Overview of Fabrication

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Consultant
Outline

• Building a Bridge Girder
  – How we do it know
    • Welding
    • Inspection
    • Efficient Sizing for Fabrication
  – How we want to do it in the future
    • Virtual Assembly
Modular Design
Crane and Wrenches Required for Assembly
*No Post Tensioning Required*
Typical Girder Proportions

• Transverse Stiffeners only as Required
Typical Girder Proportions

200 ft. Span

• Span/Depth=25-30

\[
\frac{D}{t_w} \leq 120 \quad \frac{2D_c}{t_w} \leq 137
\]

• Compression Flange

\[
- \quad \frac{1}{4} > \frac{b_f}{D} > \frac{1}{6}
\]

\[
- \quad \frac{b_f}{2t_f} \leq 12 \text{ and } < 9.2 \text{ for } 50 \text{ ksi}
\]

\[
D = 8 \text{ ft} \quad \frac{S}{D} \leq 25
\]

\[
t_w = \frac{7}{8} \text{ in.} \quad \frac{D}{t_w} = 110 \leq 120
\]

\[
b_f = 24 \text{ in.} \quad \frac{b_f}{D} \leq 0.25
\]

\[
t_f = 1.375 \text{ in.} \quad \frac{b_f}{2t_f} = 8.7
\]
Cross Sectional Limits
AASHTO LRFD Specifications

6.10.2.2—Flange Proportions

Compression and tension flanges shall be proportioned such that:

\[ \frac{b_f}{2t_f} \leq 12.0, \quad \text{Too slender, 9.2 for Grade 50} \]  \hspace{1cm} (6.10.2.2-1)

\[ b_f \geq D/6, \quad \text{Too slender, D/4 better choice} \]  \hspace{1cm} (6.10.2.2-2)

\[ t_f \geq 1.1t_w, \quad \text{Should be 1.5 to 2 x web thickness} \]  \hspace{1cm} (6.10.2.2-3)

and:

\[ 0.1 \leq \frac{I_{yw}}{I_{yw}} \leq 10, \quad \text{Important limit, eliminates “T” like sections} \]  \hspace{1cm} (6.10.2.2-4)
3/8 in. Top Flange - 1/2 in. Web

\[ \frac{b_f}{2t_f} = \frac{16 \text{ in.}}{2 \times \frac{3}{8} \text{ in.}} = 21.3 > 12.0 \Rightarrow \text{NO GOOD} \]
Flange Thickness Transition
Building a Girder
Raw Material

Longest Plate
80 feet
Limited by Railcar
Mill Lead Times

A572 gr. 50 & A588 = 4 to 8 weeks
HPS 70W = 4 to 10 weeks
Rolled beams = 3 to 8 weeks

Material Not Stocked by Fabricator
First Steps

• Splice Flange and Web Plates
  – Full Penetration Weld
  – Nest Flange Plates if Possible

• Trim Mill Edges

• Rip Flange Plates to Width From Wide Plates (Cut Curve Small Radius)

• Cut Curve Webs for Desired Camber
Welding

• Fusion Welding
  – Consumable Electrode and Base Metal Melted to Form Weld
  – Arc or Resistance Heating in the Flux Provides the Heat to Melt the Base Metal
  – Shielding Gas use to Protect the Molten Metal and Spray from Electrode Melting from the Atmosphere
  – Flux to Clean Molten Weld Pool and also used to Produce Shielding Gas in SMAW

• Base Metal Chemistry Must Be Controlled
SMAW (Shielded Metal Arc Welding)
Stick Welding
FCAW (Flux Cored Arc Welding)
SAW (Submerged Arc Welding)
Cooling Weld by Conduction of Heat Into Plate

Thicker Plates Provide Larger Heat Sink Resulting in More Rapid Cooling

Key to isotherms:
- Yellow: 1500 °C
- Red: 1200
- Red: 900
- Green: 600
- Purple: 300

