the qualified welding procedure shall meet the requirements of Table 4.1.1.2.1. The E399 testing shall be done with 1-inch specimens.

When the 1-inch compact specimen is used, the K_Q value shall be calculated from the expression

$$K_Q = 0.68R_{sc} \cdot FTY$$

where R_{sc} is the E399-74 paragraph 9.1.7 specimen strength ratio and FTY is the mill-test-report yield strength.

When the 1-inch bend specimen is used, the K_Q value shall be calculated from the expression

$$K_Q = 0.63R_{sb} \cdot FTY$$

where R_{sb} is the E399-74 paragraph 9.1.6 and FTY is the mill-test-report yield strength.

4.1.1.2.3 Groove-weld joints not meeting the toughness requirements of 4.1.1.2 and 4.1.1.2.1 may be stress relieved (local) at 1150^{o}F, or at a temperature of 50^{o}F below the tempering temperature in quenched-and-tempered (Q&T) steels.

If stress relieving is used, the stress-relief treatment shall be made a part of the weld-procedure specifications. Weld-procedure qualification including toughness testing as specified in 4.1.1.2 and 4.1.1.2.1, and nondestructive inspection as required in AWS D1.1 Section 6, as amended, shall be done after stress relieving.

4.1.1.2.4 Local stress-relief treatment shall be accomplished by electric-resistance heating or an equivalent method; torch heating shall not be used. The width of the heated zone on each side of the weld shall be at least three (3) times the base-metal thickness or six (6) inches, whichever is the larger dimension. Plate on either side of the groove-weld joint shall be insulated during and after stress relief to assure slow uniform cooling. The soaking time shall be one (1) hour per inch of thickness; at a transition butt joint, a T-joint or a corner joint, the soaking time shall be (1) hour per inch of the thicker of the adjacent groove-welded plates. The heating and cooling rates shall not exceed 400°F per hour divided by the thickness of the plate being joined (or the thickness of the thicker plate). In no case shall the temperatures measured at a point 2 inches from the weld center-line on either side of the joint be different by more than 75°F.

4.1.1.2.7 Where welds are perpendicular to the applied stress, in lieu of complete-penetration groove-weld T-joints, partial-penetration fillet welds may be approved by the Engineer providing fillet weld-procedure-qualification testing meets the Charpy V-notch impact requirement of 5.12.1.7.

4.1.1.4 When required by the Engineer, a sample (test) joint of the same cross section as the joint in construction shall be provided for testing by means of an extended "run-off" plate.

4.1.1.4.1 The Engineer may require sampling of up to ten (10) percent of the groove-weld butt splices.

4.1.1.4.2 The run-off plate shall be of sufficient length to provide all-weld-metal tensile and Charpy specimens, as specified in AWS 5.2, as amended.

4.1.1.4.3 The run-off plate shall be of the same type and grade as the member being fabricated and shall have the same edge preparation and joint design as the plate being spliced. The welding of the member being fabricated and the welding of the run-off plate shall be done without interruption as one continuous operation.

4.1.1.4.4 Any production weld, sampled by testing a run-off plate, that fails to meet the toughness requirements shall be stress relieved as specified in 4.1.1.2.3 and 4.1.1.2.4, and any untested production welds made to the same weld-procedure specification also shall be stress relieved.

Before stress relieving production welds, a test plate shall be prepared using the weld-procedure specification in question, stress relieved in accordance with 4.1.1.2.3 and 4.1.1.2.4 and tested for compliance with 4.1.1.2.

4.1.1.5 With well-documented evidence of a prequalified procedure, the Engineer may accept production-welding-procedure testing in lieu of weld-procedure-qualification testing.

4.1.1.5.1 When run-off plate production-welding-procedure testing is allowed by the Engineer in lieu of 5.2 testing, the frequency of testing and the type of testing shall be the same as specified for weld-procedure-qualification testing except that bend and transverse tensile testing will be waived.

4.1.1.5.2 In the event the production-weld testing fails to give the specified toughness values, the requirements of 4.1.1.4.4 shall be met.

4.1.2.4 Each heat/lot of electrode and welding wire shall be pretested in accordance with ASME Section III Nuclear Specifications and certified as manufactured in compliance with paragraph NB-2400, Section III (1974), Class 1, components, of the ASME Boiler and Pressure Vessel Code, except for "lot" definition. The material shall be manufactured to the lot definition approved by ASME Code Case 1567 using one heat of core wire. Each electrode and wire container shall be identified by heat and lot number.

4.2 Preheat/Interpass Temperature.

4.2.2 The preheat/interpass temperature shall conform to the MINIMUM requirements of Table 4.2 (amended) for the higher yield-strength material in any given weld joint. Quenched-and-tempered (Q&T) steel shall conform to the preheat/interpass requirements specified as a function of welding-procedure energy input, KJ/in.

4.2.2.3 When postheating is required, as in paragraph 4.2.3, at no time shall the joint be allowed to cool below the MINIMUM specified preheat/interpass temperature before postheating is started.

