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**Introduction to the
FHWA Bridge Welding Reference Manual**
December 3, 2019



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Course Description

Introduction to the FHWA Bridge Welding Reference Manual
December 3, 2019

Welding revolutionized steel bridges in the late 1950s and early 1960s. The move from rivets to welding facilitated the use of long, slender, and curved steel members that give engineers extraordinary flexibility in developing solutions. Welding is a mature technology, but there are aspects of welding that are not well understood and can sometimes cause unnecessary concerns in design, fabrication, inspection, and field installation. To help address these issues, the FHWA published the Bridge Welding Reference Manual, which is available online for free from the FHWA. In this webinar, the lead author of the manual provides an overview of this new manual that will be of interest to all of those in the steel bridge industry.



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Learning Objectives

- Describe the history of steel bridge construction, including the period of transition from riveted to welded construction.
- Identify welding standards relevant to the construction of steel bridges.
- Explain how welding procedures are qualified differently for buildings and bridges. Explain the unique testing that takes place to ensure safe welds in bridge structures.
- Explain how to properly document fracture critical members for safety and economy.



Introduction to the FHWA Bridge Welding Reference Manual




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**FHWA
Bridge Welding
Reference Manual**

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VP Technical Services
High Steel Structures, LLC


To find the manual (download for free), search on, "fhwa bridge welding", or go to fhwa.dot.gov/bridge/steel/pubs/hif19088.pdf



**Bridge Welding
Reference Manual**


Publication No. FHWA-HIF-19-088
Structures
September 2019

U.S. Department of Transportation
Federal Highway Administration





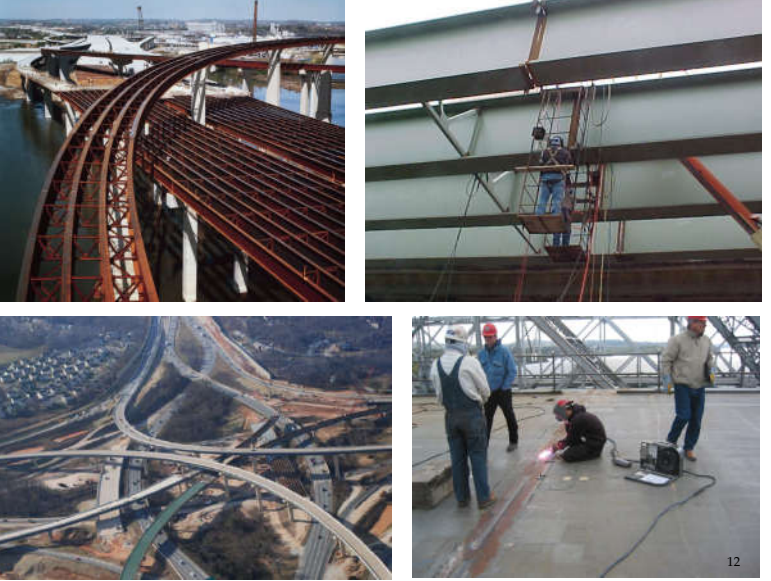
Acknowledgments

- Justin Ocel, FHWA
 - initiated the project (FHWA contract DTFH61-14-D-00049 Task Order 2)
 - FHWA PM
 - reviewed content
- Coauthors
 - Heather Gilmer, HRV
 - Duane Miller, Lincoln Electric
- Tony Ream, HDR, coauthor and FHWA liaison
 - Also Duncan Paterson, HDR
- Other content reviewers – Mary Grieco, MassDOT, Todd Niemann, Fickett, and Dayi Wang, FHWA



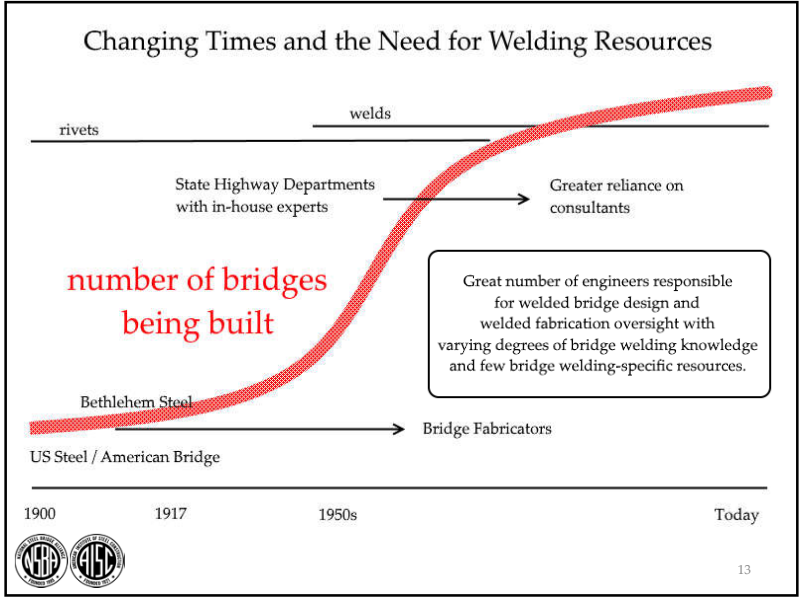
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Welding Revolution