Weld and weld pool temperatures
What Happens to Base Metal During Welding

Critical that material heated to austenite temperature is cooled slowly enough to not form martensite.
Generation of Heat Affected Zone (HAZ)
Preheat and Interpass Temperatures
AWS D1.5 Chap. 4

- Preheat - Temperature before welding
- Interpass - Temperature before starting next weld pass

<table>
<thead>
<tr>
<th>Steel</th>
<th>To $\frac{3}{4}$ in. Incl.</th>
<th>$\frac{3}{4}$ to 1- $\frac{1}{2}$ in. Incl.</th>
<th>1- $\frac{1}{2}$ to 2- $\frac{1}{2}$ in. Incl.</th>
<th>Over 2- $\frac{1}{2}$ in.</th>
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</thead>
<tbody>
<tr>
<td>A709 Grade 36,50,50S,50W &amp; HPS 50W</td>
<td>$\geq 50^\circ$ F</td>
<td>$\geq 70^\circ$ F</td>
<td>$\geq 150^\circ$ F</td>
<td>$\geq 225^\circ$ F</td>
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<tr>
<td>A709 Grade HPS 70W</td>
<td>50 to 450 °F</td>
<td>125 to 450 °F</td>
<td>175 to 450 °F</td>
<td>225 to 450 °F</td>
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<tr>
<td>A709 Grade HPS 100W</td>
<td>50 to 400 °F</td>
<td>125 to 400 °F</td>
<td>175 to 450 °F</td>
<td>225 to 450 °F</td>
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</table>

Higher Preheats Slow Cooling Rate
WPS
(Welding Procedure Specification) Qualification

• Purpose - Weld Metal Meets Mechanical Properties
  – Strength
  – Ductility
  – Notch Toughness Requirements
  – Done by Welding a Test Plate

• Generates a Procedure Qualification Record (PQR)
  – Documents Welding Variables
  – Documents Physical Test Results

• Exempt (Prequalified)
  – SMAW Welds (except E100 and E110)
  – Tack Welds Remelted by Subsequent SAW Welds
  – Welds of Ancillary Products
Heat Input

• Basis of Qualification Tests Limits

• Heat Input \( \left( \frac{kJ}{in} \right) = \frac{Amperage \times Voltage \times 0.06}{Travel \, Speed \, (in. \, per \, minute)} \)

• Each pass with +/- 10% of overall average
  – Table 5.10 Gives Min. and Max. Amperage for each Process and Electrode Diameter
Qualification Options

• 5.12.1 Maximum Heat Input Qualification
  – Production Welds Heat Input <100% Qualification Test
  – Production Weld Heat Input > 60% Qualification Test

• 5.12.2 Maximum-Minimum Heat Input Qualification (Two Test Welds Required)
  – Production Heat Input Must be Between the Max. and Min. of Test Welds

• 5.12.4 Production Procedure Qualification
  – Multiple Pass SAW with Active Flux
  – Non Standard Joint Details
  – Matching Electrodes for HPS100W

• Most Procedures are Qualified Using 5.12.1
WPS Qualification Test Plate

Specimen | Number of Specimens
--- | ---
CVN | 5 or 8 for NGESW
Side Bend | 4
Reduced Section Transverse Tensile | 2
All Weld Metal Tensile | 1
Macro Etch | 2
RT | RT+UT for NGESW