4.2.3 For weld repair, the preheat/interpass temperature of Table 4.2, as amended, shall be used as specified in 3.7.7 together with a 450°F postheat for a minimum of one (1) hour for each inch of thickness in the cross section at the weld repair.

4.7 Groove-Weld Backing.

4.7.1 The steel used for backing welds perpendicular to the applied stress shall be removed, the joint backgouged and welding completed from the back side, except where not accessible. To facilitate removal of the backing, the backing shall be tacked in place from inside the joint; therefore, the only welds holding the backing shall be incorporated in the groove weld being backed.

4.9 Electrodes for Shielded Metal Arc Welding.

4.9.2 All electrodes having low-hydrogen coverings conforming to AWS A5.1 and AWS A5.5 shall be furnished in hermetically sealed containers. All

TABLE 4.2 (AMENDED)

PREHEAT/INTERPASS TEMPERATURE (^{o}F)

AS-ROLLED, CONTROL-ROLLED AND NORMALIZED STEELS

Thickness of Thickest part at the joint	PLATE AND/OR WELD METAL YIELD STRENGTH Up to 70 ksi	70 to 90 ksi	Over 90 ksi
INCHES	MIN	MIN	MIN
to 3/4, inc.	100	200	250
over 3/4 to 1-1/2	150	250	300
over 1-1/2 to 2-1/2	200	300	350
over 2-1/2	300	350	400

QUENCHED-AND-TEMPERED STEELS

	WELDING ENERGY INPUT, KJ/in.					
THICKNESS	30	40	50	70	90	110
3/8 to 1/2	150-300	100-200	100-200	100-200		
over 1/2 to 3/4	250-400	200-350	100-250	100-200	100-200	
over 3/4 to 1		250-400	250-400	150-300	100-200	100-200
over 1 to 2			250-400	250-400	200-350	200-300
over 2			300-450	300-450	300-450	300-400

NOTES: 1) When the temperature of the base metal is below the temperature listed for the thickness of material being welded, it shall be preheated (except as otherwise provided) in such manner that the surface 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, with the preheat/interpass temperature measured on both sides of the plates being joined. Heat input when welding quenched and tempered steel shall not exceed the steel producers' recommendations.

2) Welding shall be carried to completion before the joint is allowed to cool below the minimum preheat/interpass temperature specified; i.e., the weld joint shall not drop below the minimum preheat/interpass temperature until the last weld pass of the joint is completed.

3) Welding a steel section which is at an initial temperature below 100^{o}F may require localized preheating to remove moisture from the surface of the steel.

shielded metal-arc welding of FCMs shall be done using low-hydrogen electrodes.

4.9.2.1 Within one-half (1/2) hour of removal from hermetically sealed containers, the electrodes shall be dried for at least two (2) hours, but not to exceed four (4) hours, between 500 and 550°F before they are used. Electrodes not used immediately after drying shall be placed in a holding oven at 250 to 300°F and held in that temperature range continuously until used. Electrodes removed from the holding oven shall be used within the exposure times specified in Table 4.9.2.

TABLE 4.9.2

EXPOSURE TIME OUTSIDE THE HOLDING OVEN

Electrode Type	Maximum Time Before Use
E70, E80 & E90	1 hour
E100, E110 & E120	1/2 hour

Electrodes exposed for periods longer than specified shall be redried by baking prior to use.

4.9.3.2 The coverings of all low-hydrogen electrodes supplied in hermetically sealed containers shall have a maximum moisture content of 0.3 percent by weight for E70XX-X, E80XX-X and E90XX-X classifications and 0.1 percent by weight for E100XX-X, E110XX-X and E120XX-X classifications. Each container shall be so certified by the electrode manufacturer. The Engineer may sample electrodes at random to verify the moisture content.

4.12 Electrodes and Flux for Submerged-Arc Welding.

4.12.1.1 A weld-procedure-qualification test shall be made for each thickness and each electrode/flux combination in accordance with AWS 5.2, as amended.

4.12.1.2 Alloy "active" fluxes shall not be used in groove welds or fillet welds with more than three passes.

4.12.1.3 For welding FCMs, the provisions of 4.1.2.3 , 4.1.2.4 and 4.1.3.1 require consumable certification, package heat/lot/batch identification and hydrogen determination.

4.13.1 Flux from packages more than six months old, or from damaged packages, or from opened packages that have not been stored at a minimum temperature of 250°F, shall be dried in a suitable oven for at least two hours between 500° and 550°F.

4.13.4 When flux is "dried" as in 4.13.1 and 4.13.3, the drying operation shall be performed in a suitable over with racks for spacing the trays, and each tray shall be no more than three (3) inches deep.

4.13.5 The flux from 10 percent of the packages used in welding FCMs, in a random sampling, shall be analyzed for moisture content on delivery from the manufacturer's plant and any packages not used within the specified six-month storage period shall be reanalyzed before use. The moisture content of the flux as received shall not exceed 0.2 percent by weight.

4.13.5.1 The flux manufacturer shall date each individual package of flux with the date of shipment. The six-month maximum storage shall start from that date.

