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
- $\dfrac{D}{t_w} \le 120 \qquad \dfrac{2D_c}{t_w} \le 137$
- Compression Flange
  - $\dfrac{1}{4} > \dfrac{b_f}{D} > \dfrac{1}{6}$
  - $\dfrac{b_f}{2t_f} \le 12$ and < 9.2 for 50 ksi

$D = 8 \text{ ft} \qquad \dfrac{S}{D} \le 25$

$t_w = {}^7\!/_8 \; in. \qquad \dfrac{D}{t_w} = 110 \le 120$

$b_f = 24 \text{ in.} \qquad \dfrac{b_f}{D} \le 0.25$

$t_f = 1.375 \text{ in.} \qquad \dfrac{b_f}{2t_f} = 8.7$

Cross Sectional Limits

AASHTO LRFD Specifications

6.10.2.2—Flange Proportions

Compression and tension flanges shall be proportioned such that:

$$\frac{b_f}{2t_f} \leq 12.0, \qquad (6.10.2.2\text{-}1)$$

Too slender, 9.2 for Grade 50

$$b_f \geq D/6, \qquad (6.10.2.2\text{-}2)$$

Too slender, D/4 better choice

$$t_f \geq 1.1t_w, \qquad (6.10.2.2\text{-}3)$$

Should be 1.5 to 2 x web thickness

and:

$$0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 10 \qquad (6.10.2.2\text{-}4)$$

Important limit, eliminates "T" like sections

3/8 in. Top Flange-1/2 in. Web

$$\frac{b_f}{2t_f} = \frac{16\text{ in.}}{2\times {}^{3}\!/_{8}\text{ in.}} = 21.3 > 12.0 \;\Rightarrow\; \text{NO GOOD}$$

