Document:

- **Reference Manual for Welding of Metal Structures**
- Federal Highway Administration – Office of Bridges and Structures

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Objective

- Comprehensive reference manual
- Welding of highway structures with an emphasis on steel highway bridges
- Explain AASHTO/AWS D1.5/D1.5M “Bridge Welding Code” and the AWS D1.1/D1.1M “Structural Welding Code-Steel”, including relationships to structural performance and design intent

- Target audience
  - DOT employees and their representatives and consultants involved with the welding and fabrication of steel highway structures
  - Designers, fabricators, field/construction/materials engineers and other paraprofessionals associated with structural design, material and procedure specifications, drawing approval, welding, construction, inspection, and repair.
Outline:

1. INTRODUCTION
   - 1.1. Manual Background
   - 1.2. Welds
   - 1.3. History and Importance of Welding in Bridges
   - 1.4. Applicable Codes and Specifications
     - 1.4.1. Welding Codes
     - 1.4.2. Material Specifications
     - 1.4.3. Fabrication Specifications
2. MATERIALS, EQUIPMENT AND PROCESSES
   o 2.1. Base Material
   o 2.2. Filler Metal
   o 2.3. Weld Metal and HAZs
   o 2.4. Basics of Arc Welding
   o 2.5. Welding Equipment

   2.6. Overview of Welding Processes
   • 2.6.1. Submerged Arc Welding (SAW)
   • 2.6.2. Gas Metal Arc Welding (GMAW)
   • 2.6.3. Flux Core Arc Welding (FCAW)
   • 2.6.4. Shielded Metal Arc Welding (SMAW)
   • 2.6.5. Electro-slag Welding (ESW)
   • 2.6.6. Electro-gas Welding (EGW)
   • 2.6.7. Gas Tungsten Arc Welding (GTAW)
   • 2.6.8. Stud Welding
3. QUALIFICATION OF WELDING PROCEDURE SPECIFICATIONS AND WELDERS

- 3.1. Welding Procedure Specifications
  - 3.1.1. Description
  - 3.1.2. Fabricator Research and Development

- 3.2. WPS Qualification and Creation of the Procedure
  - 3.2.1. Prequalification
  - 3.2.2. Qualification of WPSs for Groove and Welds and Multipass Welds
    - 3.2.2.1. Heat Input
    - 3.2.2.2. Production
    - 3.2.2.3. Pretest / Verification
  - 3.2.3. Fillet WPS Qualification
  - 3.2.4. Electroslag Qualification
  - 3.2.5. Plug and Slot Qualification

- 3.3. WPS Qualification Tests
  - 3.3.1. Qualification Testing
  - 3.3.2. Groove Welding Qualification Test Plate
  - 3.3.3. Executing the Groove Weld Qualification Test Plate
  - 3.3.4. Groove Weld Qualification Tests
  - 3.3.5. Fillet Weld Soundness Tests
  - 3.3.6. Combinations of PQRs and WPSs
  - 3.3.7. WPSs for PJP Groove Welds
  - 3.3.8. Unlisted Materials

- 3.4. Welding Positions

- 3.5. Standard Joints
  - 3.5.1. Tolerances and Fit-up
  - 3.5.2. Joint Details
  - 3.5.3. Backgouging
  - 3.5.4. Non-Standard Joints
3. QUALIFICATION OF WELDING PROCEDURE SPECIFICATIONS AND WELDERS, CON’T

- 3.7. Welder Qualifications
  - 3.7.1 Achievement of Quality by Skilled Workers
  - 3.7.2 Qualification versus Certification
  - 3.7.3 Fabricator Responsibility
  - 3.7.4 “Welders” versus “Operators” versus “Tack Welders”

  - 3.7.5 Process
  - 3.7.6 Weld Type: Groove versus Fillet Weld
  - 3.7.7 Position
  - 3.7.8 Qualification Frequency
  - 3.7.9 Personnel Qualification Test
    - 3.7.9.1 Materials
    - 3.7.9.2 Groove weld tests
    - 3.7.9.3 Fillet weld tests
    - 3.7.9.4 Plug welds
APPENDIX A - GUIDE TO REVIEW AND APPROVAL OF WELDING PROCEDURE SPECIFICATIONS (WPSS) AND PROCEDURE QUALIFICATION RECORDS (PQRS) UNDER THE BRIDGE WELDING CODE (AASHTO/AWS D1.5)
4. WORKMANSHIP AND WELD QUALITY
   o 4.1. Quality and the Bridge Welding Code
   o 4.2. Preheat and Interpass Temperature Controls
   o 4.3. Hydrogen Control
     • 4.3.1 The Mechanism of Hydrogen Problems
     • 4.3.2 Welding Consumable Hydrogen Controls
   o 4.4. Weld Discontinuities and Defects
     • 4.4.1 Planar Discontinuities
       » 4.4.1.1Incomplete Fusion
       » 4.4.1.2Incomplete Joint Penetration
       » 4.4.1.3Overlap
       » 4.4.1.4Laminations and Delaminations
       » 4.4.1.5Lamellar Tearing
     • 4.4.2 Cracks
       » 4.4.2.1Centerline Cracking
     • 4.4.3 Volumetric Discontinuities
       » 4.4.3.1 Undercut
       » 4.4.3.2 Porosity
       » 4.4.3.3 Slag Intrusions
     • 4.4.4 Weld Profile Requirements
       » Excessive Concavity
       » Excessive Convexity
       » Inadequate Weld Size
       » Under filled Weld Craters
   o 4.5. Spatter
   o 4.6. Arc Strikes
Outline:

4. WORKMANSHIP AND WELD QUALITY, CON’t

- 4.7. Distortion and Shrinkage
  - 4.7.1 Types of Distortion
    - 4.7.1.1 Angular Distortion
    - 4.7.1.2 Transverse Shrinkage
    - 4.7.1.3 Longitudinal Shortening
    - 4.7.1.4 Twisting
    - 4.7.1.5 Longitudinal Sweep or Camber
    - 4.7.1.6 Buckling and Warping
    - 4.7.1.7 Rotational Distortion

- 4.7.2 Distortion Control Measures
  - 4.7.2.1 Adding Restraint
  - 4.7.2.2 Weld Placement
  - 4.7.2.3 Welding Sequence
  - 4.7.2.4 Stress Relief

- 4.8. Weld Repairs
  - 4.8.1 General
  - 4.8.2 Internal Defects Discovered by NDT
  - 4.8.3 Undercut Repair
  - 4.8.4 Cracks
INSPECTION AND QUALITY CONTROL

5.1. AISC Certification

5.2. Visual Weld Inspection

5.3. Non-destructive Examination Methods

5.3.1. Magnetic Particle Testing (MT)

5.3.2. Ultrasonic Testing (UT)

5.3.3. Radiographic Testing (RT)

5.3.4. Dye Penetrant Testing (PT)

5.4. Acceptance Criteria

5.5. Documentation
6. AASHTO/AWS FRACTURE CONTROL PLAN (FCP) FOR NONREDUNDANT MEMBERS

   6.1. History
   6.2. Extent of Fracture Critical Condition
   6.2.1 Tension versus Compression Members
   6.2.2 Attachments
   6.2.3 Design Detailing Practice
   6.2.4 Shop Drawings
   6.3. Special Requirements for FCMs
   6.4 System Redundant Members (SRMs) and Internally Redundant Members (IRMs)

Figure X. Fracture critical detailing (left) and as-executed (right) (FHWA)
Outline:

7. FABRICATION CONSIDERATIONS IN DESIGN OF WELDED STRUCTURES
   - 7.1. Welding Symbols
   - 7.2. Tack Welds
   - 7.3. “Seal” Welds
   - 7.4. Weld Backing
   - 7.5. Reinforcing Fillet Welds
   - 7.6. Intersecting Welds
     - 7.6.1. Structural Concerns
     - 7.6.2. Fabrication Concerns
   - 7.7. Skewed Joints
   - 7.8. Access for Welding
   - 7.9. Weld Terminations
     - 7.9.1. Weld Tabs
     - 7.9.2. Holdbacks
     - 7.9.3. Transitions
   - 7.10. Undermatching
Outline:

8. DETAILS FOR SPECIFIC BRIDGE WELDS
   - 8.1. I-Girder Bridges
   - 8.2. Tub Girder Bridges
   - 8.3. Boxes
   - 8.4. Special Situations
Outline:

9. THE ENGINEER’S ROLE IN WELDED FABRICATION
   - 9.1. Introduction
   - 9.2. Contract Documents
   - 9.3. Approvals
   - 9.4. Unexpected Circumstances
Outline:

10. ADDITIONAL TOPICS
  
  o 10.1. Field Welding
    • 10.1.1. New Construction
    • 10.1.2. Welding of Existing Structures
  
  o 10.2. Aluminum
  
  o 10.3. Reinforcing Steel
  
  o 10.4. Stainless Steel
  
  o 10.5. Welding Coated Members
  
  o 10.6. Innovations
Outline:

11. RESOURCES

- AASHTO
  - Mandatory:
    » Bridge Design Specification
  - Consider:
    » Bridge Construction Specification
    » Traffic Structures Design

- AWS standards
  - Mandatory:
    » D1.5 - Bridge Welding Code
    » A2.4 - Symbols
    » A3.0 - Definitions
  - Consider:
    » D1.1 – Structural Welding Code—Steel
    » D1.2 – Structural Welding Code—Aluminum
    » D1.5 – Structural Welding Code—Reinforcing Steel
    » D1.6 – Structural Welding Code—Stainless Steel

- AASHTO/NSBA Steel Bridge Collaboration Standards - Include a discussion of the entire family, with emphasis on the welding related standards
- AISC
  - Design Guide 21
- FHWA
  - Design and Construction of Welded Bridge Members and Connections
  - Welding Inspection for Steel Bridge Fabrication
  - HMEC Module C – Steel, Welding and Coatings Participant Workbook
- Lincoln Electric - Procedure Handbook of Arc Welding
Outline:

12. APPENDICES

12.1. Guide to Review and Approval of Welding Procedures under AASHTO/AWS D1.5
   12.1.1. Reviewing Prequalified Procedures
   12.1.2. Groove Weld Procedures
     12.1.2.1. High Heat Input
     12.1.2.2. High-Low Heat Input
     12.1.2.3. Production
   12.1.3. Single-Pass Fillet Weld Procedures
   12.1.4. Multi-Pass Fillet Welds Procedures

12.2. Table: Differences Between D1.5 and D1.1
Questions?