Final Report

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FDOT Procedures for Welding, Testing, and Fabricating Weathering Stainless Steel for Bridge Applications

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16. Abstract

Weathering steels have been gaining acceptance in the fabrication of highway structures and bridges across the US. Over the last decade, several transportation agencies have made concerted efforts to utilize weathering steels for structures in areas where they can be used safely and effectively. The primary factor for this change is the potential cost-effective savings in maintaining these structures over the course of their lifespan. Weathering steels do not require coatings and can offer significant savings as compared to the maintenance of coatings on a typical bridge or highway structure. Weathering stainless steel, such as ASTM A709 Grade 50CR, has been utilized in various applications by several DOT's across the US, with successful results. Florida Department of Transportation (FDOT) has been considering the implementation of weathering stainless steels in the fabrication of new bridge and highway structures, where challenging environmental conditions are present. This document is the first step in developing comprehensive procedures for the welding, testing, and fabrication of weathering stainless steel for bridge applications.

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EXECUTIVE SUMMARY

The use of weathering steels has been gaining acceptance in the fabrication of highway structures and bridges across the US. Over the past decade, several transportation agencies (DOT's) have made concerted efforts to utilize weathering steels for structures in areas where they can be implemented safely and effectively. The primary factor for this change has been the cost-effective savings in maintaining the structures over the course of their lifespan. Weathering steels do not require coatings and can offer significant savings as compared to the maintenance of coatings on a typical bridge or highway structure. Weathering Stainless Steel, such as ASTM A709 Grade 50CR, has been utilized in various applications by several DOT's across the US, with successful results. While the use of this weathering steel has not yet gained widespread acceptance, it shows promising potential as an alternative to the typical materials used in bridge and highway construction, especially in Florida's coastal environments.

Florida Department of Transportation (FDOT) has been considering the implementation of weathering stainless steels in the fabrication of new bridge and highway structures, where challenging environmental conditions are present. Currently, however, FDOT's specifications and Technical Special Provisions do not address weathering stainless steel for bridge applications. In addition, AWS D1.5 Bridge Welding Code does not address the use of ASTM A709 Grade 50CR, and AWS D1.6 Structural Welding Code for Stainless Steel does not address welding for bridge structures. To create a comprehensive document for the fabrication and welding of weathering stainless steel, prior to implementation, the State Materials Office in Gainesville, Florida required a set of procedures that will merge the existing AWS D1.5 and AWS D1.6 codes for bridge applications. This document is the first step in developing comprehensive procedures for the welding, testing, and fabrication of weathering stainless steel for bridge applications.

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LIST OF ACRONYMS/ABBREVIATIONS

CJP....................... Complete joint penetration
CVN..................... Charpy V-Notch
EGW..................... Electrogas welding
ESW..................... Electroslag welding
FCAW.................. Flux cored arc welding
GMAW................ Gas metal arc welding
GMAW-S............ Gas metal arc welding short circuit arc
HAZ..................... Heat affected zone
IQI......................... Image quality indicator
MT........................ Magnetic particle testing
NDT..................... Non-destructive testing
OEM.................... Original equipment manufacturer
PJP....................... Partial joint penetration
PQR..................... Procedure qualification record
PT........................ Liquid penetrant testing
RT........................ Radiographic testing
SAW.................... Submerged arc welding
SMAW................. Shielded metal arc welding
SW....................... Stud arc welding
UT........................ Ultrasonic testing
WPS..................... Welding procedure specification

CHAPTER 1 - INTRODUCTION

Weathering steels such as ASTM A709 Grade 50W [1] are being used in Florida but are ineffective in coastal areas, industrial areas, or areas of non-uniform humidity. Weathering stainless steel such as ASTM A709 Grade 50CR [1] (previously known as ASTM A1010 Grade 50 [2]), however, may be used in these challenging environments. A709 50CR comes with a greater upfront cost due to its high chromium alloying content, however cheaper alloys with lower chromium content are not as effective in preventing corrosion. It is estimated that the increased material cost of A709 50CR compared to weathering steel would be offset in one or two repainting cycles [3].

Current FDOT Specifications and Technical Special Provisions do not address weathering stainless steel for bridge applications. AASHTO/AWS D1.5 does not address the use of ASTM A709 Grade 50CR, while AWS D1.6 addresses welding of stainless steels, but not for bridge applications. To use weathering stainless steel for bridges, Florida Department of Transportation (FDOT) has requested a set of procedures that merge the existing AASTHO/AWS D1.5 and AWS D1.6, pertaining to the use of ASTM A709 Grade 50CR for bridge applications.

Wood Environment and Infrastructure Solutions (Wood) is tasked with the primary objective to develop procedures for safe welding, testing, repairing, and fabrication of weathering stainless steel consistent with AASHTO/AWS D1.5 Bridge Welding Code. The first step in accomplishing this objective was to conduct an extensive literature review which encompassed the following documents:

- AASHTO/AWS D1.5 Bridge Welding Code [4]
- AWS D1.6 Stainless Steel Welding Code [5]
- ASTM A709 Structural Steel for Bridges [1]
- ASTM A1010 Higher Strength Martensitic Stainless-Steel Plate, Sheet, and Strip [2]
- ASTM A6 Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling [6]
- ASTM Specifications E94, E164, and E709 for Non-Destructive Testing methods [7] [8] [9]
- ASTM A193 and A194, High Temperature and/or High-Pressure Bolting [10] [11]
- 2020 FDOT Standard Specifications
- VDOT and ODOT research documents

ASTM A709 Grade weathering stainless steel has already been used to construct bridges in California, Pennsylvania, Oregon, Iowa, and Virginia [3] [12]. Research leading up to the construction of those bridges in addition to reports on how the bridges have performed over time have been used to develop these procedures.

This report is constructed to mirror the sections of AASHTO/AWS D1.5 and AWS D1.6. The framework of this report identifies differences between the two specifications, with supplemental information from ASTM Specifications along with Virginia and Oregon DOT documents added throughout. Sections of the report, begin with available approved materials, followed by design parameters and considerations. Bolting, welding, and fabrication considerations which will affect bridge construction complete this document. Bolting is not addressed in AASHTO/AWS D1.5 or AWS D1.6, however it is addressed in several Virginia DOT research documents as requiring specialized materials, as well as specialized acceptance and installation procedures. Those procedures are outlined in the bolting section of this report. After construction considerations, the report outlines WPS qualification procedures, inspection procedures, and repair procedures.

This extensive review of parameters and considerations gives a comprehensive overview of how bridge construction is modified to properly implement the use of ASTM A709 Grade 50CR [1]. Section 460 of the FDOT Standard Specifications shall apply to the construction of bridge(s) or bridge components fabricated using ASTM A709 Gr 50CR, with the exception of the items within this procedure, which shall overrule the Standard Specifications.

CHAPTER 2 - MATERIALS

2-1.1 Weathering Stainless Steel

ASTM A709 Grade 50CR is a low-grade stainless steel but does include alloying elements found in higher grade stainless steels which are more corrosion resistant; however, A709 50CR is more cost effective compared to high grade stainless steels [13]. The chemical composition of A709 50CR is tabulated in Table 2-1.

Table 2-1
Chemical Composition of ASTM A709 Grade 50CR [1]

Element	Composition %
Carbon	0.030 max
Manganese	1.50 max
Phosphorus	0.040 max
Sulphur	0.010 max
Silicon	1.00 max
Nickel	1.50 max
Chromium	10.5-12.5
Molybdenum	No requirement
Nitrogen	0.030 max

2-1.2 Bolting Systems

2-1.2.1 General

Use a stainless-steel bolting system to maximize the corrosion resistance of A709 Grade 50CR. This system has been selected due to the combination of strength, ductility, and corrosion resistance. Modified rotational capacity tests indicate that this system will safely develop a clamping force of 30 kips for a 7/8" diameter bolt, which is lower than the clamping force of 39 kips achieved by the equivalent F3125 Grade A325 bolt [13]. Account for this disparity in the design phase. Pursuit of higher clamping force results in galling of the threads, which is detrimental. The design tensile strength of the bolting system will be reduced to 100 Ksi after application of a safety factor [13].

2-1.2.2 Bolts, Nuts, and Washers

Use 7/8"[1] diameter ASTM A193 Grade B8 Class 2 bolts, ASTM A194 Grade 8 nuts, and Grade 304 washers [10] [11] [13].

[1] *Other diameters of ASTM A193 Grade B8 Class 2 bolt may be used with the approval of the Engineer. The clamping force developed for each bolt diameter shall be determined through testing as outlined in section 5-1.2 of this procedure. Assuming a 25% drop in clamping force compared with F3125 Grade 325 will provide a conservative starting point for testing of additional bolt diameters.*

2-1.2.3 Lubricating Compound

Use Never-Seez lubricant[2] to lubricate the threads of the bolt as well as the nut and washer contact surfaces [13]. Extensive testing is required to qualify other types of lubricants.

2-1.3 Filler Metals[3]

ASTM A709 Grade 50CR compatible filler metals must have a minimum ferrite number of three (3) [14]. The Lincolnweld ER309L, 3/32-inch diameter electrode with Lincolnweld 880M flux or SelectAlloy EC309L 3/32-inch diameter electrode with Lincolnweld 880M flux have been successfully used for submerged arc welding A709 50CR [15]. Table 2-2 tabulates acceptable filler metal classifications based on the welding process.