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Hence the Manual

- Welding knowledge for designers and materials engineers
- Compliments (and sometimes explains) the Bridge Welding Code (AWS D1.5)

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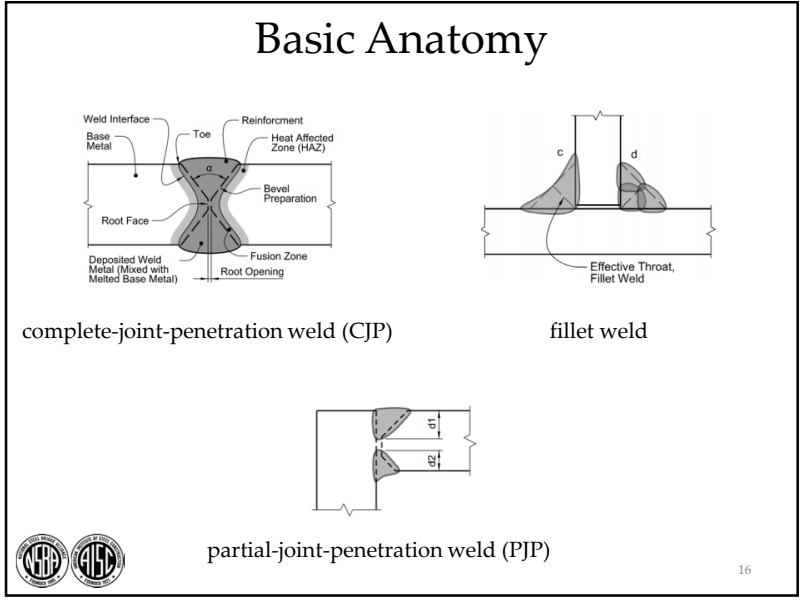