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

Raw Material

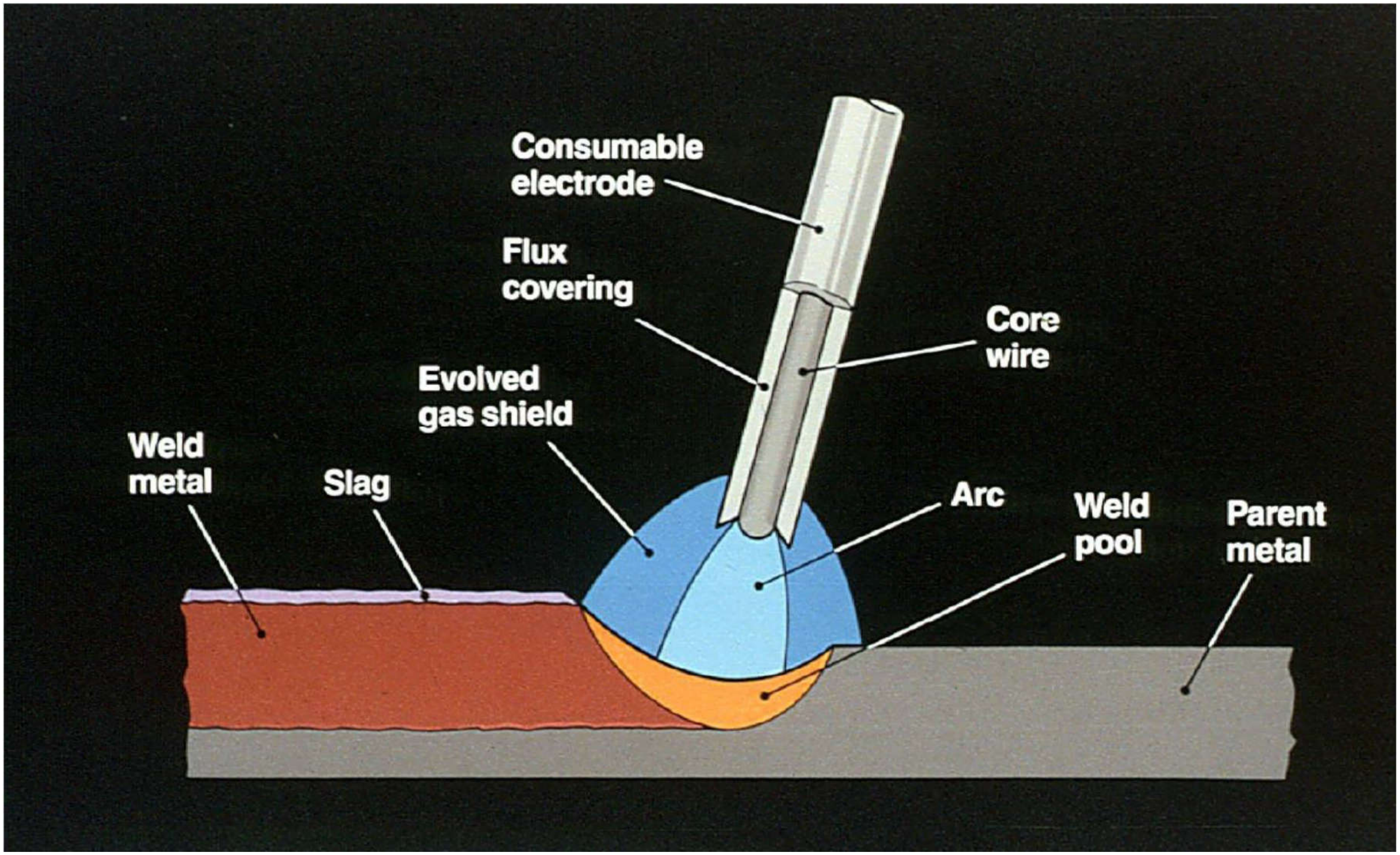
First Steps

- 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

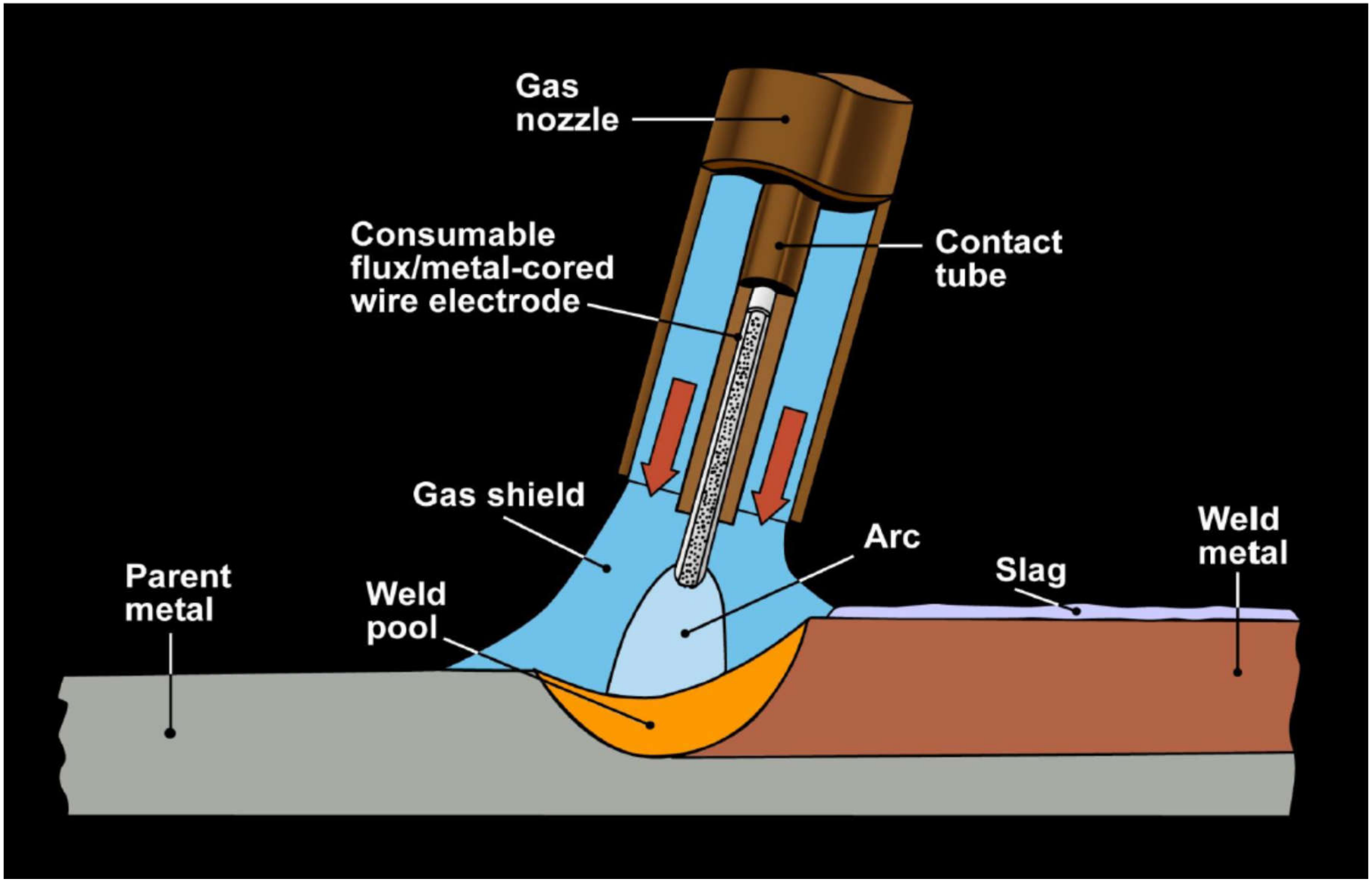
Welding

- 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

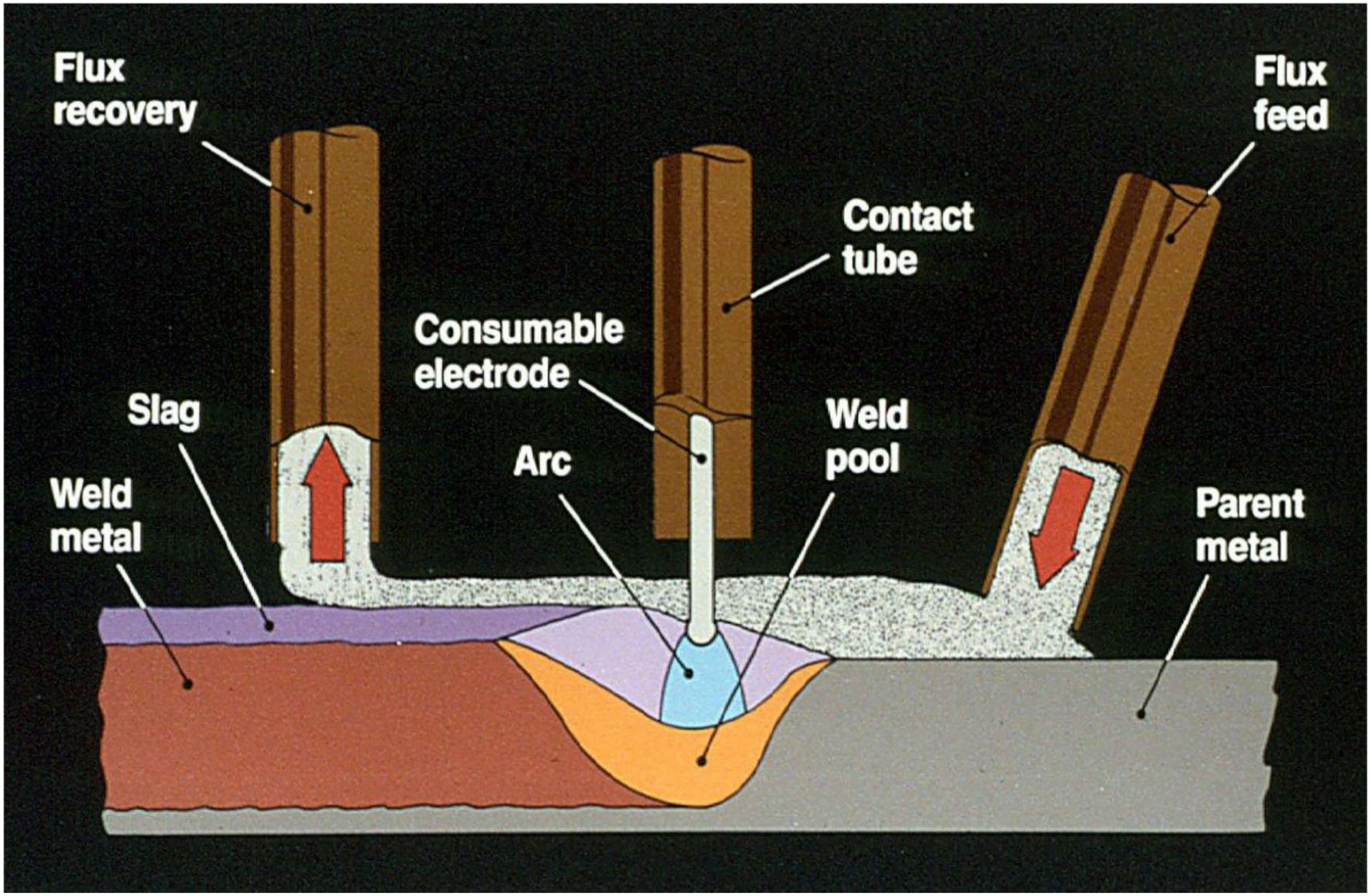
SMAW (Shielded Metal Arc Welding) Stick Welding



FCAW (Flux Cored Arc Welding)

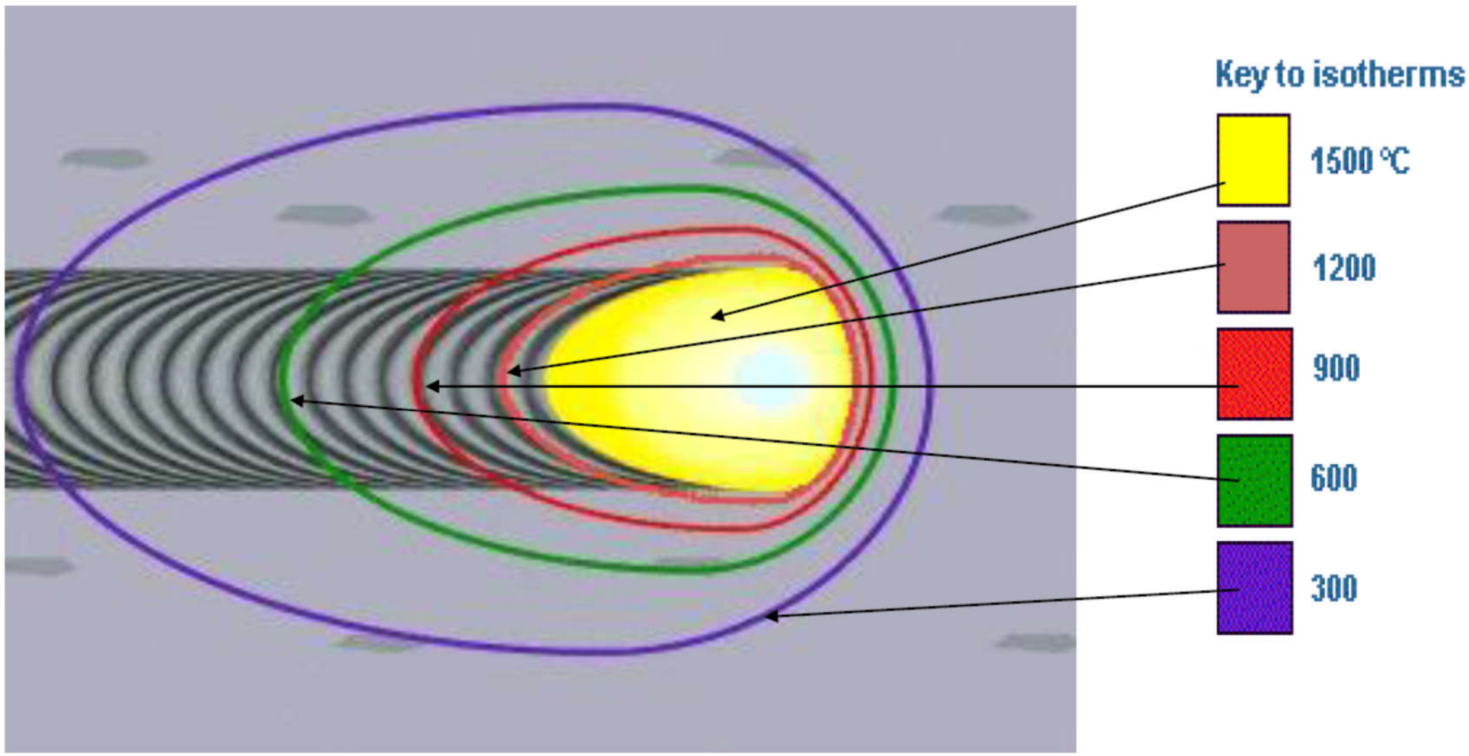


SAW (Submerged Arc Welding)