For SAW

T= 1 in.
α= 20°
R= 5/8 in.
Test Requirements

<table>
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<tr>
<th>Base Metal</th>
<th>Minimum Yield Strength (ksi)</th>
<th>Minimum Tensile Strength (ksi)</th>
<th>Minimum Elongation</th>
<th>CVN Zone I and II (ft-lbs)</th>
<th>CVN Zone III (ft-lbs)</th>
<th>Fracture Critical</th>
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<tr>
<td>Grade 36</td>
<td>45</td>
<td>60</td>
<td>22</td>
<td>20 @ 0°F</td>
<td>20 @ -20°F</td>
<td>25 @ -20°F</td>
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<tr>
<td>Grade 50, 50S</td>
<td>50</td>
<td>65</td>
<td>22</td>
<td>20 @ 0°F</td>
<td>20 @ -20°F</td>
<td>25 @ -20°F</td>
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<tr>
<td>Grade 50W Grade HPS</td>
<td>50</td>
<td>70</td>
<td>22</td>
<td>20 @ 0°F</td>
<td>20 @ -20°F</td>
<td>25 @ -20°F</td>
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<tr>
<td>50W</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade HPS 70W</td>
<td>70</td>
<td>90</td>
<td>17</td>
<td>25 @ -10°F</td>
<td>25 @ -20°F</td>
<td>30 @ -20°F</td>
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<tr>
<td>Grade HPS 100W &gt;2.5</td>
<td>90</td>
<td>100</td>
<td>16</td>
<td>20 @ -40°F</td>
<td>Engr. Approval</td>
<td>35 @ -30°F</td>
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<td>35 @ -30°F</td>
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Welding of Components

• Butt Welding of Flanges
  – SAW
  – NGESW
  – Nesting of Girder Flanges

• Welding Web to Flange
  – Plate Girders
  – Box/Tub Girders
SAW Weld Preparation
Required to Get Access to Bottom of Weld
Prepared Plates Tacked Together Ready to Weld
Flange Thickness Transition
Note Weld in Thinner Plate at the End of The Transition
Submerged Arc Welding - SAW

Run off Tab Used to Start and Stop Weld Off of the Plate
Close Up of Arc Submerged in the Flux
Multiple Pass Welds
Number of Passes Dependent Upon Plate Thickness
Back Gouge Weld Root and Clean By Grinding Weld Back Side
Finished Weld Ground Flush and Ready for Inspection by Radiography or Ultrasonics
Finished Flange Thickness Transition Butt Weld
All Surfaces Ground Smooth
A New Way to Weld
Narrow Gap Electroslag Welding
Narrow Gap Electroslag Welding

NGEW

• Developed in an Extensive Research Study at the Oregon Graduate Institute by Wood and Turpin

• Based Upon Results of the Research, FHWA Lifted Moratorium March 2000

• Included in AWS D1.5 (2010)
Advantages of NSW for Flange Welds

• Single Pass Vertical Weld-No turning of plate and no back gouging
• Fast- Approximately 5 to 10 increase in productivity (2.5 to 1.5 in/minute, 3 foot long weld in about an hour)
• Completely Automated Equipment- Computer controlled wire and flux feed as well as voltage control
Characteristics

• Single Pass Vertical Up Weld
• Molten Weld Metal Contained by Water Cooled Copper Shoes
• Narrow Gap- 3/4 +/- 1/8 inch with square plate edge preparation
• Consumable Guide Tube to Guide Welding Wire
• Submerged Arc-Molten Flux Pool on Top of Weld Metal
Schematic of ESW
Narrow Gap Reduces Susceptibility to Incomplete Fusion

Standard ESW

Consumable guide

Incomplete fusion due to off center guide

1.5” Groove Width

NG ESW

Rectangular Consumable guide

3/4” Groove Width
Enhanced Weld Pool Geometry

**Standard ESW**
\[ f = \frac{W}{D} < 1 \]
(low resistance to cracking)

**NG ESW**
\[ f = \frac{W}{D} > 3 \]
(high resistance to cracking)

- Depth of metal pool (D)
- \( > 90^\circ \)
- \( < 90^\circ \)
Demonstration Weld to Show Flux Pool

Height of Flux Pool - Controls Amperage
Plate Setup to Weld

- Square Preparation
- Remove Mill Scale From Fusion Zone
- Sump at Bottom to Start Weld
- No Beveling or Turning of Plate
- Cast Weld Vertically in One Pass

Starting Sump
Final Preparation

- Electrode Guide
- Spacers to Center Guide Tube
- Flux Feed
- Cooling Shoe
Consumable Guide and Spacers