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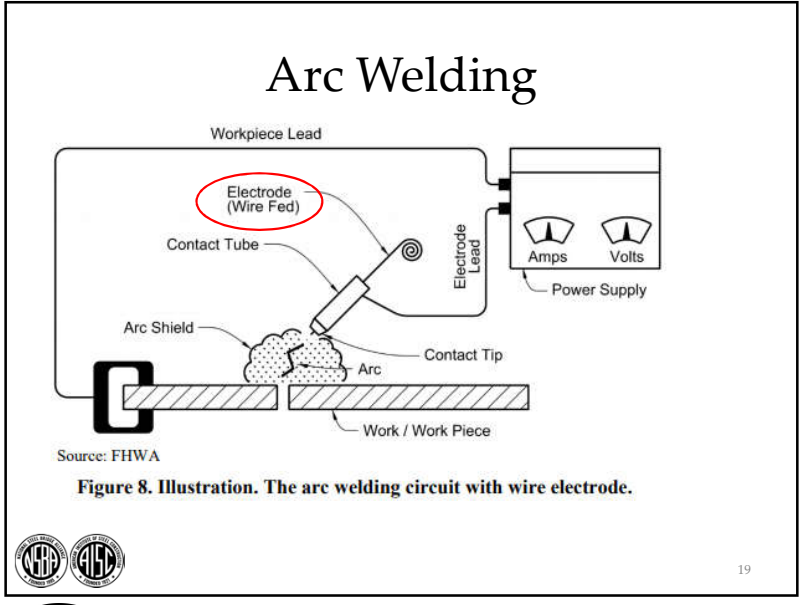
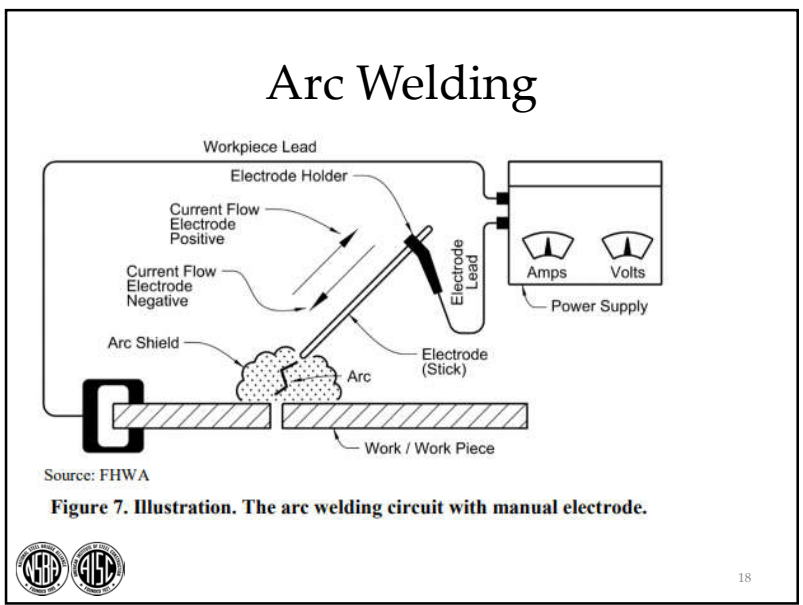
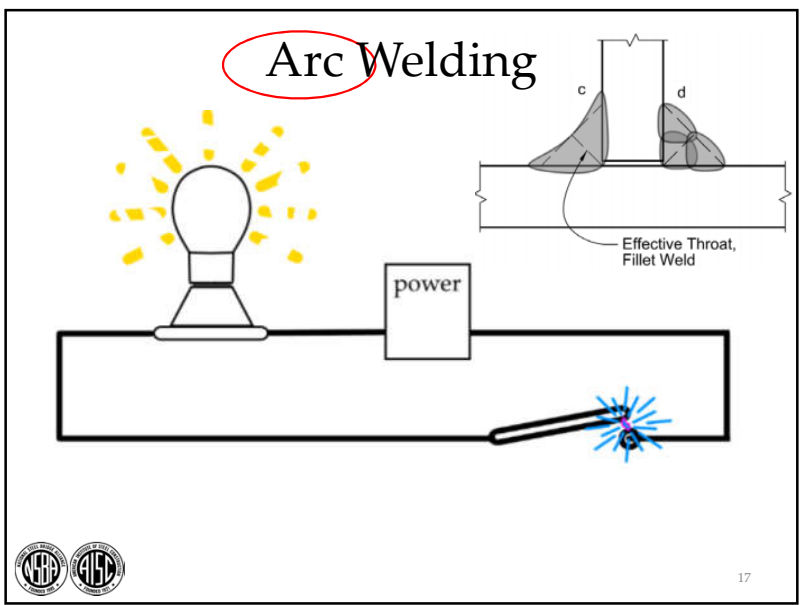
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