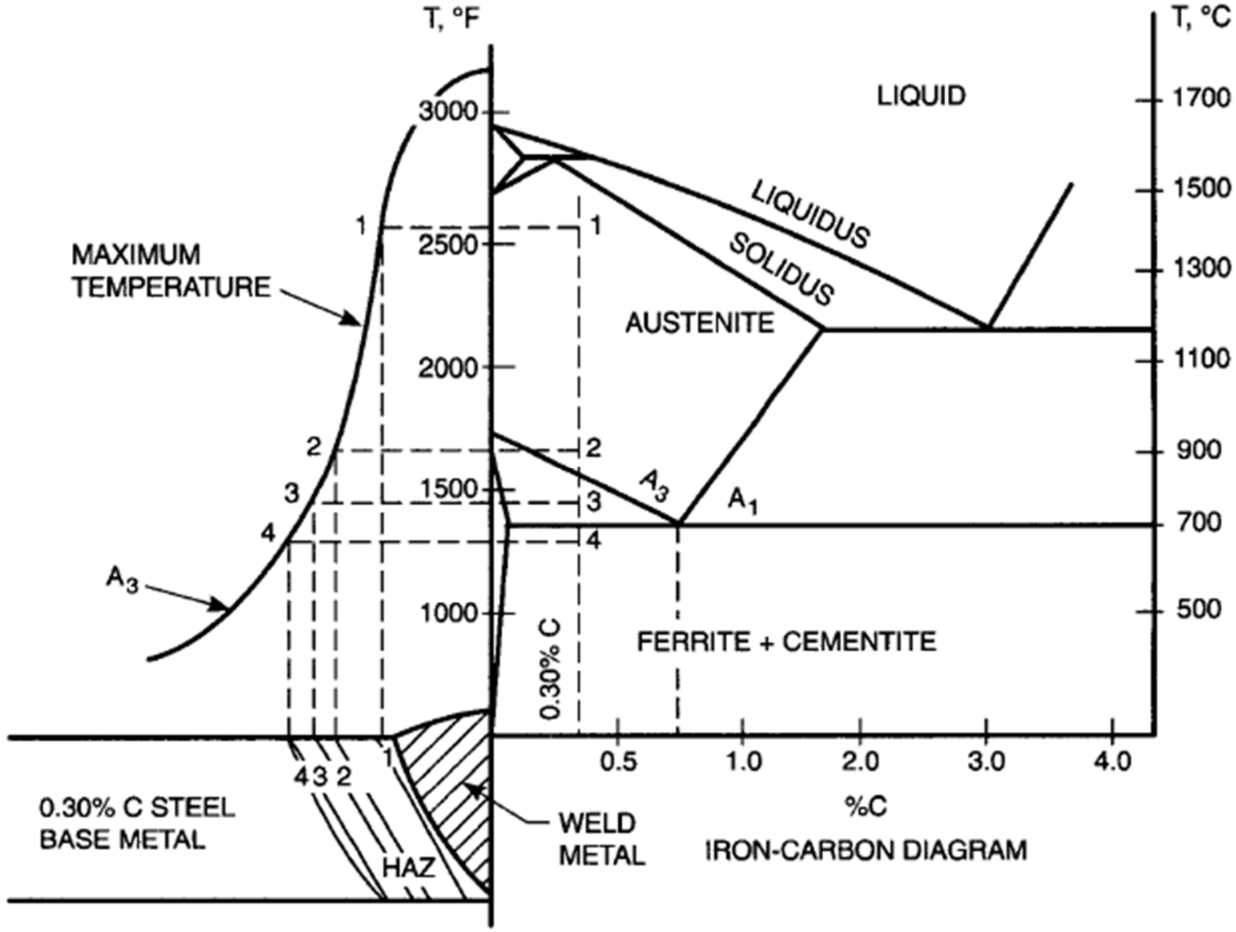
Cooling Weld by Conduction of Heat Into Plate

Thicker Plates Provide Larger Heat Sink Resulting in More Rapid Cooling



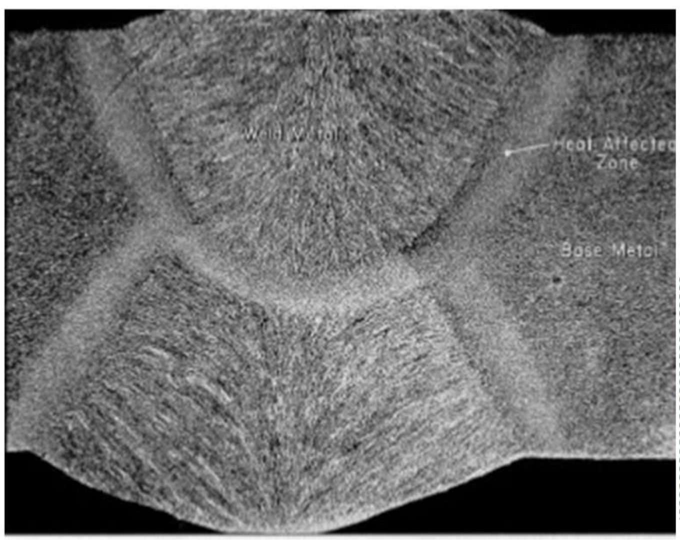
Weld and weld pool temperatures

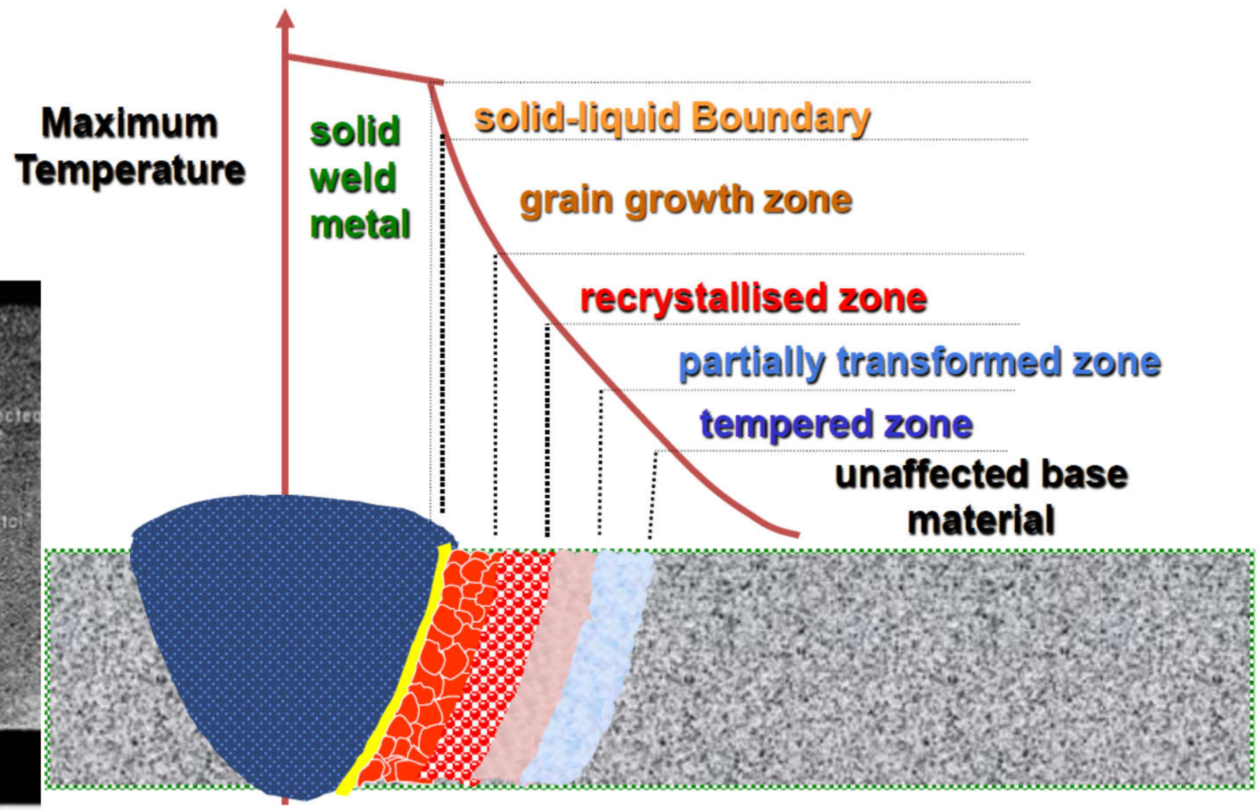
What Happens to Base Metal During Welding



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

Steel	To ¾ in. Incl.	¾ to 1- ½ in. Incl.	1- ½ to 2- ½ in. Incl.	Over 2- ½ in.
A709 Grade 36,50,50S,50W & HPS 50W	$\geq$50 ^{o}F	$\geq$70 ^{o}F	$\geq$150 ^{o}F	$\geq$225 ^{o}F
A709 Grade HPS 70W	50 to 450 ^{o}F	125 to 450 ^{o}F	175 to 450 ^{o}F	225 to 450 ^{o}F
A709 Grade HPS 100W	50 to 400 ^{o}F	125 to 400 ^{o}F	175 to 450 ^{o}F	225 to 450 ^{o}F