Ceramic Spacers to Center Guide
Plate Ready to Weld

• Water Cooled Copper Shoes to Contain Molten Weld Metal
  • Water Temperature and Flow Controlled to Produce Desired Cooling Rate

• Automatic Process
  • Computer Controlled Wire Feed
  • Computer Controlled Flux Addition
The Weld in Progress

Cooling Shoe
Cool Enough
to Touch

Height of Weld
End of Weld

- Guide Consumed
- Note Molten Metal in Run Off Pad
Completed Weld

Welding Time
Approximately-10 to 20% of multiple pass weld
Minutes versus Hours
Efficient Flange Sizing

• Change Flange Width at Field Splice to Allow Welds to Be Slabbed
• Align Flange Thicknesses Transitions to Allow Slabbing
• Minimize the Number of Plate Thicknesses (plates come in 12 foot width and 80 foot lengths)
• Design it Like You are Going to Build it.
The Costly Method of Changing Flange Size by Changing Width

Weld and grind 8 splices

Weld
A Better Way- Change Flange Thickness

Bevel (4) and taper (2) plate edges

CHANGE THICKNESS
• Flange Sizing - change thickness

Weld and grind 2 splices
• **Flange Sizing** - change thickness

Burn 4 flanges from 1 assembly

<table>
<thead>
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<th>Burn</th>
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</tbody>
</table>
• Flange Sizing - change thickness

4 flanges from 1 assembly
Good Practice

• Flange Sizing
  – Width transitions increase labor for flange assemblies up to 35%
  – If you must change flange width, do so at bolted field splice (do not clip corners of top flanges)
  – Allow fabricators to eliminate splices within a shipping piece by carrying thicker material through to next designed splice location
Plate Girder Flange Sizing

– Shop butt splices within a shipping piece – when to change area?
  • No more than 2 shop splices
  • Minimum change; 1/8” (to 2 ½” thick), 1/4”
  • Maximum change; thinner piece at least 1/2 of thicker…

• **ONLY** when material cost saved > labor cost spent
CNC Cutting and Drilling Equipment

Equipment:
16.75 ft. x 165 ft. bed

2-48 HP Drill Heads
12 tool Changer station

Plasma Automated Contour Bevel Cutting System

6-Oxy-Fuel Torch Stations

Flanges Stripped From Wider Plate
How to Prevent Slabbing of the Flanges
Bottom Flanges at Pier

Girder 1

2.5 inch Plate

Girder 2

3 inch Plate

Girder 3

3 inch Plate

Girder 4

3 and 3.5 inch Plate

As Designed-All Equal Width
Flanges Equal
Thickness Depicted

Preferred Design- Vary Flange Width on Girders
Flange Width Depicted
(All Flanges Same Thickness and Length)
Attaching the Web to the Flanges

• Plate Girders
• Box Girders
Assemble the Plates to Form Girder
Camber Cut Into Web

1. Flanges
   Squeezed to Fit Cambered Web
2. Tack Welds
   Used as Temporary Connection Between The Web and Flange
SAW Welding the Flanges to the Web
Tack Welds Consumed by SAW Weld

Weld Both Sides at Once

Welding Head and Preheat Torches
New Method of Assembly

• No Tack Welds
• Automated Welding Speed
• Preheat Built Into Fixture
• Welded T Assembly Flipped and Other Flange Welded
Clamping Force Applied by Roller at Top of Web
Web Centered on Flange Using Runoff Tab
Girder Fed Into Welding Head by Rollers
Frames to Steady Welded Section and Flip T Section
Stiffener Fit
Stiffener Dart Welding SAW
Both Sides Welded at the Same Time
Tub (Box) Girders Hand Assembled

- Flanges and Connection Plates Welded to Web
- Cross Frames Used to Control Box Geometry
Residual Stress Due to Welding

Thermal expansion due to heat input from welding

Shrinkage of beads due to cooling and solidification

Tensile residual stress in the vicinity of weld
Residual Flange Stresses in Welded Shape