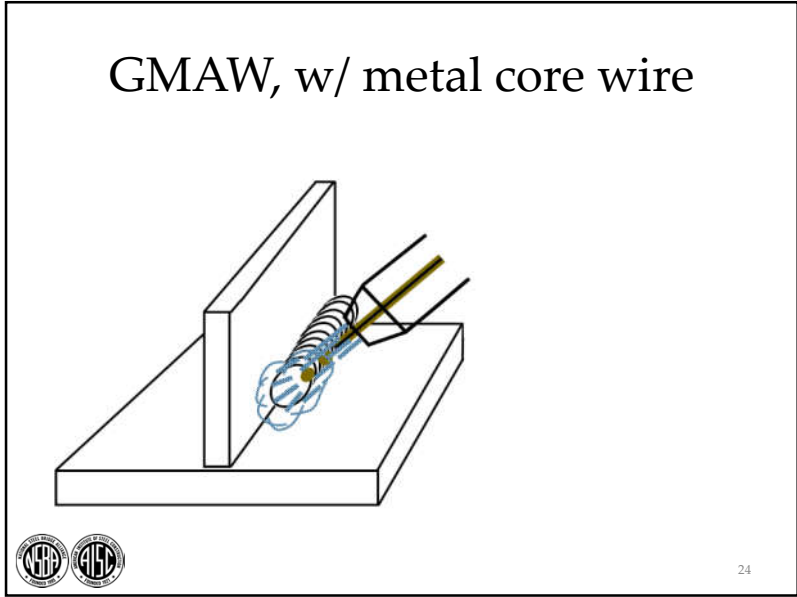
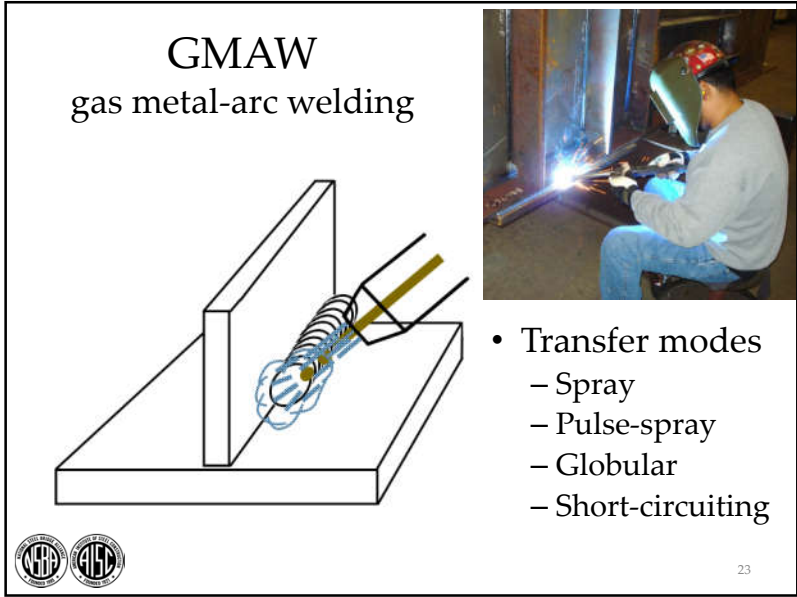
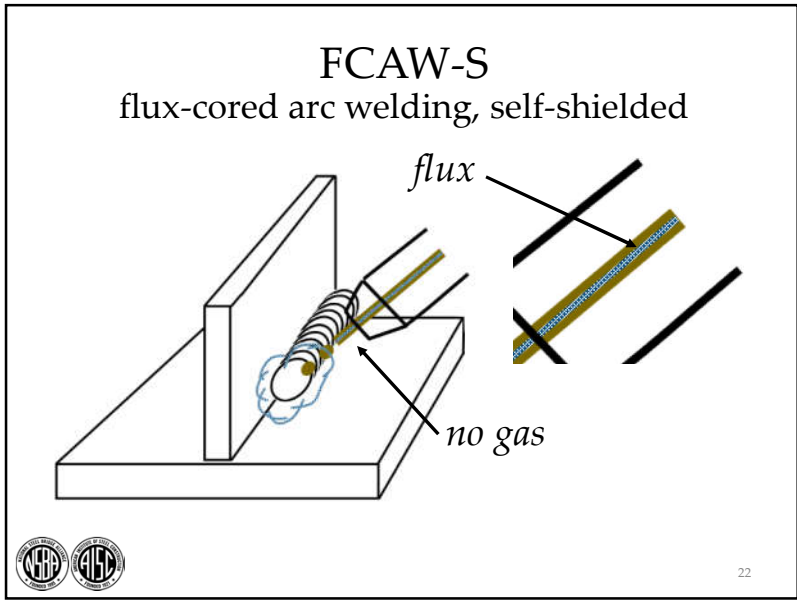
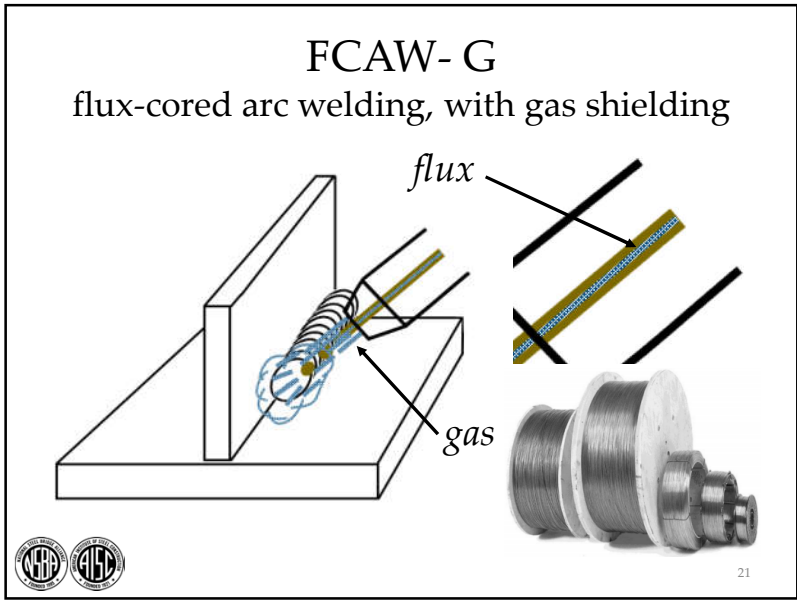
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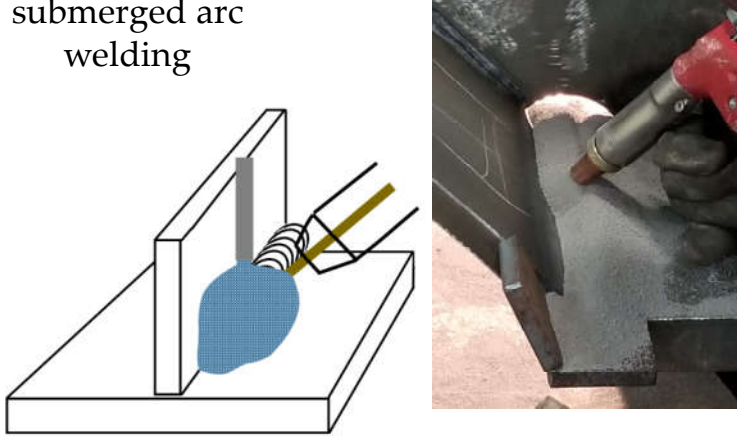