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

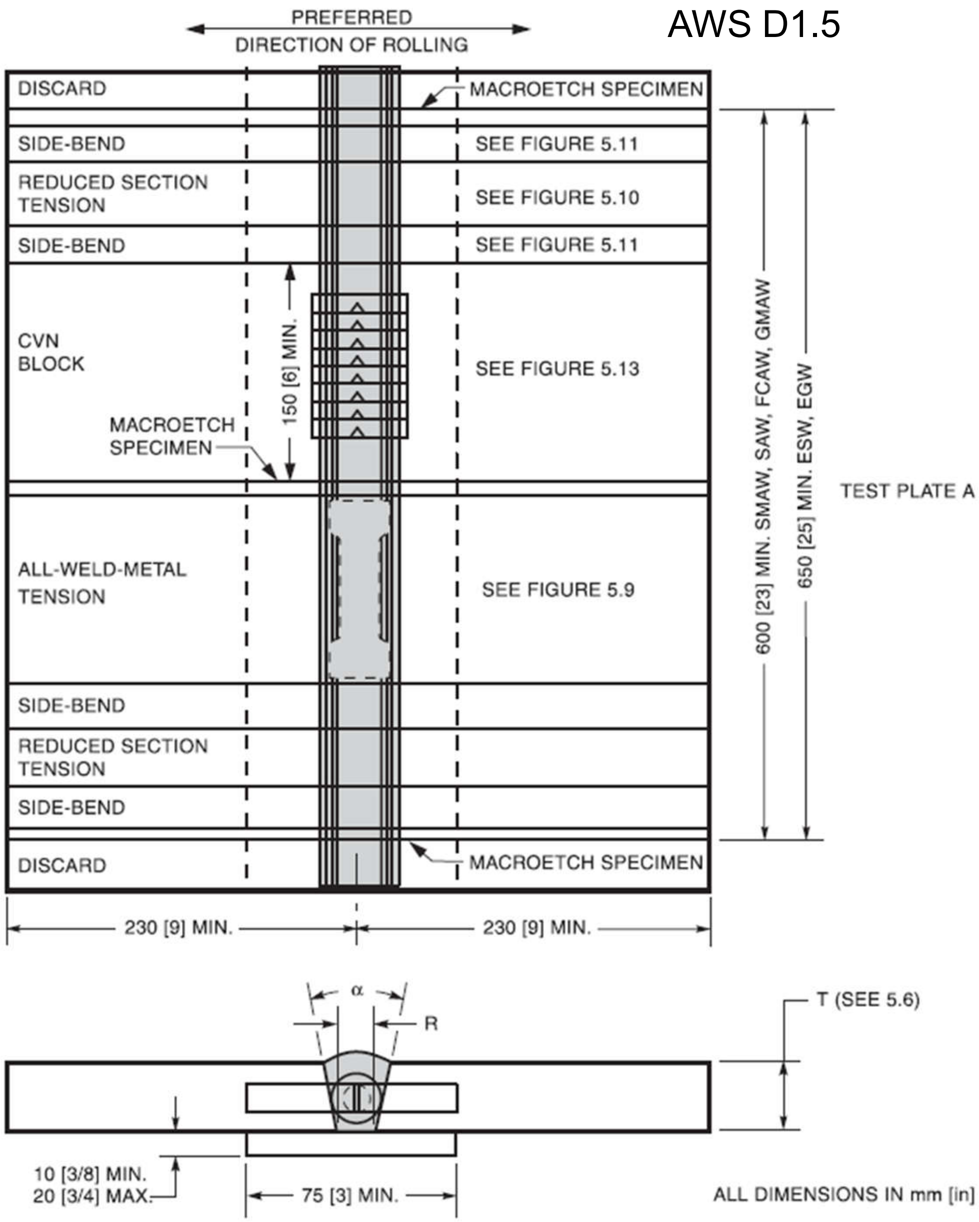
Heat Input

- Basis of Qualification Tests Limits
- $Heat\ Input\ \left(\frac{kJ}{in}\right) = \frac{Amperage\ x\ Voltage\ x\ 0.06}{Travel\ Speed\ (in.\ per\ minute)}$
- 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

AWS D1.5



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.

$\alpha = 20^{o}$

R= 5/8 in.

Test Requirements

Base Metal	Minimum Yield Strength (ksi)	Minimum Tensile Strength (ksi)	Minimum Elongation	CVN Zone I and II (ft-lbs)	CVN Zone III (ft-lbs)	Fracture Critical
Grade 36	45	60	22	20 @ 0°F	20 @ -20°F	25 @ -20°F
Grade 50, 50S	50	65	22	20 @ 0°F	20 @ -20°F	25 @ -20°F
Grade 50W Grade HPS 50W	50	70	22	20 @ 0°F	20 @ -20°F	25 @ -20°F
Grade HPS 70W	70	90	17	25 @ -10°F	25 @ -20°F	30 @ -20°F
Grade HPS 100W >2.5 in.	90	100	16	20 @ -40°F	Engr. Approval	35 @ -30°F
Grade HPS 100W ≤2.5 in.	100	110	20	20 @-40°F	Engr. Approval	35 @ -30°F

Welding of Components

- Butt Welding of Flanges
  - SAW
  - NGESW
  - Nesting of Girder Flanges
- Welding Web to Flange
  - Plate Girders
  - Box/Tub Girders

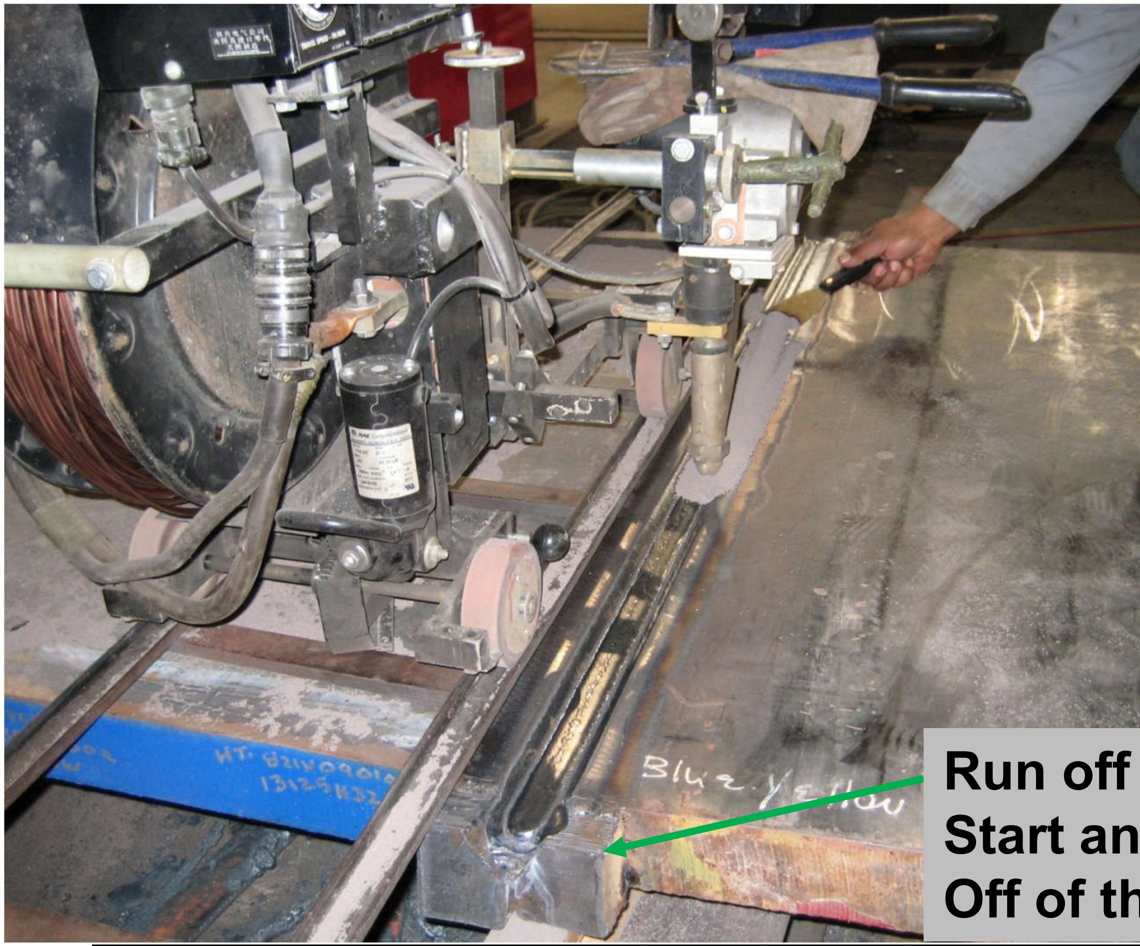
SAW Weld Preparation Required to Get Access to Bottom of Weld

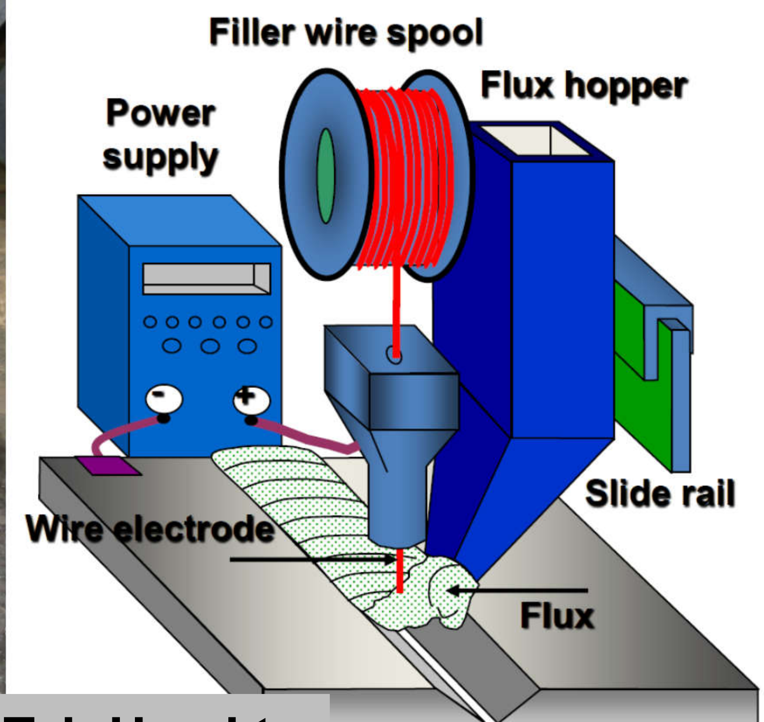
Prepared Plates Tacked Together Ready to Weld