Residual Stress From Web to Flange Weld

Residual Stress From Flame Cut Edge
Weld Inspection

• Fillet Welds
  – Visual
  – Magnetic Particle

• Butt Welds
  – Ultrasonic
  – Radiography
Visual Inspection
Magnetic Particle

- Inspection of Web to Flange Fillet Welds and Other Fillet Welds
- Surface or Near Surface Inspections
Magnetic Particle (MT)

Fish & Associates
Magnetic Particle (MT)

Magnetic Flux Leakage around suitably oriented flaws attract Magnetic Particles
Magnetic Particle (MT)

Hydrogen Cracking on Lateral Connection Plate Weld

Fish & Associates
Magnetic Particle (MT)

Crack from Internal Weld Flaw

Fish & Associates
Radiography

- Gamma Ray (Nuclear) Source or X-Ray Source
- Internal Defects
- Very Good for Volumetric Defects
  - Slag
  - Porosity
- Provides a Visual Permanent Record on Film or Digital Record
Radiography

Gamma Ray Source

One Shot at a Time-about 2 feet/per shot

Measures Density Along Ray Path

Film Holder
Radiation Hazard

Weld

Inspect at Night
Or Move Plate
Out of Shop
Radiography (RT)

- Source of radiation
- Material is thinner
- Object
- Hole
- Film
- Darkened area (when processed)

Fish & Associates
Approximate Thickness Limitations

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Thickness, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iridium-192</td>
<td>0.5-2.5</td>
</tr>
<tr>
<td>Cesium-137</td>
<td>0.5-3.5</td>
</tr>
<tr>
<td>Cobalt-60</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>
Ultrasonic Inspection

• Similar to Radar and Sonar
• Interrogate Weld Using High Frequency Waves (2-5 MHz)
• Sound Reflected Back to Transducer by Metal Air Interface (Defect)
• Portable and No Radiation Hazard
Conventional Ultrasonic Testing
Ultrasonic Inspection
Angle Beam Testing of Weld

Amplitude of Reflected Sound Indication of Reflector Size

Sound Path

Sound Path
A New Technology
Phased Array Ultrasonic Inspection

Transmission delay laws

Time delay

Linear array probe

Constant-phase front

Focal point

ANGLE START
36.0 deg

ANGLE STOP
74.0 deg

ANGLE STEP
0.5 deg

CALC

ELECTRNIC VOLUME APERTURE CLOCK SYNCH
Transducer Contain Multiple Elements
Typical Scan

1st Index point

Specimen thickness: 3.3 inches

Skew angle from Weld C_L : 90°

- 3.1 inches

Weld width : 1 inch

2nd Index point

Specimen thickness: 3.3 inches

Skew angle from Weld C_L : 90°

- 6.4 inches

Weld width : 1 inch
UT Vs RADIOGRAPHY: SPECIMEN TP3 (TOP VIEW)

Weld Cl (Weld width: 1 inch)

Skew angle from weld Cl : 90°

Skew angle from weld Cl : 270°

- : PHASED ARRAY ULTRASONICS MEASUREMENTS AT TFHRC
- : SINGLE ELEMENT ULTRASONIC TESTING IN ACCORDANCE TO AWS D1.5 AT TFHRC
- : SINGLE ELEMENT ULTRASONIC TESTING IN ACCORDANCE TO AWS D1.5 BY FABRICATOR
Scanning Weld

Position Along Weld and Returned Signal RecordedDigitally
PAUT

• Digital Record of Inspection—not just an OK
• Less Operator Dependent but Requires Experienced User to Set Up Equipment
• Faster Than Conventional UT
• No Radiation Hazard
• Recognized in AWS D1.5
In Process Inspection
Heat Curved to Match Road Geometry
Girder Lay Down to Fit Field Splices
Flange Splice
Splice Plate Used as Template
Web Splice
Match Drill Flanges and Webs Using Splice Plate for Template

1. Fabricate Splice Plates
2. Lay Down Girders
3. Clamp Plates to Girders
4. Match Drill
New Methods (Virtual Assembly)
Eliminate Manual Drilling and Shop Assembly