SMAW / Stick shielded metal arc welding


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SAW submerged arc welding

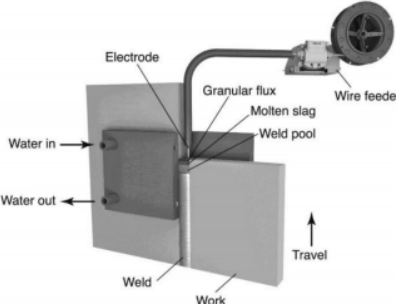


The diagram on the left shows a cross-section of a submerged arc weld joint between two plates. A wire electrode is shown entering the joint from the right, and a blue shaded area represents the molten weld pool. The photograph on the right shows a close-up of a red SAW torch being used to weld a joint in a steel structure, with a bright arc visible at the tip of the electrode.




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Electroslag Welding



The diagram illustrates the Electroslag Welding process. It shows a wire electrode being fed into a joint between two plates. Granular flux is added to the joint. As the electrode moves down, it melts the flux, creating a molten slag layer above the weld pool. The process is labeled as 'Travel' with an upward arrow. Labels include: Electrode, Granular flux, Molten slag, Weld pool, Water in, Water out, Weld, and Work.


- Not arc welding: rather, resistance welding



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Comparing Processes


- SMAW (stick)
 - Oldest process, highly versatile, low productivity
 - Out-of-position welding, small welds, repairs
 - Field welding
- FCAW / GMAW
 - Higher productivity than stick
 - Tack welds, small welds (including CJPs), robotic welding, also long mechanized long welds
 - When FCAW-S, field welding
- SAW
 - High productivity
 - Long mechanized welds, CJPs (flange and web butt splices), also small hand-held weld
- ESW
 - High productivity
 - CJPs only; only vertical; not FC or HPS



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Weld Values

- Strength
- Ductility
- Weathering characteristics
- Toughness
 - Material properties (CVNs)
 - Geometry (fatigue details)
- Soundness
- Constructability
 - Ability to be made
 - Economy



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WPS and PQR Approval Guide from the manual

APPENDIX A - GUIDE TO REVIEW AND APPROVAL OF WELDING PROCEDURE SPECIFICATIONS (WPS) AND PROCEDURE QUALIFICATION RECORDS (PQR) UNDER THE BRIDGE WELDING CODE (ANSI/AISC B15)

On High-Level Review

The Code Table of Contents - Review Sections

1.	A.1. FILLET WELD SOUNDNESS TEST (FWST) REVIEW	301
2.	A.2. GROOVE WELD QUALIFICATION TEST REVIEW (PQR REVIEW)	301
3.	A.3. WELDING PROCEDURE SPECIFICATIONS (WPS)	303
4.	A.4. NONSTANDARD JOINT QUALIFICATION	314

A.1. FILLET WELD SOUNDNESS TEST (FWST) REVIEW

Steps for review and approval of fillet weld soundness test (FWST):

1. Check that the test plate thicknesses are correct for the fillet weld size being tested.
2. Check for proper preparation of the macroetch test specimens (clause 5.10.3(2) and 5.18.2).
3. Check specimen requirements. Macroetches must satisfy requirements of clause 5.19.3.
4. For multipass fillet welds, ensure that the parameters of the FWST are within the limitation of variables of the PQR. (This means essentially checking the FWST to the PQR as if it were a WPS. See the multipass fillet weld provisions of section A.3.2 below.)