Flange Thickness Transition

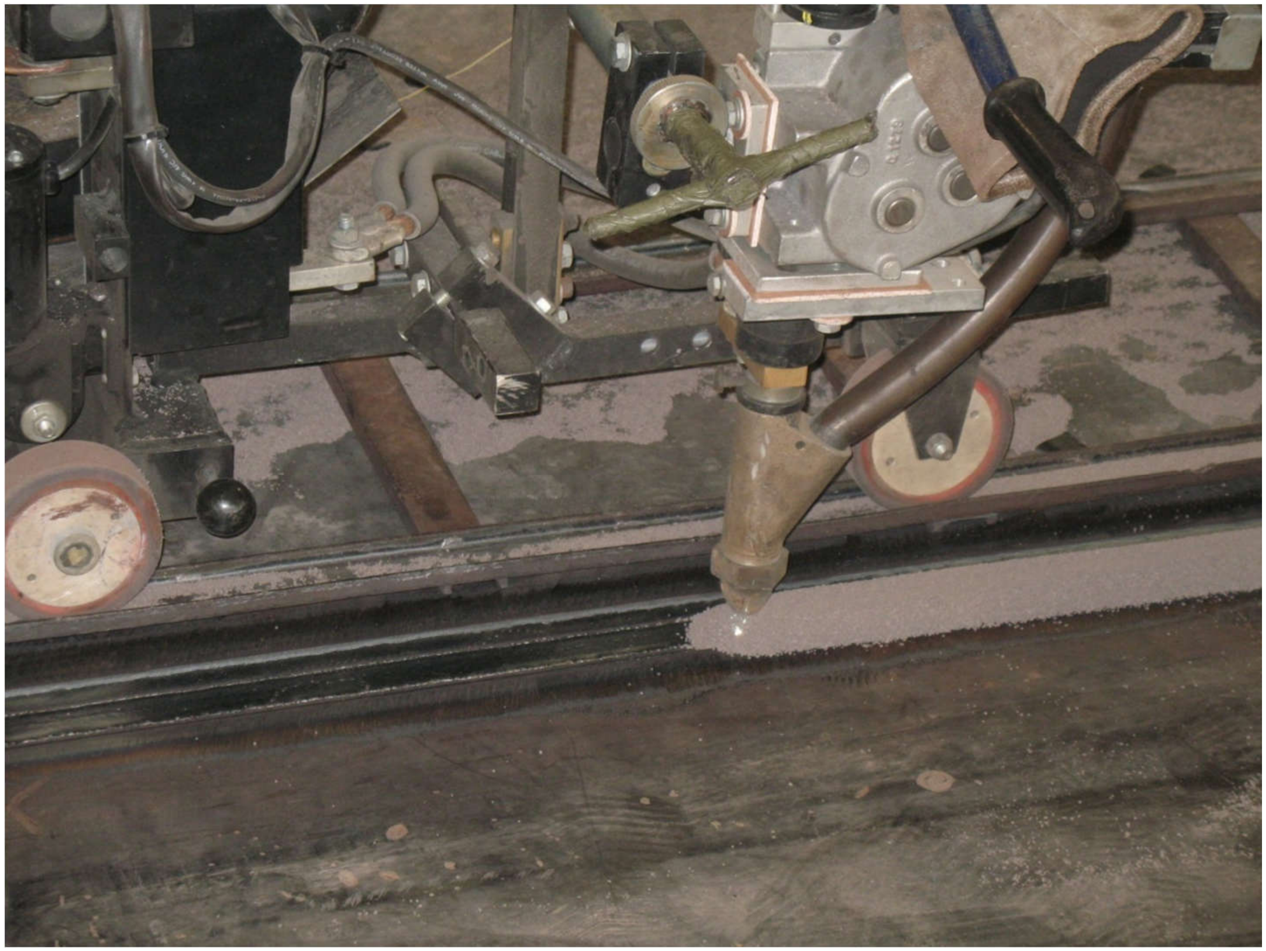
Note Weld in Thinner Plate at the End of The Transition

Submerged Arc Welding-SAW



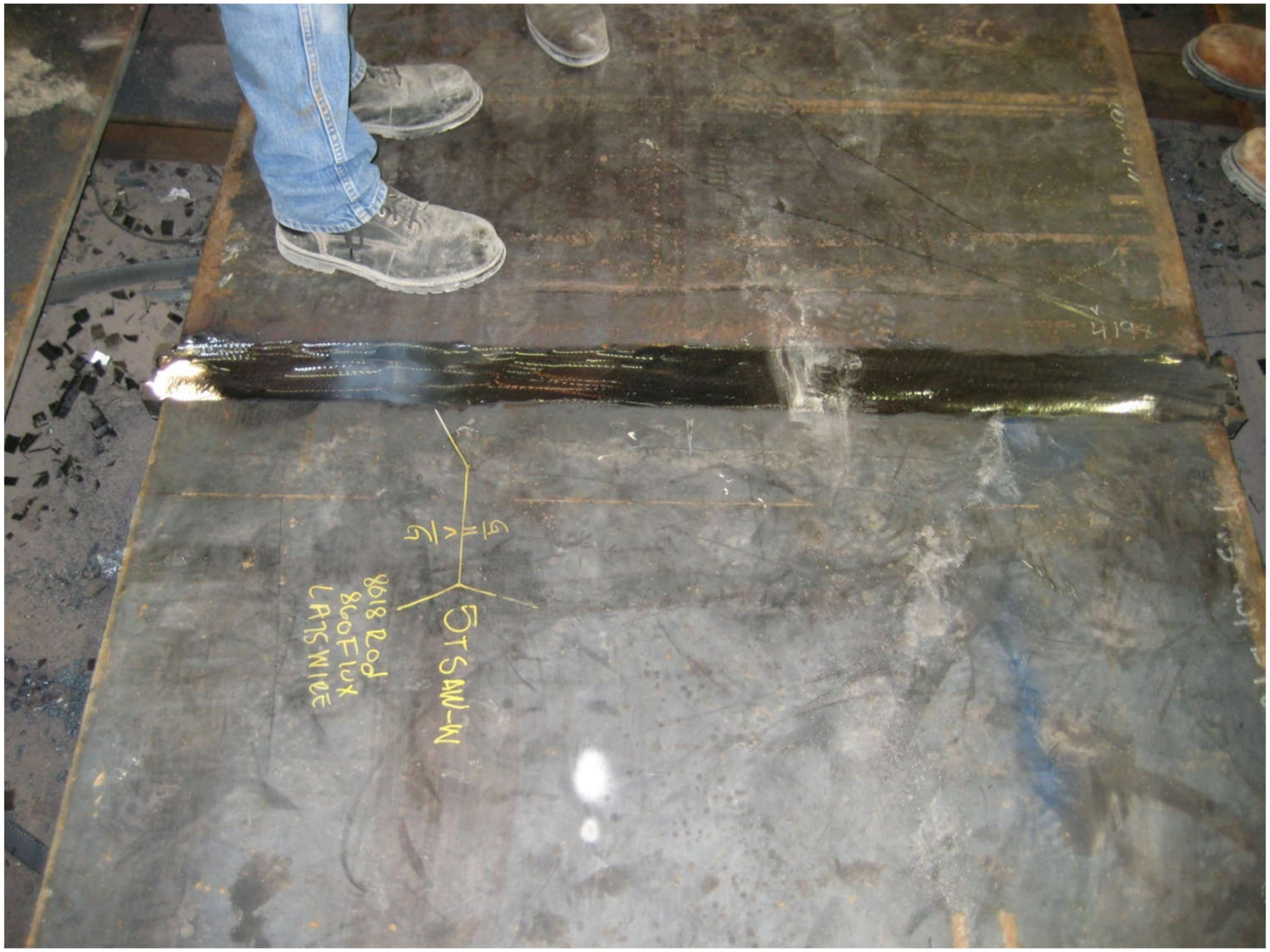


Close Up of Arc Submerged in the Flux
Multiple Pass Welds
Number of Passes Dependent Upon Plate Thickness