Table 2-2

Filler Metal Classifications Compatible with ASTM A709 Grade 50CR Steel [14]

SMAW	GMAW, SAW	GMAW, FCAW
A5.4/A5.4M	A5.9/A5.9M	A5.22/A5.22M
E316L-XX	ER316L	E316LTX-X
E309L-XX	ER316LSi	R316LT1-5
	ER309L	E309LTX-X
	ER309LC	E316TX-X
		R309LT1-5

2-1.4 Weld Cleaning

2-1.4.1 General

Cleaning prior to welding must result in areas adjacent to the joint to be welded being free of any coatings, and other materials containing hydrocarbons and coatings being removed to clean base metal a minimum of 1-inch from the anticipated toe of the weld [14].

2-1.4.2 Cleaning Between Passes and Completed Welds

Before welding over previously deposited metal, all slag and spatter shall be removed, and the weld and adjacent base metal shall be brushed clean. This requirement shall apply to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption. The same cleaning requirements shall apply to completed welds as well [4].

2-1.4.3 Iron-Free Abrasives

Use brushes with wires made of stainless steel. Perform grinding, if required, with iron-free abrasive wheels [5] [16]. Cleaning will be conducted in accordance with AASHTO/AWS D1.5 3.11 [4]. When cleaning stainless steel, it is required to use a stainless steel bristle wire brush, as a plain carbon steel brush will contaminate the stainless steel and cause rust spots to appear on the brush cleaned surface. It is always recommended

[2] *VDOT testing showed that the type of lubricant greatly affected the torque level in the B8-2 bolts and using lubricants other than Never-Seez may result in galling, therefore exceeding the maximum allowable torque without reaching the specified clamping force.*

[3] *The filler metal classifications in this section were chosen based on favorable weathering and mechanical testing results by the Virginia Department of Transportation. Any recommendation of filler metals, other than those that meet these classifications, shall require evidence of acceptable weathering characteristics, when welded to ASTM A709 Grade 50CR, and meet all quality and mechanical testing requirements set forth within these procedures.*

to use the finest wire gauge possible; fine stainless steel wires are well suited for cleaning stainless steel and welds.

Non-metallic blast-cleaning medium shall be used, since metallic blast medium causes uneven corrosion or patina development due to iron particles becoming embedded in the base metal. Blast medium could be aluminum oxide or garnet [14].

2-1.4.4 Use of Designated Equipment

Mark or tag designated tools for use exclusively on A709 50CR to avoid additional iron and carbon introduction to the base metal which could cause uneven corrosion or patina development [16]. If an inappropriate tool, such as an iron containing brush, is used, the area affected, as well as an additional two inches in each direction, shall be lightly ground or brush cleaned, to avoid excessive material loss using an iron-free wire brush (stainless steel brush) or abrasive wheel (non-iron) and excess material removed. If the affected area is too large for using hand tools, the member or component shall be blast cleaned as described in 2-1.4.3.

CHAPTER 3 - DESIGN

3-1.1 Bridge Components

Fabricate the following types of bridge components from ASTM A709 Grade 50CR: tub girders, plate girders, pier cap box girders, and movable bridge girders and components: top flanges, bottom flanges, webs, stiffeners, bearing stiffeners, intermediate diaphragms, drip plates, gusset plates, sole plates, fill plates, splice plates, and other components made of plate material.

Bend A709 50CR into the required shapes when necessary; this may include angles, channels, and other structural shapes that are not currently available [17]. It is possible that structural shapes will become available in the future from mills and producers, at which point they can be incorporated into bridge components including cross frames and external diaphragms.

For any type of bending, strains associated with cold forming/bending can cause the material to strain-harden. This can change the material's mechanical properties in the area where bending has occurred. In the case of thick materials, the fabricator must abide by a minimum inside bend radius. This would ensure minimizing the deleterious effects of strain hardening and cracking at the bend. When working with plate materials the grain direction, longitudinal(along) or transverse(across) directions should be taken into consideration to keep strain hardening at a minimum. The fabricator has the responsibility to seek bending data from the manufacturer of the material to determine minimum inside radius for cold bending and hot bending. In any case, the Engineers approval shall be required for bending of all bridge components.

3-1.2 Available Joints

Design bridge components with joints outlined in AASHTO/AWS D1.5 Clause 2 [4].

3-1.3 Requirements for Bridge Structures and Components

Connect pieces along their longitudinal joints by sufficient continuous welds to make the pieces act in unison when a member is built up of two or more pieces [5].

Prohibited Types of Joints and Welds [5]:

(1) In butt joints, PJP welds subject to tension normal to their longitudinal axes are prohibited. In other joints, transversely loaded PJP welds are prohibited, unless fatigue design criteria allow for their application.
(2) Intermittent groove welds are prohibited.
(3) Intermittent fillet welds are prohibited.

(4) Plug and Slot welds on primary tension members are prohibited.

3-1.4 Contract Plans and Specifications

Provide the following in the contract documents and shop drawings for fillet welds and skewed T-joints:

(1) For fillet welds with surfaces meeting at an angle between 80 and 100 degrees, contract documents shall specify the fillet weld size.

(2) For welds with the surfaces meeting at an angle less than 80 degrees or greater than 100 degrees, the contract documents shall specify the effective throat.

(3) End returns and hold-backs for fillet welds, if required by the design, shall be indicated on the contract documents

3-1.5 Plug and Slot Welds

The depth of filling of plug or slot welds in base metal 5/8-inch thick or less shall be equal to the thickness of the material. In base metal over 5/8-inch thick, it shall be at least one-half the thickness of the material, but no less than 5/8-inch [5]. The Engineer may specify an alternative limit of depth of filling. In no case is the depth of filling to be greater than the thickness of the thinner part joined [5].

3-1.6 Weld Details

Interrupt fillet welds deposited on opposite sides of a common plate around the common corner in accordance with AASHTO/AWS D1.5 [4]. Do not use flare-bevel-groove welds when welding structural steel on bridges [4].

3-1.7 Joint Configurations and Details for Compression Members

Connect column splices that are finished to bear by partial joint penetration (PJP) groove welds or by fillet welded details sufficient to hold the parts in place [5]. Where compression members other than columns are finished to bear at splices or connections, design welds to hold all parts in alignment and proportion for 50% of the force in the member [5]. Design welds joining splices in columns and splices and connections in other compression members that are not finished to bear to transmit the force in the members unless complete joint penetration (CJP) welds or more restrictive requirements are specified in contract documents or governing specifications [5]. Make connections adequate to hold the members securely in place at base plates of columns and other compression members [5].

CHAPTER 4 – WPS, WELDER, WELDING OPERATOR, AND TACK WELDER QUALIFICATION TESTING

4-1.1 General

WPS qualification testing shall be performed in accordance with the maximum heat input qualification test method as outlined in AWS/AASHTO D1.5 with the exception that preheat and interpass temperatures as well as heat input maximum limitations shall not exceed the values in section 6-1 of this procedure. All WPSs pertaining to the welding of A709 Grade 50CR material shall be qualified by testing; there are no prequalified WPSs for A709 Grade 50CR material.

Welders, welding operators, and tack welders shall be tested as detailed in AASHTO/AWS D1.5 for process and position with the exception that they must also qualify on ASTM A709 Gr 50CR material. Existing qualification tests shall not be accepted to allow welding on ASTM A709 Gr 50CR. The WPS used shall meet the criteria of this set of procedures.

Tack weld operators shall verify tack weld consumption one time, by testing on a 2-inch plate[4]. Tack welds shall be separated by 1-in. center to center. Each tack weld shall be verified by a macroetch test.

4-1.2 Initial Inspection of Welded Test Plates

4-1.2.1 Visual Inspection of Fillet Welds

Upon visual inspection, the fillet weld will have no cracks, will have fusion to the root of the joint but not necessarily beyond, no overlap, all craters shall be filled to the full cross section of the weld, fillet weld leg size shall meet the specified fillet weld size, and the depth of undercut shall not exceed 1/32-inch [4] [5].

The frequency of piping porosity on the surface shall not exceed one in four inches and the maximum diameter shall not exceed 3/32-inch. Upon not meeting these criteria, see AWS D1.5 6.26.1.6 for additional testing [4].

4-1.2.2 Visual Inspection of Groove Welds

Upon visual inspection, the groove weld will have no cracks, no overlap, all craters shall be filled to the full cross section of the weld, the undercut shall not exceed 1/32-inch, the weld reinforcement shall not exceed 1/8-inch[5], complete fusion shall exist between adjacent layers of weld metal and between weld metal and base metal, and the weld profile shall be deemed acceptable by the welding inspector [4] [5].

The frequency of piping porosity on the surface shall not exceed one in four inches and the maximum diameter shall not exceed 3/32-inch. Upon not meeting these criteria, see AWS D1.5 6.26.1.6 for additional testing [4].

4-1.2.3 Radiographic Inspection of Groove Welded Plates

CJP groove welds will be subject to radiography and will have no cracks or other discontinuities as described in AASHTO/AWS D1.5 6.26.2 [4].

4-1.3 Mechanical Testing of the Welded Test Plates[6]

4-1.3.1 Sample Preparation

The specimens specified in Table 4-1 will be prepared for groove weld PQRs in accordance with AASHTO/AWS D1.5 [4].

Mechanical properties of fillet welds shall be measured by testing groove welds. In addition, three fillet weld soundness macroetch test specimens shall be used to evaluate weld soundness and to gage the size, shape, and distribution of individual weld passes as detailed in AASHTO/AWS D1.5 [4].