A.2. GROOVE WELD QUALIFICATION TEST REVIEW (PQR REVIEW)

Fabricators may use Forms O-3 and O-4 (or O-8 for ESW) from the Bridge Welding Code or those their own form, as long as the form presents the same information as required by the code. If the owner has a required form, check that the owner's form is used. Even if the owner has a required form, owners frequently grant an exception for reciprocity—i.e., if the PQR was previously approved by another owner.

There are a number of approaches for conducting the groove weld qualification test (section 2.9.7). The instructions below encompass all of these methods. For use when there is a

Source: FHWA

Figure 211. Illustration. WPS approval flow chart.

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Differences between D1.1 and D1.5

- Qualification
 - Under D1.1, most welding procedures are prequalified (no testing required)

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Weld Values

- Strength
- Ductility
- Weathering characteristics
- Toughness
 - Material properties (CVNs)
 - Geometry (fatigue details)
- Soundness
- Constructability
 - Ability to be made
 - Economy

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Discontinuities

Welding Technique Related

- Incomplete fusion, incomplete joint penetration
- Cracks – bead-shape induced, surface profile induced, crater cracks
 - AKA “hot cracks”; happen while cooling
- Other volumetric discontinuities – slag intrusions, undercut, overlap, craters
- Profile – concavity, convexity, size
- Spatter, arc strikes, porosity

Material Related

- Laminations, delaminations, lamellar tearing

Hydrogen Related

- Cracks –HAZ, transverse
 - AKA “cold cracks”; happen after solidification
- Porosity

Source: FHWA

Figure 64. Illustration. Transverse cracking.

40

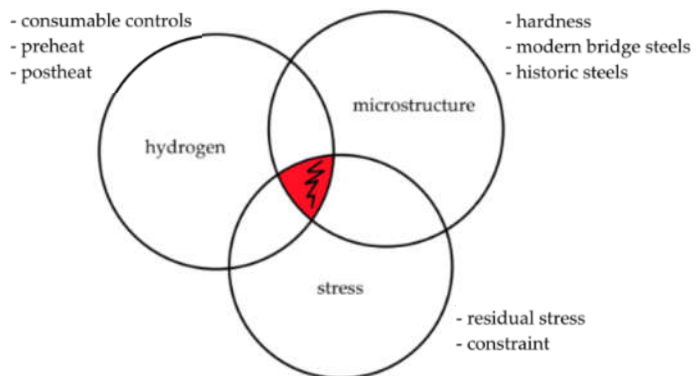
Hydrogen-Assisted Cracking

Cracking mechanism

- Hydrogen dissolves in the weld metal into free to diffuse hydrogen and non-free to diffuse hydrogen
- Weld metal cools; solubility of hydrogen reduces
- Weld solidifies; some diffusible hydrogen remains
 - Continues to diffuse
 - Accumulates in the microstructure lattice / hydrogen traps
- Residual stress from cooled weld metal pulls at **hydrogen** traps - cracks may grow under strain from residual **stress** depending on the amount of residual stress and the strength of the **microstructure**
- If cracks do form, still more hydrogen accumulates in the cracks, growing them



Hydrogen-Assisted Cracking



Non-Destructive Evaluation



Magnetic particle testing (MT)

Ultrasonic Testing (UT)

Radiographic Testing (RT)



Phased Array UT (PAUT)

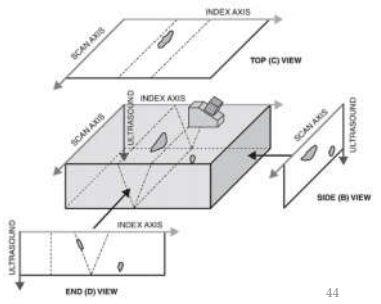
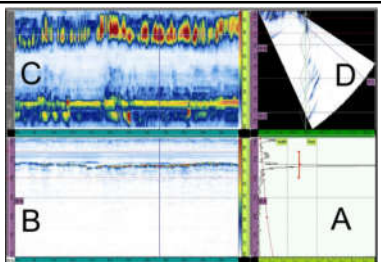
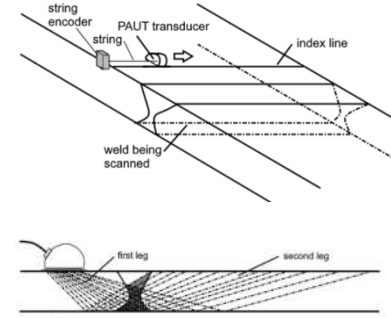


Figure 106. Illustration. Elevation of scanned weld.