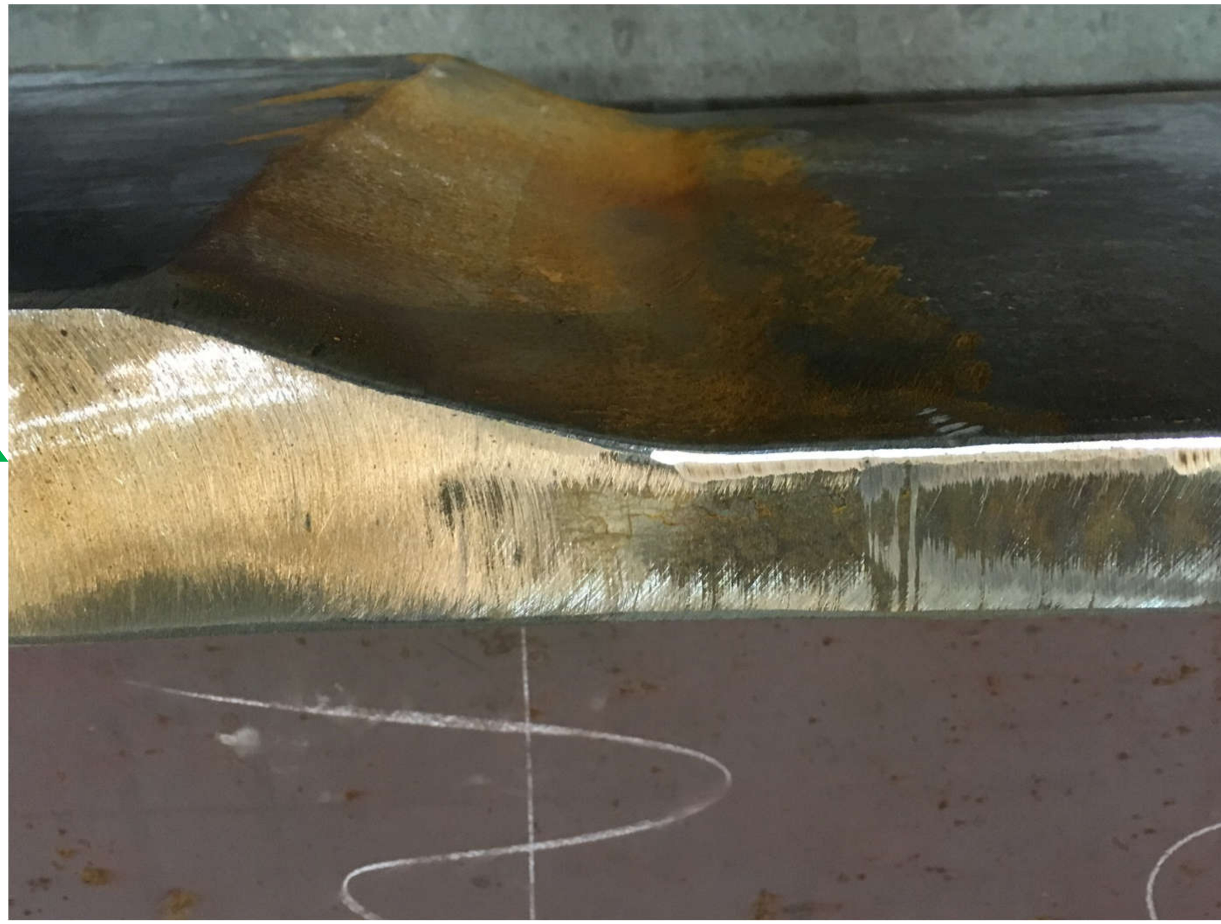
Back Gouge Weld Root and Clean By Grinding Weld Back Side

Finished Weld Ground Flush and Ready for Inspection by Radiography or Ultrasonics



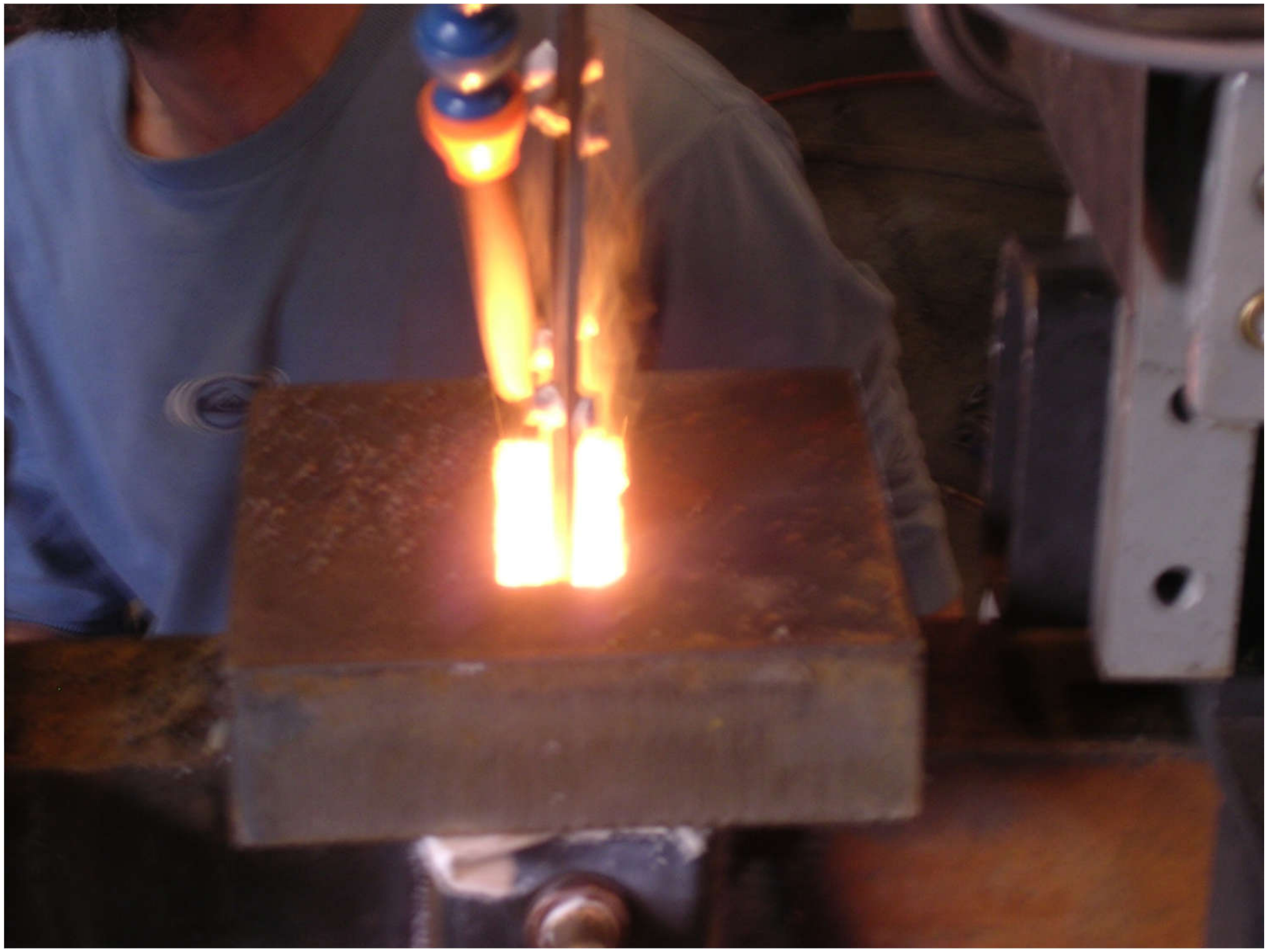
Finished Flange Thickness Transition Butt Weld All Surfaces Ground Smooth

Thicker Flange



Thinner Flange

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)