4.13.5.2 The moisture content of the flux in the 10 percent as-received sampling, and after six-month storage shall be analyzed by the method of AWS A5.5-64T paragraph 25, Figure 10 and A1.9 for SMAW electrode coverings.

4.13.5.3 If the moisture content as indicated by the as-received sampling or after six-month storage exceeds the as-received maximum allowable moisture content of 4.13.5 the flux shall not be used in welding FCMs.

4.13.5.4 Groove-weld joints found to have been welded with flux improperly stored and/or exceeding the specified moisture limit shall be given final nondestructive inspection not sooner than 96 hours after the completion of welding. When the groove-weld joints are stress relieved, the inspection may be done as soon as the weld cools to ambient temperature. Such joints found to be cracked may be rejected by the Engineer.

4.16 Electrode and Shielding Gas for FCAW.

4.16.1.1 In FCMs, all welding with the flux-cored-arc welding process shall be restricted to the flat and horizontal positions.

4.18.1.1 FCAW electrodes for use in FCMs shall be subject to a diffusible-hydrogen test conducted on the deposited weld metal in accordance with CSA Standard W487, Diffusible Hydrogen in Weld Steel and Low-Alloy Weld Metals: Test Method (Canadian Standard). The electrode manufacturer shall certify that the diffusible hydrogen in electrodes supplied for FCMs does not exceed the values in Table 4.18.1.1.

4.18.1.2 The Engineer may sample electrodes at random to determine the diffusible hydrogen content. Groove-weld joints found to have been welded with electrode exceeding the limits cited above shall be subjected to final nondestructive inspection not sooner than 96 hours after the completion of welding. Such joints found to be cracked may be rejected by the Engineer.

TABLE 4.1.1.2

WELD METAL
CHARPY-IMPACT REQUIREMENT (a)
for
FRACTURE CRITICAL MEMBERS

WELD METAL YIELD (b) STRENGTH (ksi)	MINIMUM CVN-IMPACT (ft-lb) (c)(d) AT THE LAST (e) FOR SPECIFIED THICKNESS RANGES (in.)		
	up to 2	over 2 to 1 1/2	over 2 1/2 to 3
from 36 to 60	25	30	35
over 60 to 70	30	35	40
over 70 to 80	35	40	45
over 80 to 90	40	45	50
over 90 to 100	45	50	(f)
over 100 to 110	50	55	(f)
over 110 to 120	55	60	(f)

NOTES: (a) Charpy specimens taken from weld-procedure-qualification test plates (see 5.1.1.1) and from run-off production-weld sampling (see 4.1.1.4). In weld-procedure-qualification tests of groove-weld butt joints and T- and corner-joints which are to be perpendicular to the applied stress, the fracture appearance at the LAST shall be no less than 80 percent shear (see ASTM A370-75, Section 23.2.2.1).

(b) The weld-metal yield strength is the value as measured in weld-procedure-qualification test plates or in production-weld run-off plates.

(c) A Charpy "test" shall be made with five (5) weld-metal Charpy specimens. When computing the average, the lowest value and the highest value obtained from the five specimens shall be disregarded. If the value for more than one of the three values averaged falls below the specified minimum value, or if one of the values averaged is less than 2/3 of the specified minimum value, a retest shall be made and the value obtained from all three specimens must equal or exceed the specified minimum average value.

(d) If the fracture appearance of one of the specimens used in computing the average energy value is less than 80 percent shear, a retest shall be made and the fracture appearance of each of the three retest specimens shall equal or exceed 80 percent shear.

(e) The lowest anticipated service temperature (the LAST) shall be based on the isoline in Figure 1.5.4.1 nearest the geographical location of the bridge.

(f) Plate in excess of 2-inch thick shall not be used in FCMs when the yield strength exceeds 90 ksi.

TABLE 4.1.1.2.1

PLANE-STRAIN FRACTURE TOUGHNESS OF WELD METAL

MINIMUM E399 KQ at the LAST

FOR SPECIFIED THICKNESS RANGES

YIELD STRENGTH (ksi)	up to 1	over 1 to 1 1/2	over 1 1/2 to 2	over 2 to 2 1/2	over 2 1/2 to 3
up to 50	50	60	70	80	85
over 50 to 60	60	75	85	95	105
over 60 to 70	70	85	100	110	120
over 70 to 80	80	100	115	130	140
over 80 to 90	90	110	130	145	155
over 90 to 110	100	125	140	160	(f)
over 100 to 110	110	135	155	175	(f)
over 110 to 120	120	145	170	190	(f)

NOTES:

(1) For purposes of this specification, K_Q shall be based on strength ratio as measured in one (1) inch compact specimens or one (1) inch bend specimens (see ASTM E399-74 paragraphs 1.3, 9.1.6 and 9.1.7).

(2) When the compact specimen is used, the K_Q value shall be calculated from the expression

$$K_{Ic} / FTY = 0.68\ R_{sc}$$

where R_{sc} is the specimen strength ratio (E399-74 paragraph 9.1.7) and FTY is the yield strength from the mill test report.