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[4] *Current availability of ASTM A709 Grade 50CR is limited to 2” thick plate maximum*

[5] *It may be necessary to remove all weld reinforcement to perform NDT on the completed weld.*

[6] *Due to the similarities in mechanical property requirements between ASTM A709 Grades 50W and 50CR, the results for the all weld metal tension test and CVN impact test required for ASTM A709 Grade 50W were chosen as the requirements for ASTM A709 Grade 50CR.*

Table 4-1

Groove Weld Mechanical Test Specimens [4]

Mechanical Test	Number of Specimens
All-Weld-Metal Tension	1
Reduced Section Tension	2
Side Bend	4
CVN	5
Macroetch*	2*

**Only for weld joints that do not conform to the joints detailed in the Design Clause of AASHTO/AWS D1.5*

4-1.3.2 All-Weld-Metal Tension Test

Testing will be conducted in accordance with ASTM A370. The mechanical properties shall conform to and match the values specified for ASTM A709 Gr 50W in AASHTO/AWS D1.5 Table 5.1, or as described in the contract documents [4] [5].

4-1.3.3 Reduced Section Tension Tests

Reduced section tension test specimens shall be prepared as detailed in AASHTO/AWS D1.5. The cross-sectional area of the specimen shall be measured, then the specimen shall be ruptured under tensile load to determine the maximum load. The tensile strength will be determined by dividing the maximum load by the area of the original cross section. The tensile strength shall be no less than the minimum of the specified tensile range of the base metal listed on the PQR form [4] [5].

4-1.3.4 Side, Root, and Face Bend Tests

Specimens shall be bent in a test jig meeting requirements of AASHTO/AWS D1.5 Figure 5.14, Figure 5.15, or Figure 5.16, with the maximum radius not being exceeded [4]. Specimen shall be placed on the die member of the jig with the weld at midspan. For side bend testing, the side showing greater discontinuity is directed toward the gap. For root or face bend testing, the corresponding root or face is directed toward the gap [4]. The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and HAZ shall be centred and completely within the bent portion of the specimen after testing. If using a wraparound jig, the specimen shall be firmly clamped so that there is no sliding of the specimen. test specimens shall be removed from the jig when the outer roll has been moved 180 degrees from the starting point [4] [5].

Surface shall contain no discontinuities exceeding the following dimensions: 1/8-inch measured in any direction on the surface, 3/8-inch for the sum of the greatest dimensions of all discontinuities exceeding 1/32-inch, but less than or equal to 1/8-inch, or 1/4-inch for the maximum corner crack except when the corner crack resulted from a visual slag inclusion or other fusion-type discontinuity, the 1/8-inch maximum shall apply or specimens with corner cracks exceeding 1/4-inch with no evidence of slag inclusions or other fusion-type discontinuities shall be disregarded and a replacement test specimen from the original weldment shall be tested [4] [5].

4-1.3.5 Impact Testing (CVN)

Specimens shall be prepared in accordance with AASHTO/AWS D1.5 Figure 5.13, and testing shall be conducted in accordance with ASTM A370, “Charpy Impact Testing” [4].

Only full-size specimens shall be used. The highest and lowest CVN values shall be disregarded, and the remaining three values shall be averaged. The average of the three remaining CVN energies shall meet or exceed the minimum specified CVN test energy value given for ASTM A709 Gr 50W in AASHTO/AWS D1.5 Table 5.1, or as described in the contract documents. No more than one specimen may have an impact energy less than the minimum specified, and no specimen shall have a value less than 2/3 of the minimum specified value [4] [5].

4-1.4 Macroetch Testing of Welded Test Plates

4-1.4.1 Macroetch of Groove Welds

The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution, such as 2%Nital, 10%Nitric with 90%Water, or other reagent(s) suitable for etching weathering stainless steel, shall be used for etching to give clear definition of the welds showing the fusion line, individual weld passes, and the heat affected zone (HAZ) [4] [5]. The weld must conform to the following requirements: no cracks, thorough fusion between adjacent layers of weld metal and between weld metal and base metal, weld profiles must conform to design details, no undercut exceeding 1/32-inch, and PJP groove welds must be the designated weld size [4] [5].

4-1.4.2 Macroetch of Fillet Welds

The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution, such as 2%Nital, 10%Nitric with 90%Water, or other reagent(s) suitable for etching weathering stainless steel, shall be used for etching to give clear definition of the welds showing the fusion line, individual weld passes, and the heat affected zone (HAZ). The weld must conform to the following requirements: no cracks, thorough fusion between adjacent layers of weld metal and between weld metal and base metal, weld profiles must conform to design details, no undercut exceeding 1/32-inch, weld must be the designated weld size, minimum fillet weld leg size shall meet the specified fillet weld size, fillet welds shall have fusion to the root of the joint, but not necessarily beyond [4] [5].

4-1.4.3 Macroetch of Tack Weld Consumption

The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution, such as 2%Nital, 10%Nitric with 90%Water, or other reagent(s) suitable for etching weathering stainless steel, shall be used for etching to give clear definition of the welds showing the fusion line, individual weld passes, and the heat affected zone (HAZ). The weld must conform to the following requirements: no cracks, thorough fusion between weld metal and base metal, tack welds shall have fusion to the root of the joint.

4-1.5 Retests of the Welded Test Plates

4-1.5.1 Tension Specimens

Two retests may be conducted if any one specimen of all those tested fails to meet the test requirements. The retest specimens shall be cut from the same WPS qualification test plate or a new plate conforming to the same specification. The results of both test specimens shall meet the test requirement [4] [5]. For material over 1-1/2-inch thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material [4] [5].

4-1.5.2 Bend Specimens

Two retests may be conducted if any one specimen of all those tested fails to meet the test requirements. The retest specimens shall be cut from the same WPS qualification test plate or a new plate conforming to the same specification. The results of both test specimens shall meet the test requirement. For material over 1-1/2-inch thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material [4] [5].

4-1.5.3 CVN Specimens

Retests can be made if CVN test results do not meet the requirements. The impact energy value of each of the required test specimens, after disregarding the highest and lowest test values, shall equal or exceed the minimum specified CVN test energy average [4] [5].

4-1.6 Retests for Welders and Welding Operators

4-1.6.1 Immediate Retest

In the event a welder or welding operator fails to meet any of the weld test requirements, an immediate retest may be given consisting of two test welds of each type and position in which the welder or welding operator failed. [4]

4-1.6.2 Retest After Further Training or Practice

Upon evidence of training and/or practice after initially failing the weld test, a retest may be provided to the welder or welding operator. [4]

4-1.6.3 Tack Welder

In the event a tack welder fails the initial weld test, one retest may be taken without additional training. [4]

4-1.7 PQR Essential Variables

Changes in the essential variables listed in Table 4-2 will require requalification of a new WPS.

Table 4-2

Essential Variables Requiring Requalification [4] [5]

Essential Variable Changes to PQR Requiring Requalification	SMAW	SAW	GMAW	FCAW
Addition or deletion of supplemental powdered or granular filler metal or cut wire		x		
Increase or decrease in the amount of supplemental powdered or granular filler metal or wire		x		
If the alloy content of the weld metal is largely dependent on supplemental powdered filler metal, any WPS change that results in a weld deposit with the important alloying elements not meeting the WPS chemical composition requirements		x		
A change in the ratio of supplemental powdered, granular filler metal, or cut wire to electrode		x		
A change in the flux trade name		x		
A change from one flux trade name-electrode combination to any other flux trade name- electrode combination		x		
A change in diameter of electrode(s) when using an alloy flux		x		
A change from solid or metal cored to flux cored or vice versa		x	x	x
A change to tubular flux cored or powdered metal or vice versa		x		

Table 4-2 (Continued) Essential Variables Requiring Requalification [4] [5]				
Essential Variable Changes to PQR Requiring Requalification	**SMAW**	**SAW**	**GMAW**	**FCAW**
A change in the AWS A5.X classification, or to a weld metal or filler metal classification not covered by A5.X specifications	x	x	x	x
A change in the flux/wire classification, or a change in either the electrode or flux trade name when not classified by an AWS specification, or to a crushed slag		x		
A change in the manufacturer or the manufacturer's brand name or type of electrode				x
A change in the number of electrodes used	x	x	x	x
Increase or decrease in electrode diameter by more than one standard size	x	x	x	x
Change in the amperage by	To a value not recommended by the electrode	> 10% increase or decrease	> 10% increase or decrease	> 10% increase or decrease
A change in the type of current (AC or DC) or polarity	x	x	x	x
A change in mode transfer				x
A change in voltage by more than 10% of the average value used in the qualification test, except when welding with alloy or active fluxes the voltage shall not exceed 100% of the average value from the test	x	x	x	x
A change in the travel speed that when combined with the current and voltage exceeds 100% or is less than 60% of the average heat input from the qualification test	x	x	x	x
A change in the mode of metal transfer from globular, spray, or pulsed spray transfer to short circuit transfer, or vice versa			x	
Any combination of variable changes which exceeds 100% or is less than 60% of the average heat input from the qualification test. The heat input can be measured by: $\boldsymbol{Heat\ input} = \frac{\boldsymbol{V * A * 0.06}}{\boldsymbol{travel\ speed}}$	x	x	x	x
For the PQR groove area, an increase or decrease >25% in the number of passes	x	x	x	x