PAUT v RT

- PAUT superiority
 - Better detection of planar discontinuities
 - Documented full volumetric view
 - RT: cannot tell depth of discontinuity
 - Joint flexibility (not just butt splices)
 - Improved productivity – result availability, equipment portability, safety (and standoff impact)

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Differences between D1.1 and D1.5

- Qualification
 - Under D1.1, most welding procedures are prequalified
- Mandated NDE

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Fracture Critical Welding

FC History

- Point Pleasant Bridge
- Catastrophic failures due to welds

Proper use / abuse of FC

- Not pedestrian bridges (unless special circumstances)
- Not compression members

FC material designations

- Use grade and zone
 - ASTM A709 grade 50W, zone 2
 - ASMT A709 grade 50WF2
- Do not designate by calling out
 - CVN requirements, i.e. “25 ft. lbs. at 40 degrees”
 - Service temperature, i.e. “Service temperature 0 to -30”

Detailing

- Use sketches showing limits
- Address attachments
- Do not designate welds

FRACTURE CRITICAL DESIGNATION
Note: Shaded area indicates areas that are FC.

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Differences between D1.1 and D1.5

- Qualification
 - Under D1.1, most welding procedures are prequalified
- Mandated NDE
- Special requirements for FC welding
 - Increased preheats
 - PQR expiry
 - Increased NDE

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Intersecting Welds

- Synergy with upcoming FHWA publication
- Original guidance based on Hoan bridge misconstrued

small gap - no relief from constraint
discontinuous weld as crack-like condition
constraint from these elements
tension

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Intersecting Welds

- Synergy with upcoming FHWA publication
- Original guidance based on Hoan bridge misconstrued
- Intersections in fabrication
- Component splicing – do avoid intersections at CJP corners
- As a general rule, touching welds are not a problem

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Constructability – Box Details

Source: FHWA
Figure 186. Illustration. Box corners with only outside fillet welds.

Source: FHWA
Figure 187. Illustration CJP groove weld box corner details.

Possible lamellar tear concern
Non-preferred bevelled plate
Bevel this plate
NON-PREFERRED
PREFERRED

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Constructability – Skewed Joints

- Maximum fillet weld 60 degrees
- Then go to PJP or bent plate

Square; could bevel
Effective throat
Bevel length as needed to provide effective throat

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Constructability

Weld types

- CJP's v PJP's v fillet welds
- Target single pass fillet welds
- Consider PJP's and PJP/fillet combinations

Bearing stiffeners

- Avoid multiples
- Use as connection plates
- Avoid CJP's – use finish to bear or finish-to-bear with fillet weld

1 Flange (typ) 2 3

* Gap is exaggerated 53

Constructability - Access

Height + 3"

USE

AVOID

OK

Then strip flanges

PREFERRED
Flange Thickness Transitions

Then splice flanges

AVOID
Flange Width Transitions

Symbols

- Follow AWS A2.4
- Not crucial that symbol fully conforms with A2.4
 - Don't be afraid to use a sketch – just be sure the intent is clear

ANSI A2.4-2013
An American National Standard

Standard Symbols for Welding, Brazing, and Nondestructive Examination

PAUT

Other Topics

- Field Welding
 - New construction
 - Existing structures
- Other materials
 - Aluminum
 - Stainless Steel
- Reinforcing steel welding
- Welding coated members



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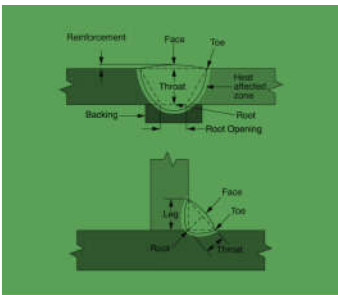


Differences between D1.1 and D1.5

- Qualification
 - Under D1.1, most welding procedures are prequalified
- Mandated NDE
- Special requirements for FC welding
 - Increased preheats
 - PQR expiry
 - Increased NDE
- Far greater range of structural materials in D1.1
- Tubular material and joints



Resources



Design Guide 21
**Welded Connections—
A Primer for Engineers**



CHAPTER 12 - RESOURCES

The documents listed in this chapter are useful references for engineers and others seeking information about welding and weld design.