(3) When the bend specimen is used, the K_Q value shall be calculated from the expression

$$K_{Ic} / FTY = 0.63\ R_{sb}$$

where R_{sb} is the specimen strength ratio (E399-74 paragraph 9.1.6) and FTY is the yield strength from the mill test report.

(4) The lowest anticipated service temperature (the LAST) shall be based on the isoline in Figure 1.5.4.1 nearest the geographical location of the bridge.

TABLE 4.18.1.1

HYDROGEN CONTENT OF WELD METAL

Electrode Classification	Max. Hydrogen ml/100g Average	Single rdg.
E70T	8.0	10.0
E80T and E90T	5.0	6.3
E100T and E110T	3.0	3.8

5. QUALIFICATION

5.1 General. For FCMs, there are requirements which supersede those presently specified in the AWS/AASHTO Structural Welding Code Section 5. The following is a digest of AWS D1.1, as amended.

5.1.1.1 All materials and welding procedures shall be qualified prior to use. Welders, welding operators and tackers shall be qualified before welding structural steel. The Contractor, as his option, may combine qualification tests for materials, welding procedures and welding personnel, provided that all requirements pertaining to the respective testing are satisfied, as specified hereinafter.

5.1.1.3 Welding procedures for manual shielded metal-arc welding, which conform to the provisions in Section 1-General Provisions, Section 2-Design of Welded Connections, Section 3-Workmanship, Section 4-Techniques and Section 9-Design of New Bridges of AWS D1.1-75, will be considered prequalified and exempt from weld-procedure-qualification testing under the following conditions:

Exemption of SMAW from weld-procedure qualification testing shall be allowed only if (1) the base-metal yield strength as certified in the mill test reports does not exceed 50 ksi, (2) the base-metal sulfur and phosphorus do not exceed 0.03 percent, (3) the base-metal carbon does not exceed 0.20 percent, and (4) the electrode is certified by the producer for toughness down to -40°F or lower.

5.2.1 With the exception of 5.1.1.3, the Engineer will not consider evidence of previous qualification of welding procedures for the following weld categories in FCMs:

(1) groove-weld butt joints in or contiguous to tension components,

(2) complete-penetration groove-weld T- and corner-joints in or contiguous to tension components where the welds are perpendicular to the applied stress, and

(3) fillet welds in or contiguous to tension components where the welds are perpendicular to the applied stress.

Weld-procedure qualification testing of groove-weld T- and corner joints shall be done by making groove-weld butt joints of the same joint design (single bevel, double bevel, etc.) and using the thickness of the plate containing the weld in the T- or corner-joint. If the thickness of the plate is less than one (1) inch, one-inch plate shall be used in testing. The steel shall be of the same grade/type as in the structure.

5.2.2 The Charpy V-notch impact MINIMUM values as specified herein are mandatory for qualifying the welding procedures used in groove-weld joints as specified above. The Charpy test results in groove welds shall conform to the requirements of Table 4.1.1.2.

5.2.3 ASTM E399-76 may be used as an alternate test method for determining the fracture toughness of deposited weld metal in groove welds, testing at the lowest anticipated service temperature (the LAST), with the test result as specified in 4.1.1.2.1.

5.5 Limitation of Variables.

5.5.1.1 Qualification of a welding procedure shall be accomplished using base metal of the same ASTM/AASHTO Specification type and grade as that to be used in the bridge.

5.5.1.3 Qualification of a welding procedure shall be accomplished using welding consumables of the same heat, lot and batch as to be used in the FCMs. Each shipment of consumables shall be accompanied by the producer's certification as to heat/lot/batch in the shipment in accord with 4.1.2.5. A change in heat, lot and/or batch shall be considered an essential change and shall require establishing a new procedure by qualification The certified chemistry for each heat, lot and batch of consumables shall include the hydrogen (1) in the wire, and (2) the moisture content of the coatings and/or fluxes, or the diffusible hydrogen in deposited weld metal, as specified in 4.1.3.1, 4.9.3.2, 4.13.4 and 4.18.1.

5.6 Types of Tests and Purposes.

5.6.1.1 For groove welds the following tests shall be performed as specified herein:

(1) Reduced-section tension test (for tensile strength)

(2) Root-bend test (for soundness)

(3) Face-bend test (for soundness)

(4) Side bend test (for soundness)

(5) All-weld-metal test (weld-metal tensile)

(6) Impact test (weld-metal toughness)

(7) Free bend test (for ductility)

(8) Radiographic test (for soundness)

(9) Ultrasonic test (for soundness)

5.6.1.2 For fillet welds the following tests shall be performed as specified herein:

(1) Macroetch test (for soundness)

(2) Fracture test (for soundness)

(3) T-Bend test (for ductility)

5.10.3.4 Incomplete-penetration fillet welds may be used in lieu of complete-penetration groove-weld T-joints when weld-procedure-qualification testing is in accordance with Figure 5.10.3.4 (see 2.15.12.3 and 4.1.1.2.7).