Table 4-2 (Continued) Essential Variables Requiring Requalification [4] [5]				
Essential Variable Changes to PQR Requiring Requalification	**SMAW**	**SAW**	**GMAW**	**FCAW**
A change from a U-groove to a V-groove (but not vice versa)	x	x	x	x
A change in the type of groove to a square groove and vice versa	x	x	x	x
A change exceeding the tolerances of approved joints in AASHTO/AWS D1.5 in the shape of any type of groove involving a) a decrease in the groove angle, b) a decrease in the root opening, c) and increase in the root face that will not be subsequently removed by backgouging	x	x	x	x
The omission, but not inclusion, of backing or backgouging	x	x	x	x
Addition or deletion of PWHT	x	x	x	x
A change in nominal fillet weld size (as listed in figure 5.8 of AASHTO/AWS D1.5)	x	x	x	x
From the same nominal fillet weld size, an increase or decrease >25% in the number of passes	x	x	x	x
A change in the dihedral angle by more than 10 degrees increase or decrease	x	x	x	x
A change from a single shielding gas to any other single shielding gas or to a mixture of shielding gases, or a change in specified percentage composition of shielding gas mixture			x	x
The addition or deletion of shielding gas				x
Any increase in the maximum interpass temperature used during the qualification test	x	x	x	x
A change in the PWHT temperature and/or time ranges. The PQR test shall be subject to 80% of the aggregate times at temperature(s). The PWHT total time(s) at temperature(s) may be applied in one heating cycle	x	x	x	x
A change >10% or 1/8in, whichever is greater, in the longitudinal spacing of the arcs		x		
A change >10% or 1/16in, whichever is greater, in the lateral spacing of the arcs		x		
An increase or decrease of more than 10 degrees in the angular orientation of any parallel electrode		x		
For machine or automatic SAW; an increase of more than 3 degrees in the direction of travel		x		
For machine or automatic SAW; an increase or decrease of more than 5 degrees normal to the direction of travel		x		

4-1.8 Period of Effectiveness

4-1.8.1 Non-Fracture Critical

All approved PQRs are valid indefinitely unless application of the WPS results in consistently substandard welds. The welder's, welding operator's, or tack welder's qualification shall be considered as remaining in effect indefinitely unless (1) not engaged in a given process of welding for which they are qualified for a period exceeding six months or (2) there is some specific reason to question their ability [4] [5].

4-1.8.2 Fracture Critical

When a specific Contractor has not previously performed production welding in accordance with a WPS qualified in accordance with this or a previous AASHTO FCP, the required tests shall be completed within one year prior to the start of production welding. All subsequent tests shall be conducted at a frequency that will ensure no groove weld PQR used as a basis for preparation of WPS is more than 60 months old. There is no limit to the period of effectiveness for fillet weld soundness tests [4].

All welders, including welding operators and tack welders, shall be qualified by test within 6 months before beginning FCP production welding or shall be regularly requalified on an annual basis. A continuity log[7] for all welders shall be maintained. Upon beginning work on a Fracture Critical project, the qualification of a welder or welding operator shall be considered valid until the project is completed provided the welder or welding operator meets the continuity requirements of AASHTO/AWS D1.5 5.21.4 and continuities to produce quality welds. For welders and welding operators performing Fracture Critical CJP groove welds, initial qualification shall be based on acceptable results of both mechanical (bend) tests and radiography as described in AASHTO/AWS D1.5 Clause 5, Part B. Welders and welding operators performing Fracture Critical fillet welding shall be qualified based on acceptable results of AASHTO/AWS D1.5 Clause 5, Part B. Tack welders shall be qualified as described in AASHTO/AWS D1.5 Clause 5, Part B and this Clause 4.1. Annual requalification may be based on acceptable results of radiography of production groove welds (for CJP groove welders) or test plates as approved by the Engineer [4].

CHAPTER 5 - BOLTING

5-1.1 General

Use a stainless-steel bolting system[8] to maximize the corrosion resistance of ASTM A709 Grade 50CR. The design tensile strength of the bolting system will be reduced to 100 Ksi after application of a safety factor. This lower tensile strength and clamping force requires a modified acceptance and installation procedure [13]. Turn-of-Nut tightening method shall be utilized to tension bolt assemblies.

5-1.2 Rotational Capacity Testing[9]

Perform rotational capacity testing as described below on two test assemblies for each LOT designation in the presence of the Engineer. The bolt, nut and washer shall come from the same

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[7] *Due to the current lack of exposure to ASTM A709 Grade 50CR in fabrication facilities, the fabricator's continuity log will be an important record of ensuring qualified welders are performing the work. This log shall at a minimum effectively identify each welder and the position, process, WPS used, and date of each individual's qualification test. It shall also identify that the test was performed on ASTM A709 Grade 50CR material and whether it is for fracture critical welding.*

[8] *The system outlined in Provision 2-1.2 has been selected due to the combination of strength, ductility, and corrosion resistance [10]. Modified rotational capacity tests indicate that this system will safely develop a clamping force of 30 kips, which is lower that the clamping force of 39 kips achieved by A325 bolts. This disparity will be accounted for in the design phase. Pursuit of higher clamping force results in galling of the threads, which is detrimental.*

[9] *Records of calibration of all equipment including but limited to tension measuring devices (Skidmore-Wilhelm) and torque wrenches shall be provided to FDOT's inspector to ensure accurate working equipment. All bolt testing shall be documented on paper and copies provided to the inspector for project records. Testing documents shall include*

LOT and be packed in the same container (or group of containers assigned the same LOT), except in special cases where nuts and washers have only one production LOT number for each size. If any of the required tests fails, the entire LOT will be rejected.

(1) Apply Never-Seez lubricant evenly to threads of the bolt as well as the nut and washer contact surfaces.
(2) Load the bolt assembly into the Skidmore-Wilhelm and tighten the nut to standard initial tension loading of 4 kips.
(3) Mark colinear lines on the wrench socket and testing apparatus.
(4) Tighten the nut until a tensile force of 30 kips is achieved on the B8-2 bolt and record the angle of nut rotation and torque values. The torque must be measured with the nut in motion.
    a. The maximum allowable torque (T) is calculated by multiplying the tensile force (P) in pounds by the bolt diameter (D) in feet by 0.25. (T = 0.25 x P x D)
    b. For a 7/8-inch diameter B8-2 bolt under 30 kips of tensile load, the maximum allowable torque is 550 ft-lbs.
(5) Tighten the nut to the rotation listed in Table 5-1 to produce the design clamping force.

Table 5-1
Required Rotation Necessary to Meet Design Clamping Force [13]

$L \leq 4d_b$	$4d_b > L \geq 8d_b$	$8d_b > L \geq 12d_b$
1/2 turn	2/3 turn	1 turn

L = Length of bolt, d_b = Bolt diameter

(6) Record the tensile force and torque, with the maximum allowable torque remaining at the value calculated by step 4a.
(7) Tighten the nut by the rotation level listed in Table 5-2 to produce a tensile force of at least 34.5 kips.

Table 5-2
Required Rotation Necessary to Produce at Least 1.15 Times Clamping Force in Bolt [13]

$L \leq 4d_b$	$4d_b > L \geq 8d_b$	$8d_b > L \geq 12d_b$
1 turn	1-1/3 turn	1-1/2 turn

L = Length of bolt, d_b = Bolt diameter

(8) Record the tensile force and torque and ensure that the 34.5 kip tensile force was achieved.
(9) Remove the bolt assembly from the Skidmore-Wilhelm and examine the threads on the nut and bolt. No signs of shear failure, stripping, or torsional failure of the bolt should be evident. Assemblies that have evidence of shear, stripping, or torsional failure have failed the test. Further check the thread condition by rethreading the nut to the position on the bolt where the test was performed. If the nut cannot be advanced by hand onto the bolt, the assembly has failed the test.
(10) Visibly inspect the appearance of the assembly. Assemblies with visible manufacturing defects such as incomplete threading, geometric distortions, cracks, or surface fissures have failed the test.

at a minimum the lot numbers and diameter or size of each bolt, nut, and washer as well as the torque, tension, and nut rotation achieved at each step of the testing and whether the test was a pass or fail. The testing records shall be signed by the fabricator's quality inspector.

5-1.3 Pre-Installation Verification Testing

For each work shift and in the presence of the Engineer, perform tests utilizing a representative sample of five fastener assemblies, from each LOT to be installed that shift. Perform the tests using a tension measuring device, following the same procedure to be used for actual installation of the fastener assemblies, to a snug-tight tension and corresponding torque, which, when the additional turns required in Table 5-1 are added, will result in at least 32 kips or 1.05 times the minimum required fastener installation tension of 30 kips. Place a washer under the part turned in the tightening of the bolt. Consider the job inspection snug-tight torque as the average of three test values determined after rejecting the high and low-test values.

5-1.4 Installation Procedure

(1) Apply Never-Seez lubricant to all threaded parts and washer contact surfaces.

(2) Tighten nuts to snug-tight position to ensure that all parts of the connection are in firm contact with each other. For the purposes of this procedure, "firm contact" shall mean the condition that exists on a faying surface when the plies are solidly seated against each other, but not necessarily in continuous contact. The Contractor or fabricator and the Engineer shall verify snug-tight condition based on the torque value established during pre-installation verification testing as described above.

(3) Mark collinear lines with a center punch[10] on steel plate, nut, and wrench socket, along with the finish marks indicating the stopping position of the nut where the bolt could be considered pretensioned as determined in Table 5-1.

(4) Conduct final tightening of all the fasteners using the rotation marks from step 3 within the same work shift.