Operations:

1. Cut and Drill Plates on Cutting Table
2. Assemble Girder-Weld Web to Flanges
3. Measure Girders to Determine Exact Hole Locations and Girder Geometry
4. Input Girder Geometry Into Computer
5. Assemble on Girders Virtually in Computer
6. Output Required Splice Plate Geometry to CNC Equipment
First Implementation

• Implemented in Virginia Sponsored Pooled Fund Study
  – Principal Investigator- Paul Fuchs (Fuchs Consulting, Inc.)
  – Tennessee DOT Bridge
  – Girder Fabrication by Hirschfeld Industries
Tennessee DOT Bridge Job

830 ft
Virtual Assembly Software
Welding of Girder With Splice Holes
Predrilled Girders Trimmed and Adjusted for Correct Length and Camber
Hole Location Measurement Using Laser
The Target-SMR
Spherically Mounted Retroreflector
Scan Ends of Girders in Lay Down
Development of Splice Plate Geometry
Splice Plate Detailed in Autocad
Check of Splice Plate Fitup
Flange Splice Fit
It Fits!
State of the Art

• Short Term:
  – Lay down two girders to determine splice geometry
  – Verify splice plate geometry by laser measurement
  – Verify fit up of stack up of splice plates and fillers on computer

• Long Term:
  – Full Virtual Assembly- Elimination of Lay Down of 2 Girders
The Savings

• Reduced Material Handling-Drilling and Cutting in One Operation
• Speed- Hole Drilling About 10 times faster (3 seconds a hole)
• No Girder Lay Down Required (Girders can be fabricated in separate shops)
Girder Surface Prepared by Blasting Before Painting

Masked for Field Welded Connection of Cross Frame
Blasted Curved Girder
Painting
Often 3 Coats
Final Inspection

Final inspection is performed first by in-house QC department and lastly by the owner’s quality representative.
Over Road Shipping
Too Tall-Ship with Web Flat
Super Loads Require Escorts and Special Permits
Too Long and Too Tall-Railroad as Last Resort
Tappan Zee Girders Loaded On Barge For Shipment From North Carolina to Hudson River Assembly Site
Optimal Fabrication Capacities

Transportation Limits

Standard

Up to 120” Girders depths with parallel Flanges

Up to 144” Haunched Girders

Conditional

Up to 168” with State permission for Girder lay down during shipment
Shipping Permits

Annual Permit
12’ wide and 75’ long or less
Travel only allowed on Non Posted Roads and Bridges – Specified Routes if over 80 kip

Single trip Permit
15’ Wide, 14‘ Tall , Max. Length120’
Over 14‘ tall loads require 2 more days review time
Gross weight Limits
5 Axle 112,000 Lbs
6 Axle 120,000 Lbs
7 Axle 132,000 Lbs

Superload Permit
Over 120’ in length
10 day Minimum Review Time
Gross weight > 132 kip requires 3 additional days for Bridge review
Summary

• Welding and Weld Inspection
  – D1.5 Controls
  – PQR Demonstrate Ability of Fabricator to Make the Weld
  – WPS is the Procedure Based Upon the PQR
  – Thicker Higher Strength Plates Require Higher Preheats and Greater Welding Skill
  – SAW is the Most Common Welding Process
  – NGESW Gaining Popularity

• Weld Inspection
  – RT is Slow and Dangerous, Film Record
  – UT Portable and Fast, no Record
  – PAUT Ease of UT with Digital Record
Summary

• Residual Stresses are Unavoidable and Not Calculated
• Virtual Assembly Field Spices on the Computer
  – Proven Technology Used in Other Industries
  – Provides a Digital Record of Fitup
• Design it Like You are Going to Build It
  – Avoid Short Lengths of Unique Plates
  – Space Welded Splice to Allow Slabbing of Welds
  – Size Field Pieces to Shipping Lengths
  – Ask the Fabricator About Any Questions
Good Design of Simple Bridge
A New Day Another Bridge
Questions?