5.12 Test Results Required.

5.12.1.4 All-weld-metal tension test. The tensile properties measured in all-weld-metal testing of groove welds shall conform to the following requirements:

The minimum yield strength of weld metal deposited in weld-procedure-qualification testing shall be the minimum yield-strength of the base-metal grade/type being joined, with the following exception: In partial-penetration groove welds, the yield strength of the deposited weld metal may be lower than that of the base metal providing the effective weld-throat is sufficient to develop the design strength as demonstrated by sectioning and macroetch testing.

The maximum yield strength of weld metal deposited in weld-procedure-qualification testing shall not exceed the following values:

YIELD STRENGTH (ksi)

BASE METAL GRADE/TYPE	WELD-METAL MAXIMUM
over 90 to 100	110
over 70 to 90	100
over 50 to 70	90
over 40 to 50	80

5.12.1.6 Weld-toughness tests. The Charpy impact testing of groove-welds shall produce an average of three tests values not less than the minimum energy level specified in Table 4.1.1.2.

If ASTM E399 testing is used as an alternative to Charpy V-notch impact testing of groove welds, the minimum acceptable toughness at the LAST as determined in this testing shall be a function of plate (weld) thickness and weld yield strength as specified in 4.1.1.2.1.

5.12.1.7 In the groove-weld (90-degree included angle) test of a fillet welding procedure, the minimum acceptable impact values at the LAST shall be as specified in Table 5.10.3.4 footnote (7).

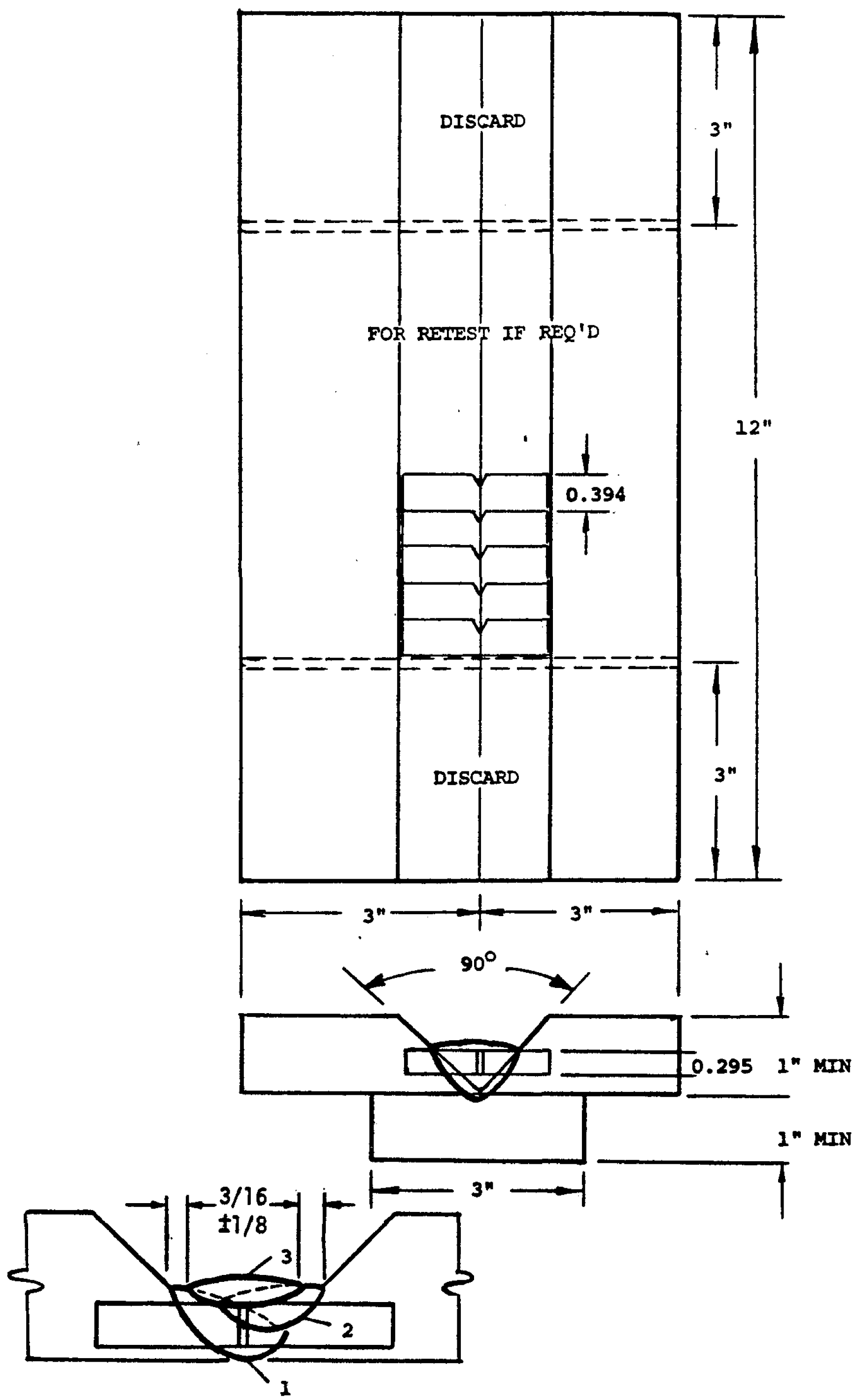


Figure 5.10.3.4 - Weld-Procedure-Qualification Test for Fillet Welds (see NOTES, p. 81).