(5) Inspector will use a calibrated torque wrench to ensure torque values do not exceed the maximum allowable torque value, as determined in Provision 3-2.2 step 4a. This shall be performed on 10% but no less than 3 of the bolts in each connection.

CHAPTER 6 - WELDING

6-1.1 Acceptable Welding Processes

Weld ASTM A709 Grade 50CR with shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), or flux cored arc welding (FCAW) [14]. GMAW short-circuiting (GMAW-S), Electroslag welding (ESW), and Electrogas welding (EGW) are prohibited [4] [14].

6-1.2 Preheat and Interpass Temperatures[11]

Apply a maximum preheat and interpass temperature for A709 Grade 50CR of 450°F [14] [15]. Apply a minimum preheat and interpass temperature which is dependent on the thickness of the base metal to be welded, as shown in Table 6-1 and Table 6-2.

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[10] *VDOT observed that paint marking did not adhere well to stainless-steel bolts and nuts so use of center punch was adopted.*

[11] *In the case of welding performed without the required preheat and interpass temperatures, whether exceeding or failing to meet the minimum, the fabricator shall submit a nonconformance for approval by the Engineer and the State Materials Office. If approved by both entities, additional NDT, hardness testing, or metallurgical analysis should be performed to determine the condition of the area affected.*

Table 6-1
Minimum Preheat and Interpass Temperatures (°F) for Non-Fracture Critical Members [4] [14]

To 1-1/2in Incl.	Over 1-1/2in to 2-1/2in Incl.	Over 2-1/2in
70	150	225

Table 6-2
Minimum Preheat and Interpass Temperatures (°F) for Fracture Critical Members [4]

	Heat Input (as calculated by D1.5 5/12) kJ/in								
	30<HI≤50			50<HI≤70			HI>70		
Thickness t, in	H4	H8	H16	H4	H8	H16	H4	H8	H16
t≤ ¾	100	125	150	100	100	125	100	100	100
¾<t≤1-1/2	200	225	250	175	200	225	150	175	200
1-1/2<t≤2-1/2	300	325	350	275	300	325	250	275	300
t>2-1/2	350	375	400	325	350	375	300	325	350

Preheat temperature shall be maintained during the welding operation for a distance at least equal to the thickness of thickest welded part, but not less than 3 in in all directions from the edge of the weld joint, measured at the location of the welding arc [4].
The maximum interpass temperature shall be measured at a distance of 1 in to 3 in in all directions from the edge of the weld, measured just prior to welding the next pass [4].
For combinations of base metals, preheat and interpass temperatures shall be based upon the higher of the required temperatures [4].
Welding shall not be done when the ambient temperature in the immediate vicinity of the weld is lower than 0°F. The ambient environmental temperature may be lower than 0°F, provided supplemental heat and protection from the elements are sufficient to maintain a temperature adjacent to the weldment at 0°F, or higher [4].
When the base metal temperature is below 32°F, the weld area shall be heated to at least 70°F, and this minimum temperature shall be maintained during welding [4].

6-1.3 Heat Input Limitations

For base metal up to 3/4-inch thick, the recommended welding heat input is 55 kilojoules per inch; the maximum allowable heat input is 75 kilojoules per-inch [15]. For base metal greater than 3/4-inch thick, the maximum allowable heat input is 90 kilojoules per-inch [15].

6-1.4 Weld Backing and Termination

Use A709 50CR steel for weld tabs and backing for A709 50CR connections. [14]

6-1.4.1 Weld Terminations and Weld Tabs

Welds shall be terminated at the end of a joint in a manner that will ensure sound welds. Where possible, this shall be done by use of weld tabs (extension bars and run-off plates) placed in a manner that will duplicate the joint detail being welded [4]. Weld tabs and sumps 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 the abutting parts [4].

6-1.4.2 Weld Backing

Backing not exceeding 3/8 in x 1-1/4 in, furnished as bar stock or cut from plate, shall be exempt from CVN testing requirements [4].

Groove welds made with stainless steel backing shall have the weld metal thoroughly fused with the backing. Stainless steel backing shall be continuous for the full length of each weld made with backing. A continuous length of backing may be made by welding shorter sections together so long as the following conditions are met:

1. All welds shall be CJP groove welds made with the same controls as similar CJP groove welds in the structure.
2. RT or UT shall be used to assure weld soundness.
3. All welding and testing of the backing shall be complete before the backing is used to make the structural weld [4].

Stainless steel backing on welds transverse to the direction of computed stress shall be removed, and the joint shall be ground smooth. Stainless steel backing parallel to the direction of stress or not subjected to computed stress need not be removed unless specified in the contract documents or ordered by the Engineer [4].

For welds in compression in T-joints and columns, stainless steel backing need not be removed, unless required by the contract documents or ordered by the Engineer [4].

Where the stainless steel backing of longitudinal welds is externally attached to the base metal by welding, such welding shall be continuous for the length of the backing [4].

Stainless steel backing shall be sufficiently thick to prevent melt through when welding. The minimum nominal thickness of stainless steel backing is shown in Table 6-3 below:

Table 6-3
Backing Minimum Thickness [4]

Process	Min. Nom. Thickness, (in)
SMAW	3/16
GMAW	1/4
FCAW-S	1/4
FCAW-G	3/8
SAW	3/8

Stainless steel backing shall be placed and held in intimate contact with the base metal. The maximum gap between stainless steel backing and the base metal at the weld root shall be 1/16 in [4].

6-1.5 Multipass Welds

Capping weathering filler metal passes with stainless filler metal is prohibited[12]. Welds will be entirely comprised of one filler metal.

[12] *Austenitic filler metal used for welding A709 50CR has a different thermal expansion coefficient than traditional weathering filler metal. Capping a weathering filler metal with an austenitic stainless filler metal may lead to cracking upon cooling, or undesirable corrosion and is therefore prohibited.*

6-1.6 Arc Strikes

In the event of an arc strike outside the area of permanent welds on any base metal, grind cracks or blemishes to remove all of the defect [4]. On tension and reversal of stress members, use magnetic particle testing (MT) (preferably the yoke method) or dye penetrant testing (PT) to determine that no open to the surface discontinuities are present in the structure[13] [4]. Employ hardness testing in accordance with AASHTO/AWS D1.5 3.3.7.4. MT can be used on the base metal to confirm removal of any cracks; however, MT cannot be used on the non-magnetic weld metal. PT is acceptable for both base metal and weld metal, in the event MT cannot be performed or PT is better suited for the component(s) involved.

6-1.7 Stress Relief Heat Treatment

Where required by contract drawings or specifications, welded assemblies shall be stress relieved by heat treating. Finish machining shall be done after stress relieving. If heat treatment is required for tension elements, the contract may require prototype testing with similar configurations to evaluate effects on HAZ grain growth, ductility, and toughness [4].

The temperature of the furnace shall not exceed 600°F at the time the welded assembly is placed in it [4].

Above 600°F the rate of heating in °F/hr shall not exceed 400°F per hour divided by the maximum metal thickness in inches. During the heating period, variation in temperature throughout the portion of the part being heated shall be no greater than 250°F within any 15 ft interval of length [4].

After a mean temperature range between 1100°F and 1200°F is reached, the temperature of the assembly shall be held within the specified limits for a time not less than specified in Table 6-4 below, based on the thickness of the thickest part.

Table 6-4
Minimum Holding Time

1/4 in or Less	Over 1/4 in Through 2 in	Over 2 in
15 minutes	4 minutes / 1/16 in	2 hrs plus 15 minutes for each additional 1 in over 2 in

During the holding period, the highest and lowest temperature throughout the portion of the assembly being heated shall not vary by greater than 150°F [4].

Above 600°F, cooling shall occur in a closed furnace or cooling chamber at a rate in °F/hr not exceeding 500°F per hour divided by the maximum metal thickness in inches, but not more than 500°F/hr. Below 600°F, the assembly may be cooled in still air [4].

Alternatively, when it is impractical to post weld heat treat to these requirements, welded assemblies may be stress relieved at lower temperatures for longer periods of time as shown in Table 6-5 below [4].

[13] *MT cannot be used on the deposited weld metal, as it is not magnetic. PT must be used on the deposited weld metal to check for discontinuities that are open to the surface.*

Table 6-5
Alternate Stress-Relief Heat Treatment

Decrease in Temperature Below Minimum Specified Temperature, Δ °F	Minimum Holding Time at Decreased Temperature, Hours per 1 in of Thickness
50	2
100	3
150	5
200	10

6-1.8 SMAW Requirements

Electrodes supplied in hermetically sealed containers may be used directly from the new container. Once opened, the electrodes shall be stored in an oven at 250°F to 300°F. Electrodes received in containers that are not hermetically sealed, whether by design or damage, shall be redried according to the manufacturer's instructions, then stored until use in an oven at 250°F to 300°F [5].

Electrodes exposed to the atmosphere upon removal from drying or storage ovens or hermetically sealed containers shall be used within 4 hours or redried according to the manufacturer's instructions, then stored until use in an oven at 250°F to 300°F. If exposed to the atmosphere for less than 4 hours, electrodes may be returned to the storage oven and reissued after a period of no less than 4 hours at 250°F to 300°F [4][5].

The maximum diameter of SMAW electrodes shall be as follows:

1. 1/4 in for all welds made in the flat position, except root passes
2. 1/4 in for horizontal fillet welds
3. 1/4 in 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. 5/32 in for welds made in the vertical and overhead position
5. 3/16 in for root passes of groove welds and all other welds not included in 1-4 above

The maximum thickness in root passes in groove welds shall be 1/4 in [4].