12.1. AASHTO DOCUMENTS

LRFD Bridge Design Specifications
These specifications are required by the FHWA for the design, evaluation, and rehabilitation of highway bridges. Chapter 6 covers steel bridge design, including provisions for welded details (AASHTO, 2017a).

LRFD Bridge Construction Specifications
These specifications are not adopted directly by many states but are used as a reference for many state standard specifications. They represent a conservative consensus among all states. Chapter 11 addresses steel fabrication and erection, and refers to AASHTO/AWS D1.5 (AASHTO/AWS, 2015) for welding. As of this writing, AASHTO is in the process of creating a standalone steel fabrication specification that will supersede the steel bridge fabrication portions of chapter 11 (AASHTO, 2017). The LRFD Bridge Construction Specifications are discussed in section 1.4.3 of this manual.

LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signs
These specifications address design, fabrication, and erection of highway signs, luminaires, and traffic supports (AASHTO, 2015).

LRFD Guide Specifications for the Design of Pedestrian Bridges
These guide specifications govern the design and construction of common pedestrian bridge types (AASHTO, 2009).

12.2. AWS DOCUMENTS

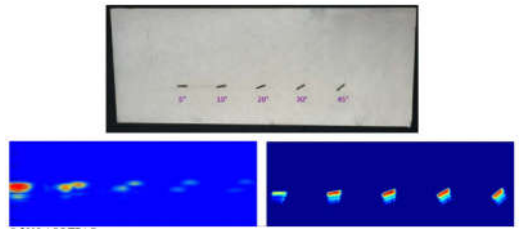
12.2.1. AWS D1 Documents

The AWS D1 documents are introduced in section 1.4.1. All include some weld-related design provisions, inspection and acceptance requirements, workmanship requirements and tolerances, and requirements for qualification of procedures and personnel.

AASHTO/AWS D1.5, Bridge Welding Code
This code, which is the main focus of this manual, is specified by almost every bridge-owning agency in the United States and used in some other countries as well. It is a joint publication of AASHTO and AWS. The commentary is helpful for understanding the background and intention of many of the code's provisions. Many of its details are discussed throughout this manual. Designers should be particularly aware of the document revisions of Issue 3 and the fabrication

Topics on the Horizon

- Full matrix capture, total focus method (FMC TFM)
- PAUT
- Pipe stiffener



Topics on the Horizon

- 50CR
- Tubular structures
- Welding coated surfaces
- Homopolar welding
- HLAW
- Multi-wire GMAW
- QST grades
- Castings



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Bridges & Structures

Structures
Manuals

- [Manual for Refined Analysis in Bridge Design and Evaluation](#) (.pdf) (May, 2019)
- [Design and Evaluation of Steel Bridges for Fatigue and Fracture Reference Manual](#) (.pdf) (December, 2016)
- [Load and Resistance Factor Design \(LRFD\) for Highway Bridge Superstructures](#) (.pdf) (July, 2016)
 - [Design Examples](#) (.pdf, 8 mb)
- [Steel Bridge Design Handbook](#) (December, 2015)
- [Engineering for Structural Stability in Bridge Construction](#) (.pdf) (April, 2015)
- [Contracting and Construction of ABC projects with Prefabricated Bridge Elements and Systems](#) (.pdf) (June, 2013)
- [Manual for Repair and Retrofit of Fatigue Cracks in Steel Bridges](#) (.pdf) (March, 2013)
- [Engineering Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems](#) (.pdf) (June, 2013)
- [Guide for Heat-Straightening of Damaged Steel Bridge Members](#) (.pdf) (09/16/2008)
- [High Performance Steel Designers' Guide](#) (.pdf) (04/30/2002)
- [Heat-Straightening Repairs of Damaged Steel Bridges - A Technical Guide and Manual of Practice](#) (.pdf) (October, 1998)



Summary

- The Manual
 - Is published and available for free
 - Is published as online .pdf only
 - Complements (and explains) D1.5
 - Emphasizes weld quality, knowledge, and constructability
- Remember
 - Consider specifying AWS D1.1 when AASHTO/AWS D1.5 is not appropriate
 - Expedite review, approval, and return of WPSs
 - Consider use of PAUT in lieu of RT
 - Clearly identify FC zones and attachments but do not call out FC welds
 - Do not be afraid of “touching welds”
 - Consider use of field welding to facilitate new construction as well as retrofits
 - Follow manual constructability recommendations and check with local fabricators for their preferences
- Feedback welcome



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