FIGURE 5.10.3.4 NOTES

(1) For purposes of determining the toughness of the weld metal in fillet joints, the weld shall be deposited in a groove-weld butt joint with a 90 degree included angle, in the position to be used in production;

(2) in fillet weld-procedure-qualification testing for toughness, the electrode diameter, the energy input (amps, volts, and arc travel speed), preheat/interpass temperature, consumables, and all other variables under AWS D1.1 paragraph 5.5.2 shall be the same as proposed for production welding;

(3) the steel and backing shall be of the same grade/type as that to be used in production;

(4) multiple-pass fillets shall be deposited in three (3) passes where (a) the first and second passes may be deposited as two separate passes or with two electrodes in a single pass; (b) the third pass shall be deposited after the joint has cooled to within 100°F of the MINIMUM interpass temperature of 4.2, as amended; and (c) the third pass shall not penetrate the base metal at any point;

(5) for multipass fillet welds, a change in sequence and/or positioning of the weld passes within the joint shall be considered an essential change under AWS D1.1 paragraph 5.5.2;

(6) the Charpy impact specimen shall be the ASTM E23-72 5 mm or 7.5 mm subsize specimen positioned with the notch centered on the weld (in the plane of the throat of the "fillet"), and with the notch oriented so as to drive the crack down the length of the "fillet".

(7) In the groove-weld test of fillet-weld procedure, the minimum acceptable impact values at the LAST shall be as specified in the following table:

FILLET	CHARPY	ENERGY REQUIRED (FT-LB)	
SIZE (in.)	SIZE	E60, 70, 80[a]	E90, 100, 110[b]
5/16 to 3/8	0.197 (5 mm)	15	25
7/16 to 1/2	0.295 (7.5 mm)	25	35
9/16 and up	0.394 (10 mm)	35	45

(a) filler classification including F6X-EXXX, F7X-EXXX and F8X-EXXX
(b) filler classification including F10X-EXXX and F11X-EXXX

6. INSPECTION

PART A - GENERAL REQUIREMENTS

6.1 General. For FCMs, there are requirements which supersede those presently specified in the AWS/AASHTO Structural Welding Code Section 6. The following is a digest of AWS D1.1, as amended.

6.1.1 Quality Control (QC) is the responsibility of the Contractor; Quality Assurance (QA) is the prerogative of the Engineer. In FCMs, QC will be randomly verified by QA performing actual nondestructive testing of welds previously found acceptable by QC.

6.1.1.1 If a weld is found to contain rejectable planar-type indications in verification sampling, the two (2) consecutive welds of the same type preceding the defective weld, shall be verified by QA. If two consecutive welds are found by QA to contain rejectable planar-type indications, four (4) consecutive welds of the same type preceding the defective welds shall be verified by QA; etc.

6.1.1.2 In the event that QA inspection, as directed by the Engineer, discloses defective welds, the repair and reinspection of the defective welds shall be performed by the Contractor at his expense.

6.1.2 The Welding Inspector(s) performing QC for FCMs shall be qualified under provisions of the American Welding Society (AWS) Qualification and Certification Program, or other demonstration of competance acceptable to the Engineer.

6.1.3 Personnel performing nondestructive testing of FCMs in both QC and QA shall be qualified as NDT Level-II technicians under ASNT Recommended Practice SNT-TC-1A.

6.1.3.3 Ultrasonic testing (UT) of FCMs shall be done by an ASNT Level-II person under the supervision of an ASNT-Certified Level-III person.

6.3 Inspection of Welding-Procedure Qualification and Equipment.

6.3.1 The QC Welding Inspector shall make certain that the variables under AWS D1.1 paragraph 5.5, as amended, are accurately recorded in the course of weld-procedure qualification and included in the weld-procedure specification.

6.3.1.1 The QC Welding Inspector shall verify that amperage and voltage are accurately metered in making the weld-procedure-qualification test plates.

6.3.2 The QA Welding Inspector designated by the Engineer shall be present when weld-procedure-qualification test plates are prepared by the Contractor. The Contractor shall notify the Engineer at least 24 hours in advance of preparing his weld-procedure-qualification test plates.

6.5 Inspection of Work and Records.

Except as revised below, AWS D1.1 paragraphs 6.5.1 through 6.5.7 shall refer to the "QC Welding Inspector" in lieu of "the Inspector" (see 6.1.1).

6.5.2 The QC Welding Inspector shall make certain that only welding procedures meeting the provisions of 5.1 and 5.2, as amended, are employed, and that the limitations on essential variables of 5.5, as amended, are strictly adhered to in production welding.