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

1. 3/8 in in the flat position
2. 5/16 in in the horizontal or overhead positions
3. 1/2 in in the vertical position

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

1. 1/8 in for subsequent layers of welds made in the flat position
2. 3/16 in for subsequent layers of welds made in the vertical, overhead, or horizontal positions

6-1.9 SAW Requirements

Flux shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored under normal conditions for at least six months without such storage affecting its welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 500°F for one hour before use. Flux shall be placed in the dispensing system immediately upon opening a package or withdrawal from an oven or, if used from an open package, the top 1 in shall be discarded or dried as above. All flux in hoppers and other delivery systems open to the atmosphere shall be removed and replaced with new, or freshly dried flux, whenever welding operations have not been conducted for more than 24 hours. All flux in pressurized tanks, flux recovery systems, and other delivery systems closed to the atmosphere shall be removed and replaced with new or freshly dried flux, whenever welding operations have not been conducted for more than 96 hours. Flux that has been wet shall not be used [4][5].

SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, use of catch pans, sweeping from weldment surfaces or other means. Recovered flux shall be passed through an appropriate screen and over a suitable magnet to remove unwanted particles and materials before being returned to the flux supply system. Flux that is not reclaimed from weldment surfaces within one hour of being deposited on the weld shall be dried before being used and described above [4].

The Contractor shall have a system for collecting un-melted flux, mixing with new flux as required, and welding with a mixture of these two such that the flux composition and particle size distribution at the arc are relatively constant. Flux fused in welding shall not be reused [4].

6-1.9.1 Single Electrode SAW Procedures

The maximum welding current to be used in making a groove weld for any pass that has fusion to both faces of the groove shall be 600 A [4].

The maximum current to be used for making fillet welds in the flat position shall be 1000 A [4].

The thickness of weld layers, except root and surface layers, shall not exceed 1/4 in. When the root opening is 1/2 in or greater, a multiple-pass, split-layer technique shall be used. The split layer technique shall also be used in making multiple-pass welds when the width of the layer exceeds 5/8 in [4].

6-1.9.2 Parallel and Multiple Electrode SAW Procedures

When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 1/2 in, a split-layer technique shall be used to assure adequate corner fusion. If parallel electrodes are used, the electrodes may be displaced laterally instead of using a split-layer technique. When the width of a previously deposited layer exceeds 1 in for multiple electrodes or 5/8 in for parallel electrodes, and only two electrodes are used, a split-layer technique with electrodes in tandem shall be employed [4].

The thickness of weld layers shall not be limited [4].

Parallel and multiple electrode welds may also be made using GMAW in the root of groove or fillet welds followed by single or multiple submerged arcs, provided the GMAW conforms to the requirements within this set of procedures [4].

6-1.10 GMAW and FCAW Requirements

A gas or gas mixture used for shielding in GMAW or FCAW shall conform to the requirements of the latest edition of AWS A5.32/A5.32M, Specification for Welding Shielding Gases. When requested by the Engineer, the Contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and shall meet the dew point requirement. When mixed at the welding site, suitable meters shall be used for proportioning the gases. Percentages of gases shall conform to the requirements of the WPS [4] [5].

The maximum electrode diameter shall be 5/32 in for the flat and horizontal positions, 3/32 in for the vertical position, and 5/64 in for the overhead position [4].

The maximum size single pass fillet weld shall be 1/2 in for the flat and vertical positions, 3/8 in for the horizontal position, and 5/16 in for the overhead position [4].

The thickness of weld layers in groove welds, except root and surface layers, shall not exceed 1/4 in. When the root opening is 1/2 in or greater, a multiple-pass split-layer technique shall be used. The split layer technique shall also be used in making multiple-pass welds when the width of the layer exceeds 5/8 in [4].

The thickness of weld layers in groove welds, except root and surface layers, shall not exceed 1/4 in. When the root opening is 1/2 in or greater, a multiple-pass split-layer technique shall be used. When the width of a layer of a groove weld in the flat, horizontal, or overhead position is 5/8 in or greater, a multiple-pass split-layer technique shall be used. When welding in the vertical position, a split layer technique shall be used when the width of the layer exceeds 1 in [4].

Welding shall not be performed in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of 5 mph [4].

6-1.11 Post Weld Heat Treatment (PWHT)

Approval of the Engineer is required for any post weld heat treatment. Post weld heat treatment temperatures shall not exceed 600°F in accordance with AWS D1.6 [5]. In the event that post weld heat treatment has been approved by the Engineer, the fabricator should submit a procedure for PWHT. The procedure should take into account the thicknesses of the materials and welds, should address time and temperature for the heat treatment and any steps that the fabricator may employ to control cooling of the material to ambient conditions. Verification of the hardness of the material may be required by the Engineer on a case-by-case basis and the fabricator would be required to document the procedures that will be used to obtain hardness values, and acceptable hardness gradients that will be acceptable for the material(s) pre and post weld heat treatment.

CHAPTER 7 - FABRICATION

7-1.1 Cutting

Plasma cut using a water table, with a 35% hydrogen and 65% argon gas mixture [16]. Oxyfuel cutting is prohibited. Cutting equipment shall remain in a condition that it produces consistent cutting operations. Perform monitoring to determine measures needed to comply with OSHA standards [14].

7-1.2 Preparation of Base Metal

Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other discontinuities that would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to a weld shall also be free from scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes [4] [5].

Steel and weld metal shall be cut using mechanical guides and the flame adjusted and manipulated to avoid cutting beyond (inside) the prescribed lines. Cut material shall have a smooth and regular surface free from cracks and notches. The roughness of cut surfaces shall be no more than 1000 μin for material up to 4 in thick and no more than 2000 μin for material over 4 in thick up to 8 in thick. Roughness exceeding these values and occasional notches or gouges no more than 3/16 in deep on otherwise satisfactory surfaces shall be removed by grinding or machining. Notches or gouges in material edges, that are not to be subsequently welded, shall be removed by machining or grinding if the actual net cross-sectional area that would remain after removal of the discontinuity is 98% or greater of the area of the material based on nominal dimensions. Such removal shall be faired to the material edge with a slope not steeper than one in ten and with machine or grinding marks parallel to the material surfaces [4].

Occasional notches or gouges in cut edges, resulting from improper operation of the cutting process, may, with the approval of the Engineer, be repaired by welding. Material discontinuities, such as significant non-metallic inclusions, shall not be repaired by welding unless RT or UT have defined the limits of the defects and the Engineer has approved of the method(s) of defect removal and repair [4].

Welded repairs to the surfaces and edges of tension and reversal-of-stress members shall be subject to UT and PT. Weld quality shall conform to the visual requirements of AASHTO/AWS D1.5 and AWS D1.6 [4] [5].

Re-entrant corners of base-metal cut edges shall be formed to provide a smooth transition with a radius of not less than 1 in that meets the adjacent edges without offset or cutting past the point of tangency [4].

Radii of beam copes and weld access holes shall provide a smooth transition, free of notches or cutting past the points of tangency between adjacent surfaces [4].

7-1.3 Acceptable Joint Preparation Methods

Prepare joints or make repairs using machining, thermal cutting, saw cutting, gouging, chipping, or grinding [4] [14].

7-1.4 Assembly and Tolerances

The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening shall not exceed 3/16 in except in cases involving either shape or plates 3 in or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in may be used, with a backing weld or suitable backing. If the root opening is greater than 1/16 in, the leg of the fillet weld shall be increased by the amount of the root opening or the Contractor shall demonstrate that the required weld size has been obtained [4].

The separation between faying surfaces of plug and slot welds, and of butt joints landing on a backing, shall not exceed 1/16 in [4].

The use of filler plates shall be prohibited except as specified on the approved drawings or as approved by the Engineer [4].

The root opening between parts to be joined by PJP groove welds parallel to the member length (bearing joints excepted) shall be zero, or as small as practicable [4].

Tolerances for bearing joints shall be in conformance with the applicable contract specifications [4].

Parts to be joined by groove welds shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, the offset from theoretical alignment shall not exceed 10% of the thickness of the thinner part joined, but in no case shall be more than 1/8 in. In correcting misalignment in such cases, the parts shall not be drawn into a greater slope than 1/2 in in 12 in. Measurement of offset shall be based on the centerline of parts unless otherwise shown on the drawings [4].

Groove weld joints containing root openings greater than allowed in AASHTO/AWS D1.5 but no more than twice the thickness of the thinner part or 3/4 in, whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding. Larger root openings may only be repaired by welding upon approval by the Engineer [4].

Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practicable. Suitable allowances shall be made for warpage and shrinkage [4].

Ends of welded butt joints required to be flush shall be finished so as not to reduce the width beyond the detailed width or the actual width furnished, whichever is greater, by more than 1/8 in or so as not to leave reinforcement at each end that exceeds 1/8 in. Ends of welded butt joints shall be faired to adjacent plate or rolled shape edges at a slope not to exceed one in ten unless otherwise shown on the drawings [4].

7-1.5 Tack Welds

Tack welds shall be subject to the same quality requirements as the final welds except that discontinuities such as undercut, unfilled craters, and porosity need not be removed before being incorporated into a final weld made using SAW [4].

Tack welds incorporated into the final weld shall be made with electrodes meeting the requirements of the final welds and shall be cleaned thoroughly. Multiple-pass tack welds shall have cascaded ends [4].