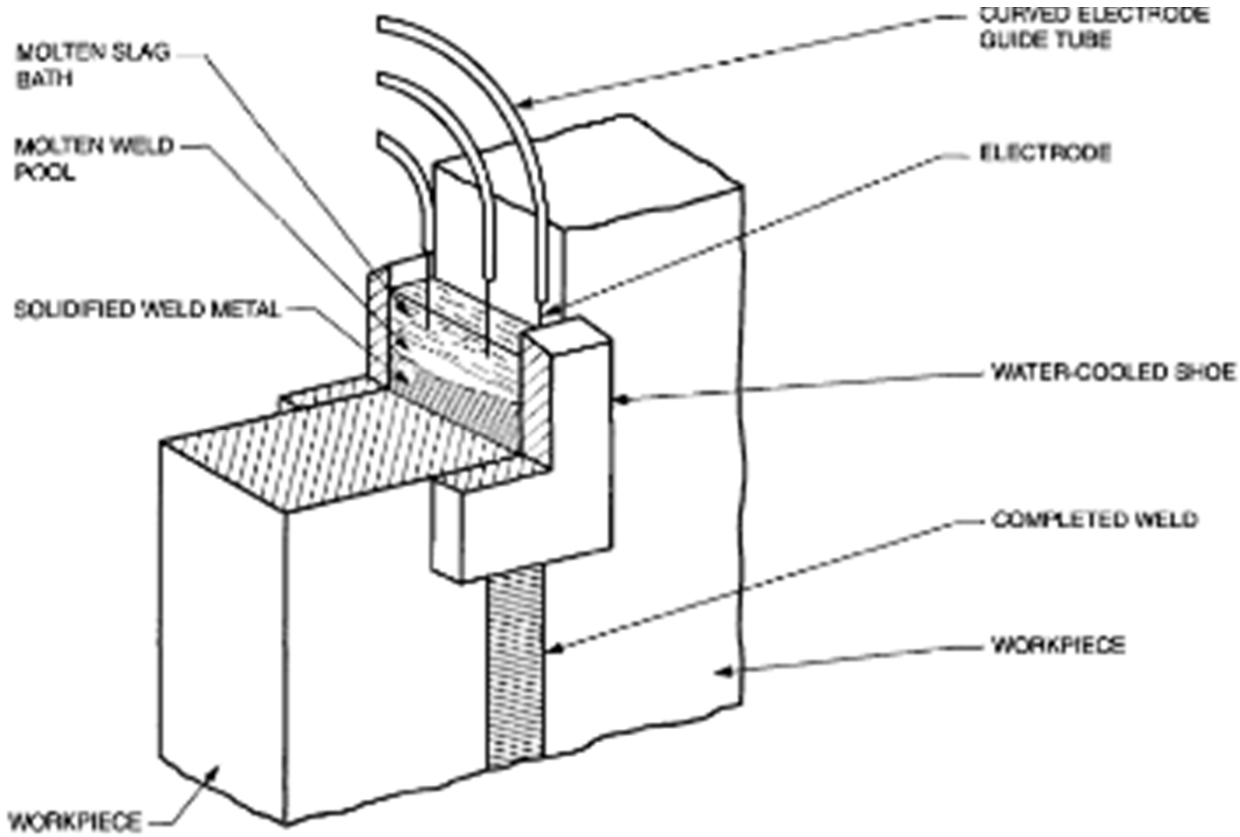
Advantages of NSW for Flange Welds

- 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

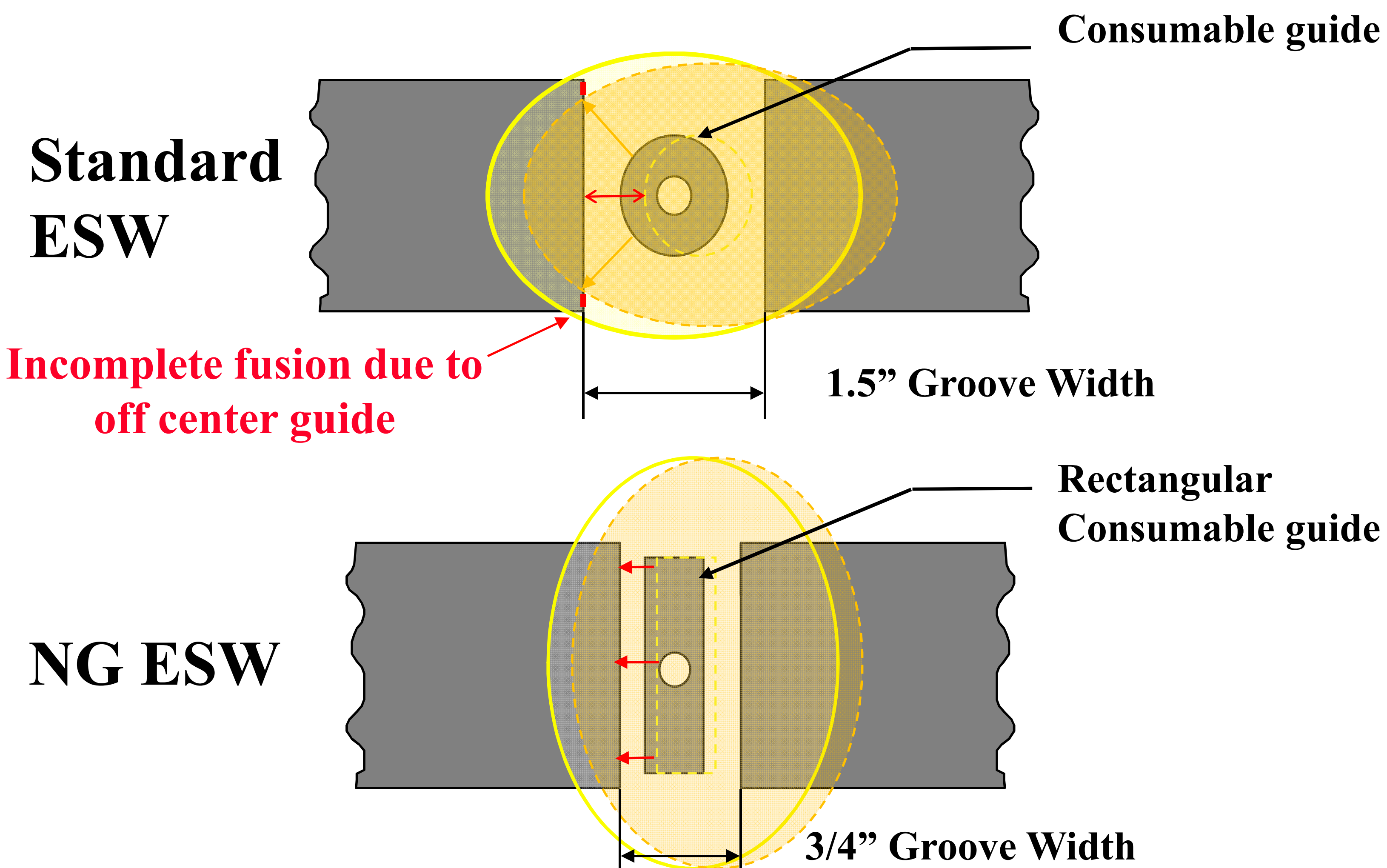
Characteristics

- 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

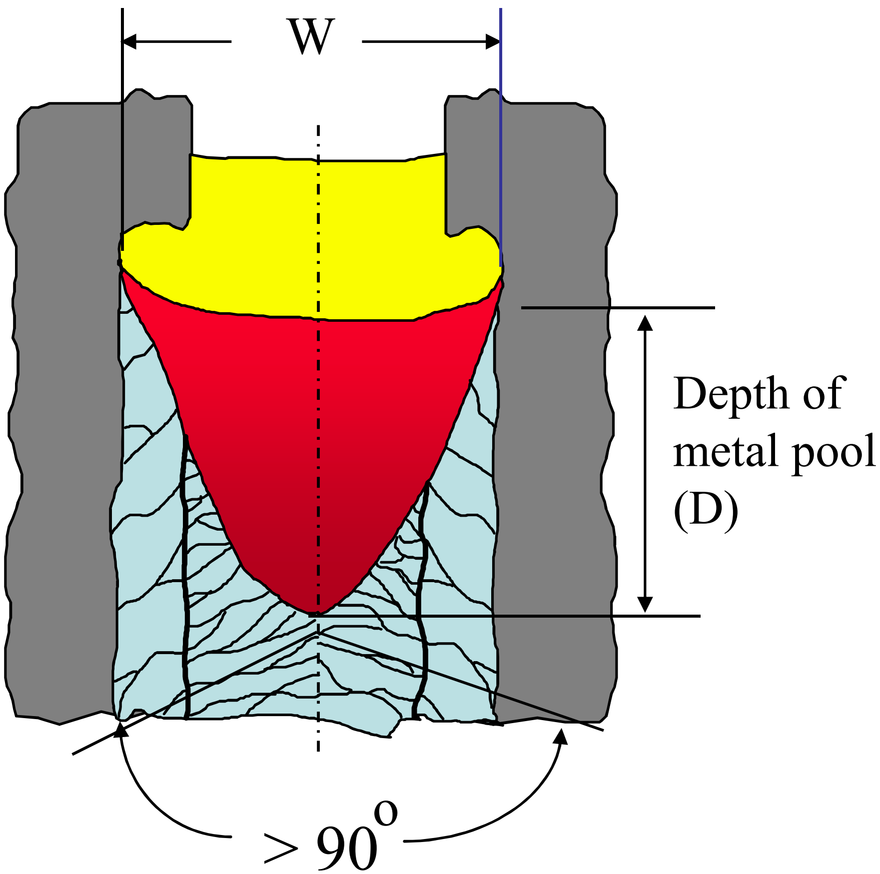


Enhanced Weld Pool Geometry

Standard ESW

f = W/D < 1

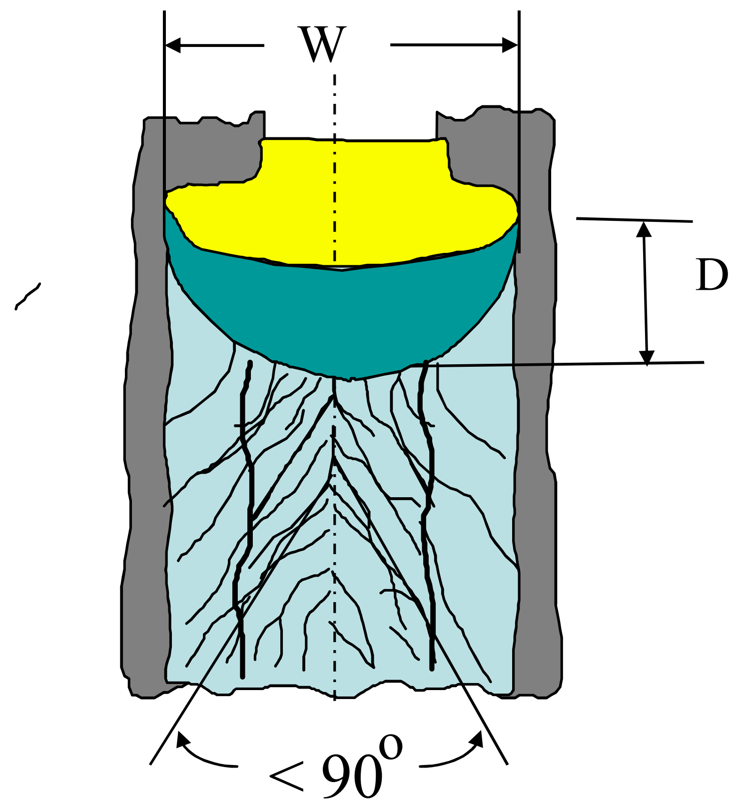
(low resistance to cracking)