6.5.2.1 The welding-procedure specifications applicable to each welding operation shall be attached to the power source for each welding operation.

PART B

RADIOGRAPHIC TESTING OF WELDS

6.8.1 The precedures and standards herein described are specifically for radiographic examination of groove welds in butt joints by X-ray or gamma-ray sources. The methodology shall conform to ASTM E94 "Standard Recommended Practice for Radiographic Testing" and ASTM E142 "Standard Method for Controlling Quality of Radiographic Testing", except as amended herein.

6.9.1 All groove-weld butt joints in FCMs as defined in 1.2.1 shall be radiographed including attachment butt joints contiguous to the tension component of an FCM.

6.9.2 Radiographic inspection will be used to determine the soundness of tension butt welds throughout their entire length unless otherwise specified.

6.10.1 Radiographs shall be made using a single source of either X or gamma radiation. The minimum radiographic sensitivity shall be 2-2T or 2-4T depending on thickness as described in Table 6.10.1. The equivalent penetrameter sensitivity for these levels of inspection is 2.0 and 2.8 percent, respectively.

Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required penetrameters and the essential holes as described in the specification. The density difference between the image of the holes and the penetrameter image shall be the same as that between the edge of the penetrameter and the adjacent film area. Identifying numbers and letters shall show clearly on the radiographs.

TABLE 6.10.1

THICKNESS, PENETRAMETER DESIGNATIONS AND ESSENTIAL HOLES
To Produce Required Equivalent Penetrameter Sensitivity

Material Thickness Range, In.	Penetrameter Designation	Thickness of Penetrameter, In.	Essential* Hole
Up to 1/4, incl	5	0.005	4T
Over 1/4 thru 3/8	7	0.007	4T
Over 3/8 thru 1/2	10	0.010	4T
Over 1/2 thru 5/8	12	0.0125	4T
Over 5/8 thru 3/4	15	0.015	4T
Over 3/4 thru 7/8	17	0.0175	4T
Over 7/8 thru 1	20	0.020	2T
Over 1 thru 1-1/4	25	0.025	2T
Over 1-1/4 thru 1-1/2	30	0.030	2T
Over 1-1/2 thru 2	35	0.035	2T
Over 2 thru 2-1/2	40	0.040	2T
Over 2-1/2 thru 3	45	0.045	2T

*NOTE:

Equivalent Penetrameter Sensitivity is defined as "...that thickness of penetrameter, expressed as a percentage of the part thickness, in which a 2T hole would be visible under the same radiographic conditions." Table 6.10.1 is identical to the requirements of the ASME Boiler and Pressure Vessel Code. Penetrameters 5, 7, 10, 12, 15 and 17 produce 2.8% penetrameter sensitivity or less. Radiographic inspection of steel 7/8 inch thick or less cannot always be relied upon to delineate discontinuities having a thickness equal to 2.0% of the thickness of the part.

PART C

ULTRASONIC TESTING OF GROOVE WELDS

6.14.1 In FCMs all groove welds shall be ground flush and UT tested, including any attachment groove-weld butt-, T- and corner-joints contiguous to the tension component of an FCM.

All groove-weld procedure-qualification test plates shall be ground flush and UT tested.

6.14.2 In groove-weld butt-, T- and corner-joints, the complete length of the weld in each designated joint shall be tested. (see 1.3.4)

Extraordinary attention shall be given to the ends of welds at locations where run-off plates were attached, and at the intersection of welds.

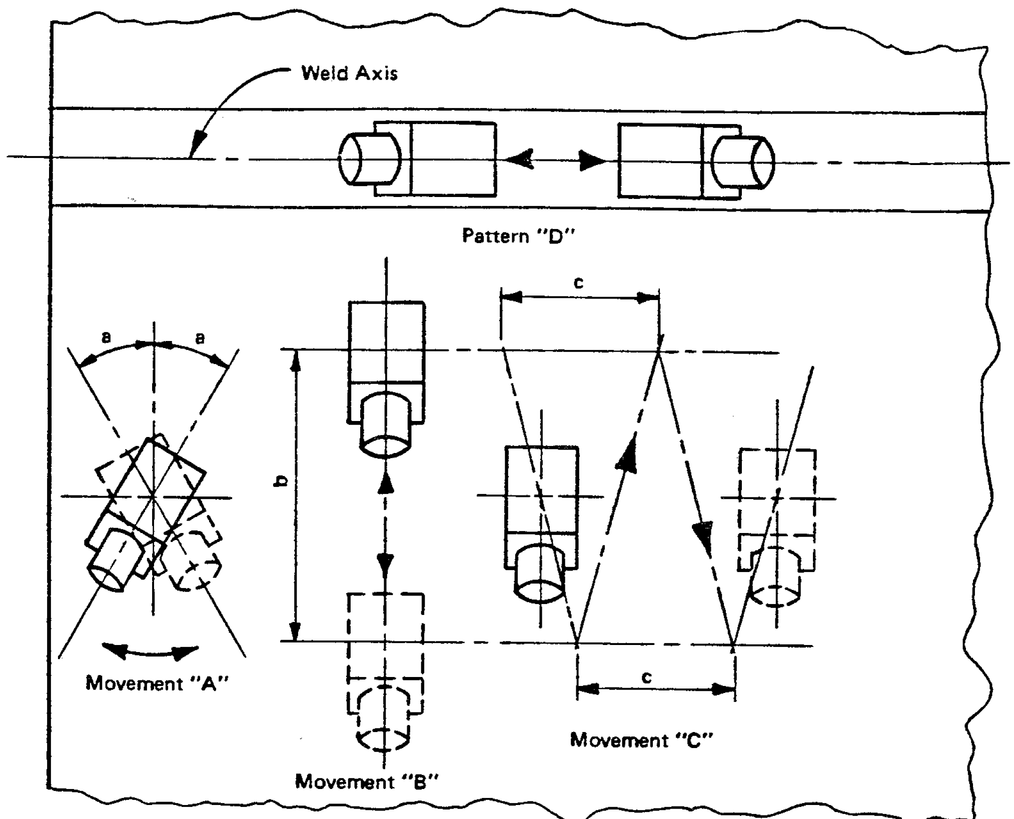
6.19.2 All surfaces to which a search unit is applied shall be free of weld spatter, dirt, grease, oil, loose scale and <u>paint</u> and shall have a flat contour permitting intimate coupling.