Tack welds not incorporated into the final weld shall be removed in a manner that the base metal is not nicked or undercut. PT shall be performed on the removal area along with hardness testing. Hardness values shall not exceed Rockwell C30 or the hardness value of the unaffected base metal, whichever is higher. If the base metal is damaged or unacceptably hard, the Engineer shall approve any repair performed [4].

Tack welding of stainless steel backing shall be done within the joint whenever possible and be incorporated into the final weld. If the stainless steel backing is attached externally, it shall be made by fillet welding continuously for the full length or be removed [4].

7-1.6 Temporary Welds

Temporary welds are prohibited in tension zones of members of quenched and tempered steels. Temporary welds shall be subject to the same WPS and quality requirements as final welds. Unless approved by the Engineer to remain, all temporary welds shall be removed and shall be detailed on the approved drawings [4].

7-1.7 Assembly Sequence

J and U grooves may be prepared before or after assembly. Second side grooves may be prepared after welding the first side. Before welding, J and U grooves shall meet the quality requirements of cut members [4].

7-1.8 Control of Distortion and Shrinkage

The procedure and sequence of welding, joining, and assembling parts and members shall minimize distortion and shrinkage [4].

Insofar as practicable, all welds shall be made in a sequence that will balance the applied heat of welding while the welding progresses [4].

The Contractor shall include and make available a distortion control program as part of their quality control program prior to the commencement of welding. The program shall include any mechanical or heat straightening procedures to be utilized when common distortion control practices are ineffective [4].

The direction of the general progression in welding on a member shall be from points where the parts are relatively fixed in position with respect to each other toward points where they have a greater relative freedom of movement [4].

Joints expected to have significant shrinkage should usually be welded before joints expected to have lesser shrinkage. They should also be welded with as little restraint as possible [4].

All shop splices in a component shall be completed and accepted prior to incorporating the component into a member [4].

In making welds under conditions of severe external shrinkage restraint, the welding shall be carried continuously to completion or to a point that will ensure freedom from cracking before the joint is allowed to cool below the minimum specified preheat and interpass temperature [4].

7-1.9 Heat Straightening and Cold Leveling

Straighten members distorted by welding by mechanical straightening methods specified and approved by the Engineer [5]. This clause does not prohibit, but makes no provisions for, the use of heat straightening of stainless steels with the following exception: If heat straightening is used, it is the Engineer's responsibility to determine the effect that the heat has on corrosion resistance of stainless steels and external stresses of fabrication. Heat straightening temperatures will not exceed 600°F for ASTM A709 Grade 50CR material [5].

Cold leveling after plasma cutting has been found to potentially introduce edge cracks and result in lower CVN values, therefore cold leveling is not recommended [18].

7-1.10 Peening

When approved by the Engineer, peening may be used to prevent cracking and lamellar tears by mechanically reducing residual stresses created by welding. To prevent sharp impressions, peening shall be performed by mechanically striking convex surfaces of intermediate weld beads or layers with a round tool with a 1/4 in radius unless otherwise approved. Root and final passes shall not be peened. When approved by the Engineer, final passes that contain excess weld metal may be peened, provided all the excess weld metal and all peening marks are removed by grinding [4] [5].

Peening shall be done when the weld is at a temperature of 150°F – 450°F. Care shall be taken to avoid striking fusion boundaries or the base metal. Peening energy shall be sufficient to mechanically elongate the surface of the weld without creating overlapping or cracking. Pneumatic tools shall be operated in a manner that prevents contamination of the weld by moisture, oil, or other materials [4].

Manual slag hammers, chisels, and lightweight vibrating tools for the removal of slag and spatter may be used and shall not be considered peening [4].

7-1.11 Blasting

Use non-metallic blast-cleaning medium of either aluminum oxide or garnet. Metallic or other non-metallic blast cleaning-medium is prohibited [16].

7-1.12 Shear Stud Connectors

Shop apply all shear stud connectors [14]. Low carbon steel shear studs are acceptable [14].

7-1.13 Crevice Corrosion

Avoid producing crevices such as those present at faying surfaces. Crevice corrosion prevents the formation of a stable passive layer for A709 50CR [3].

7-1.14 Marking

Prohibit die stamping of cyclically loaded members without the approval of the Engineer [4] [14].

7-1.15 Safety

Each fabricator shall comply with OSHA standards related to welding and cutting chromium steel and shall assess their shop conditions in determining proper ventilation and protection [14].

CHAPTER 8 - REPAIRS

8-1.1 General

Remove damaged weld metal or portions of the base metal by machining, air carbon arc gouging (provided that oxidized surfaces are removed), chipping, grinding, or plasma cutting. Control the processes for removal such that the adjacent weld metal or base metal is not nicked or gouged, and without substantial removal of base metal [4]. Oxyfuel cutting is not permitted [5]. Grind air carbon arc gouged surfaces to bright metal. Grind with iron-free grinding wheels [5]. Use magnetic particle testing (MT) to determine that no nicks, gouges, or cracks remain in the base metal. Use dye penetrant testing (PT) to determine that no nicks, gouges, or cracks remain in the weld metal or base metal. The Engineer shall be notified before improperly fitted and welded members are cut apart [4].

Use a qualified or prequalified WPS to repair or replace welds. The Contractor has the option of repairing an unacceptable weld, removing the defective area, or replacing the entire weld. Inspect the repaired or replaced weld again by the method originally used and apply the same technique and quality acceptance criteria [4].

If, after an unacceptable weld has been made, work is performed rendering 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 and or members before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed according to and approved revised design [4].

8-1.2 Overlap or Excessive Convexity

Excess weld metal shall be removed [4].

8-1.3 Excessive Concavity of Weld or Crater, Undersized Welds, Undercutting

Surfaces shall be prepared, and weld metal deposited [4].

8-1.4 Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion

Unacceptable portions shall be removed and rewelded [4].

8-1.5 Cracks in Weld or Base Metal

The extent of the crack shall be ascertained by PT if weld metal and MT or PT if base metal. The metal shall be removed for the full length of the crack plus 2 in beyond each end of the crack, and rewelded [4].

8-1.6 Distorted or Damaged Members

Members damaged or distorted beyond what is allowed in the distortion control plan may be straightened by mechanical means or application of a limited amount of localized heat with the approval of the Engineer [4].

8-1.7 Welded Restoration of Material with Mislocated holes[14]

Except where restoration by welding is necessary, punched or drilled mislocated holes may be left open or filled with a bolt upon approval by the Engineer. If welding restoration is required and with the approval of the Engineer, the affected area shall be excavated into an elongated shape

[14] *Use of spiral welding is not acceptable for restoring the full cross-section of a mislocated hole. Spiral welding shall not be used to repair mis-drilled holes.*

with a slope of one in ten. Temporary A709 50CR backing shall be used to weld the first side of the excavation. The welding shall be performed using an approved WPS that utilizes longitudinal stringer weld beads. After the first side is completed and before welding the second side, the root shall be back gouged to sound weld metal. Upon completion of the weld restoration, the surface and any weld reinforcement shall be ground flush. Areas in tension shall receive RT, areas in compression shall receive UT or RT, and fracture critical areas shall receive both RT and UT as required per AASHTO/AWS D1.5 [4].

8-1.8 Base Metal Discontinuities

Type W, X, Y, and Z discontinuities shall be evaluated and repaired in accordance with AASHTO/AWS D1.5.

8-1.9 Fracture Critical Members

8-1.9.1 General Requirements

Repair welding shall be done in conformance with an approved WPS[15]. The WPS may be preapproved or individually approved. The Contractor may use preapproved repair WPSs as soon as the QA inspector has verified the discontinuity to be repaired is covered by the WPS. Repair WPSs shall include sketches, or full-size drawings, as necessary to describe the unacceptable discontinuity and the proposed method of repair. WPSs for critical repairs shall document the location of the unacceptable discontinuities to be repaired. [4]

Unacceptable discontinuities to be repaired shall be shown in plan view, elevation, and section as necessary to describe the discontinuity prior to repair. The drawings shall be revised, if necessary, at the completion of repairs to document differences between the presumed initial type, size, orientation, and location of the unacceptable discontinuity and the final complete description of the unacceptable discontinuity as observed and measured during repair [4].

All repair welding shall be subject to oversight by QC and QA inspection [4].

8-1.9.2 Noncritical Repair Welds

Noncritical repair welds are generally welds that deposit additional weld beads or layers to compensate for insufficient welds size and to fill limited excavations to remove unacceptable edge or surface discontinuities, rollover or under cut, including [4]:

(1) Gouges in cut edges that are 3/8-inch deep, or less.
(2) Laminar discontinuities less than 1-inch deep, or with a depth less than one-half the thickness of the cut edge, whichever is less, provided the discontinuity is not within 12-inch of a butt joint loaded in tension. Repair shall be made by excavating from the cut edge.
(3) Repair of base-metal surfaces as provided in ASTM A6.
(4) First-time excavation and repair from one side of groove welds and fillet welds containing unacceptable porosity, slag, and fusion discontinuities, provided the excavations do not exceed the limits in Table 8-1.

[15] *Additional repair guidelines can be found in AASHTO/AWS D1.5 Clause 3.7 and in Florida Department of Transportation Repair Procedures.*

Table 8-1
First-Time Excavation Noncritical Limits

Length of Weld "L"	Length of Excavation
Up to 1-1/2 feet	L or 10 inch, whichever is less
Over 1-1/2 feet to 3 feet	1 foot
Over 3 feet to 6 feet	1-1/2 feet
Over 6 feet to 12 feet	2 feet
Over 12 feet to 24 feet	3 feet
Over 24 feet	3 feet or 10% L, whichever is greater

(5) Repairs to cracks confined to the root passes discovered and corrected before depositing subsequent weld passes.
(6) Repairs to ends of members where there is no dead load or live load stress.
(7) Deposition of weld metal up to 3/8-inch deep, or 1/4 the base metal thickness, whichever is less, to correct for length or joint geometry.
(8) Except as required by AASHTO/AWS D1.5 12.15, post weld heat treatment shall not be required, unless the excavation is greater than 1/2-inch deep.

8-1.9.3 Critical Repair Welds

Except as provided in Provision 3-5.2.2, all welded repairs shall be considered critical. They include, but are not limited to the following [4]:
(1) Repair of gouges in cut edges greater than 3/8-inch deep.
(2) Repair of laminar discontinuities, except as provided in 3-5.2.2(2). Repair may be made from the cut edge, or from a surface, ad approved by the Engineer.
(3) Repair of surface or internal discontinuities in rolled, forged, and cast products not covered by 3-5.2.2(3).
(4) Repair of cracks in the base metal and welds including lamellar tears except as provided in 3-5.2.2(5).
(5) Corrections requiring weld removal and rewelding except as provided in 12.17.2(4).
(6) All welding to correct errors in fabrication such as improper cutting, punching, drilling, machining, assembly, etc.

All critical repairs to base metal and welds shall be approved by the Engineer prior to beginning the repair and shall be documented giving details of the type of discontinuity and extent of repair [4].

8-1.9.4 Repair Procedure Minimum Provisions

With the exception that noncritical repairs need not be recorded, all repair WPSs shall include at least the following provisions described in the order in which the work will be performed [4]:
(1) Surfaces shall be cleaned as necessary to facilitate visual inspection and NDT so that QC and QA inspectors can accurately characterize the discontinuities of concern. Surfaces shall be ground when necessary with iron-free grinding wheels [5] to facilitate visual inspection and NDT.
(2) Unacceptable discontinuities to be repaired shall be recorded as required in 3-5.2.1, and in addition, the location of the excavation and proposed repair to edges, ends, holes, welds, and other details of the FCM shall be shown.

(3) The preheating temperature prior to air carbon arc gouging shall be described in the WPS. Preheat for gouging shall not be less than 150°F.
(4) The method and extent of excavation to removed unacceptable weld and base metal discontinuities shall be completely described, and when appropriate, shall include the sequence of progressive excavations.
(5) MT, PT, or other NDT, if ordered by the Engineer, shall be sued to verify that all unacceptable discontinuity is removed.
(6) All thermal cut and gouged surfaces that shall be welded on shall be ground to produce a smooth, bright surface. Oxygen gouging shall be prohibited.
(7) All temporary weld extensions and steel backing, including the method of attachment, shall be shown in detail.
(8) Preheat and interpass temperature controls shall be listed. They shall meet or exceed the following minimum requirements:
    a. All steels with a minimum specified yield stress of 70 ksi or less, in thicknesses up to 1-1/2-inch inclusive, shall have a minimum preheat and interpass temperature of 325°F. For thicknesses greater than 1-1/2-inch, the minimum preheat and interpass temperature shall be 400°F.
(9) Welding shall be done as described in the approved repair procedure. WPSs qualified for welding of FCMs need not be requalified for repair welding, provided the joint detail used allows access for welding.
(10) Peening, if required, shall be listed in the repair procedure and shall conform to the requirements of AASHTO/AWS D1.5 Clause 3.8. Any additional requirements shall be completely described.
(11) All repair welds in groove excavations shall be post heated as described in AASHTO/AWS D1.5 Clause 12.15. Other weld repairs, such as repair or replacement of fillet welds and welding of noncritical shallow excavations shall be post heated when ordered by the Engineer. Post heating, when required, shall be as described in the repair procedure.
(12) Repaired surfaces shall be ground flush with adjacent base metal or weld surfaces or finished with slight reinforcement that is faired to adjoining surfaces as approved by the Engineer.
(13) Post weld heat treatment, when required, shall be described in the repair procedure and shall conform to the requirements of AASTHO/AWS D1.5 Clause 12.15.

CHAPTER 9 - INSPECTIONS

9-1.1 General

All weld inspections shall be performed by an individual with a current American Welding Society Certified Welding Inspector with at least 5-years of direct experience in fracture critical bridge welding or 3-years of experience with an appropriate Bridge Welding Endorsement.
Complete Joint Penetration (CJP) groove welds in main members shall be QC tested by non-destructive testing (NDT). Unless otherwise provided, radiographic testing (RT) shall be used for examination of CJP groove welds in butt joints subject to calculated tension or reversal of stress. All CJP groove welds in “T” and corner joints shall be tested by ultrasonic testing (UT). When required, testing of CJP groove welds in butt joints in compression or shear may be done by RT or UT in accordance with AASHTO/AWS D1.5 6.7.1 [4]. Frequency of testing is addressed in AASHTO/AWS D1.5 6.7.1.2 [4]. NDT shall begin not less than 24 hours after the completed welds

have cooled to ambient temperature in accordance with AWS D1.6 8.11b [5]. Fracture critical welds shall be allowed to cool to ambient temperature in accordance with AWS D1.5 12.6.4 [4].

9-1.2 Visual Inspection

Conduct visual inspection in accordance with AASHTO/AWS D1.5 and AWS D1.6 [4] [5].

9-1.3 Radiographic Testing (RT)

Film radiographic testing is preferred to digital radiographic testing. Digital RT scans of thin plates may produce artifacts of unknown origin [16].

Radiographic testing will be conducted in accordance with AWS D1.6. A Cobalt 60 source may be used once the part thickness exceeds 2-1/2-inch [5]. Edge blocks will be limited to a gap of 1/16-inch [5]. Hole and wire type Image Quality Indicator (IQI) requirements are tabulated in Table 9-1 and Table 9-2[16].

Table 9-1
Hole-Type Image Quality Indicator (IQI) Requirements [5]

Nominal Material Thickness Range, in	Source Side	
	Designation	Essential Hole
Up to 0.25 incl.	10	4T
Over 0.25 to 0.375	12	4T
Over 0.375 to 0.50	15	4T
Over 0.50 to 0.625	15	4T
Over 0.625 to 0.75	17	4T
Over 0.75 to 0.875	20	4T
Over 0.875 to 1.00	20	4T
Over 1.00 to 1.25	25	4T
Over 1.25 to 1.50	30	2T
Over 1.50 to 2.00	35	2T
Over 2.00 to 2.50	40	2T
Over 2.50 to 3.00	45	2T
Over 3.00 to 4.00	50	2T
Over 4.00 to 6.00	60	2T
Over 6.00 to 8.00	80	2T

[16] *film side requirements have been eliminated from these tables as they only apply to tubular structures.*

Table 9-2
Wire Image Quality Indicator (IQI) Requirements [5]

Nominal Material Thickness Range, in	Source Side Maximum Wire Diameter, in
Up to 0.25 incl.	0.010
Over 0.25 to 0.375	0.013
Over 0.375 to 0.625	0.016
Over 0.625 to 0.75	0.020
Over 0.75 to 1.50	0.025
Over 1.50 to 2.00	0.032
Over 2.00 to 2.50	0.040
Over 2.50 to 4.00	0.050
Over 4.00 to 6.00	0.063
Over 6.00 to 8.00	0.100

9-1.4 Ultrasonic Testing (UT)

The written procedure shall be qualified by testing mock-up welds made by the same welding process and made from the same type of material, joint configuration and material thickness, which represent the production welds to be examined. The mock-up welds shall be sectioned, properly examined, and documented to prove satisfactory performance of the procedure. The procedure and all qualifying data shall be approved by an individual who has been certified Level III in UT by testing in accordance with ASNT SNT-TC-1A and who is further qualified by experience in examination of the specific types of weld joints to be examined.

The calibration block shall be made from ASTM A709 Grade 50CR and shall include a weld made from an approved filler metal. The transducer frequency may be up to 6 MHz [5]. The weld configuration shall be any prequalified complete joint penetration butt joint as shown in AASHTO/AWS D1.5 Figure 2.4 and Figure 2.5 [4]. The standard reflector shall be a 0.06-inch diameter side-drilled hole or equivalent, placed in accordance with AWS D1.6 Figure 8.16 [5]. The calibration block from AWS D1.6 Figure 8.17 shall be used to adjust the horizontal sweep for distance. UT Testing shall be conducted in accordance with AWS D1.6 Clause 8 [5].

It is important to note that UT will be sensitive to differences in density between A709 50CR and the weld metal [14]. Inspectors will be aware of the potential differences in signal and take this into account during the inspection.

9-1.5 Magnetic Particle Testing (MT)

ASTM A709 Grade 50CR base metal may be evaluated for cracks with magnetic particle testing, however the austenitic weld metal is non-magnetic, and cannot be evaluated with MT [14]. Wherever MT is required in AASHTO/AWS D1.5 Clause 6 for production welds, PT shall be used instead [16], and methods of inspection and acceptance shall be in accordance with AASHTO/AWS D1.5 Clause 6.7.7 [4].

9-1.6 Dye Penetrant Testing (PT)

Dye penetrant testing may be used in place of MT [16]. PT may be conducted in accordance with AASHTO/AWS D1.5 [4].

CHAPTER 10 - REFERENCES

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