6.19.5.1 <u>Scanning patterns</u>. All welds shall be scanned from both sides on the same face where mechanically possible using the scanning movements and patterns of Figure 6.19.5.1, executed on a systematic, preplanned basis.

6.19.5.7 <u>Acceptance criteria</u>. Each weld discontinuity shall be accepted or rejected on the basis of its defect rating and its length and location in accordance with Table 6.6.4.3.

6.20.1 The ultrasonic test report shall include the Contractor Number, the date of the inspection was made, and the name of the inspector. The test report shall not only record all rejectable discontinuities but also all other indications with defect ratings within 5 db of being rejectable. The latter shall be fully recorded as to indication rating, size and position.

FIGURE 6.19.5.1 - SCANNING PATTERNS/MOVEMENTS



Plan View of Welded Plate

NOTES:

(1) for scanning-movement "A", rotation angle "a" is 10 degrees

(2) for scanning-movement "B" the scanning distance "b" shall be such that the full section of the weld being tested is covered.

(3) for scanning-movement "C", the progression distance "c" shall be approximately one-half the transducer width.

(4) scanning-movements "A", "B" and "C" shall be combined into one scanning pattern, and shall be executed from both sides of the weld axis where mechanically possible.

(5) scanning-pattern "D" shall be combined with scanning-movement "A" and the weld traversed in both weld directions.

(6) testing patterns are all symmetrical about the weld axis with the exception of Pattern "D" which is conducted directly over the weld axis.

(7) for FCMs all of the above scanning-patterns and movements shall be executed on each groove-weld butt-, T- and corner-joint.

TABLE 6.6.4.3-ULTRASONIC ACCEPTANCE CRITERIA

MINIMUM ACCEPTANCE LEVELS (DECIBELS)

REFLECTOR SEVERITY	WELD THICKNESS (in.) AND TRANSDUCER ANGLE							
	5/16 to 3/4	>3/4 to 1-1/2	1-1/2 to 2-1/2			2-1/2 to 3		
	70°	70°	70°	60°	45°	70°	60°	45°
Strong Reflectors	+14	+ 9	+ 6	+ 9	+11	+ 4	+ 7	+ 9
Moderate Reflectors	+15	+10	+ 8	+11	+13	+ 6	+ 9	+11
Weak Reflectors	+16	+11	+10	+13	+15	+10	+13	+15

NOTES:

(1) Strong Reflectors: Any discontinuity, REGARDLESS OF LENGTH, having a more serious rating (smaller number) than this level shall be rejected.

Moderate Reflectors: Any discontinuity longer than 3/4 in. (19 mm) having a more serious rating (smaller number) than this level shall be rejected.

Weak Reflectors: Any discontinuity longer than 2 in. (51 mm) having a more serious rating (smaller number) than this level shall be rejected.

(2) Discontinuities which have a more serious rating than those of "Weak Reflectors," shall be separated by at least 2L, L being the length of the larger discontinuity. Discontinuities not separated by at least 2L are considered to be one continuous discontinuity whose length is determined by the combined length of the discontinuities plus their separation distance.

(3) Discontinuities which have a more serious rating than those of "Weak Reflectors" shall not begin at a distance smaller than 2L from the end of the weld or from any intersecting weld, L being the discontinuity length.

(4) Discontinuities detected at 'Scanning Levels' in the root-land areas of complete joint penetration double-V-, double-J-, double-U- and double-bevel-groove welds shall be evaluated at an acceptance level 4db* more sensitive than prescribed in this table when such welds are designated on design drawings as 'tension welds'.

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*i.e., add +4 db to the number in the table.

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