NG ESW

f = W/D > 3

(high resistance to cracking)



Demonstration Weld to Show Flux Pool

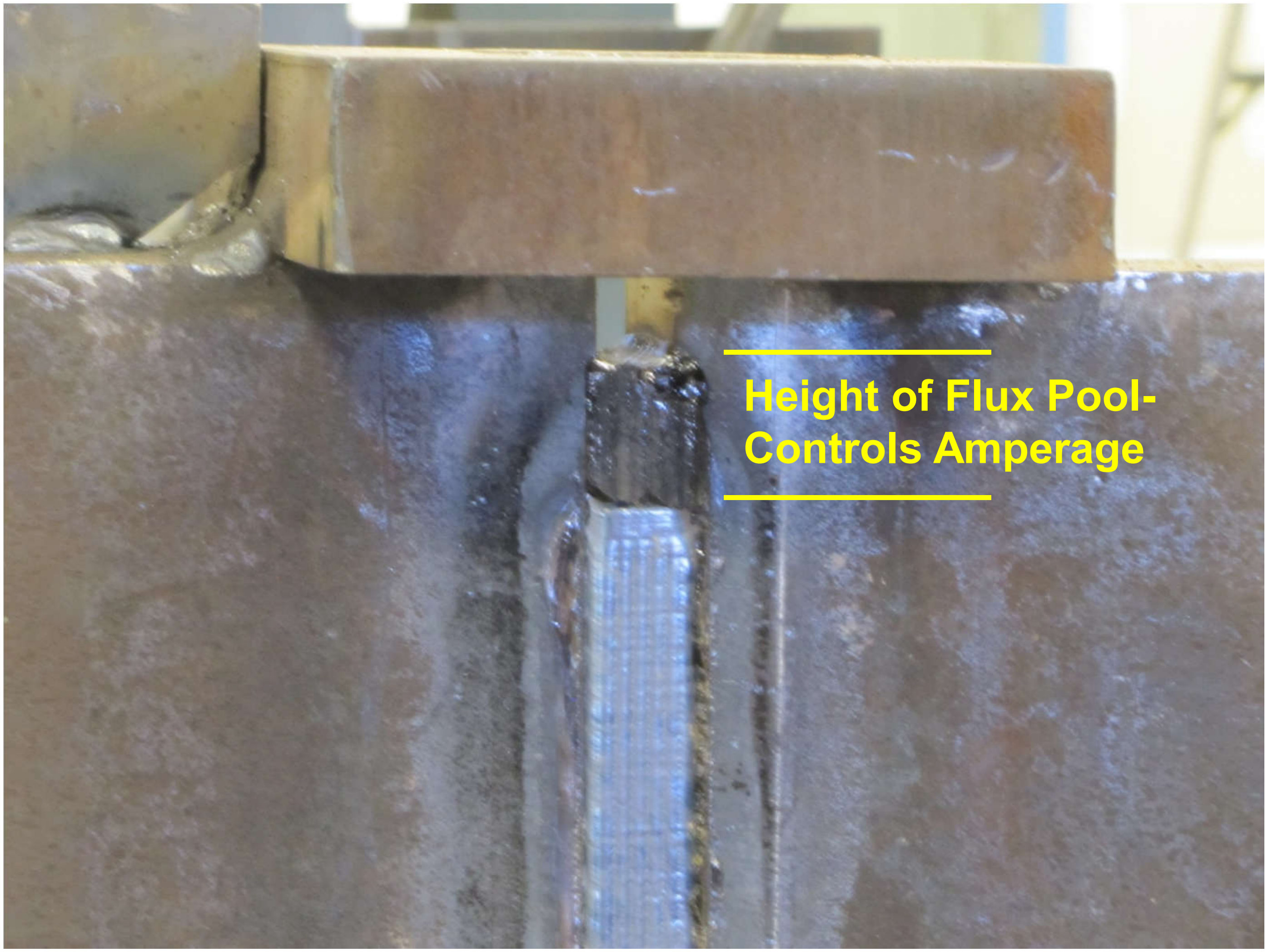
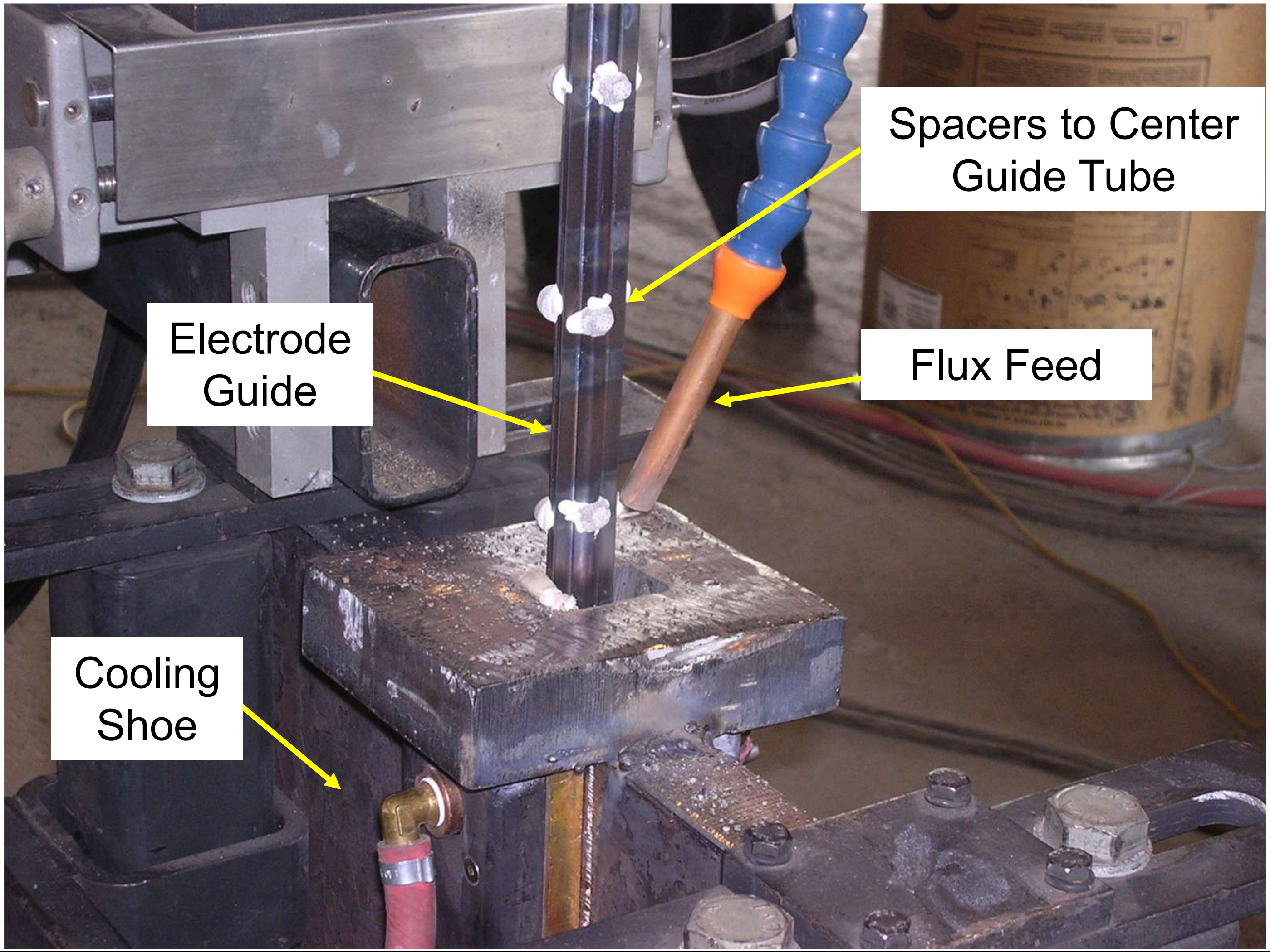


Plate Setup to Weld

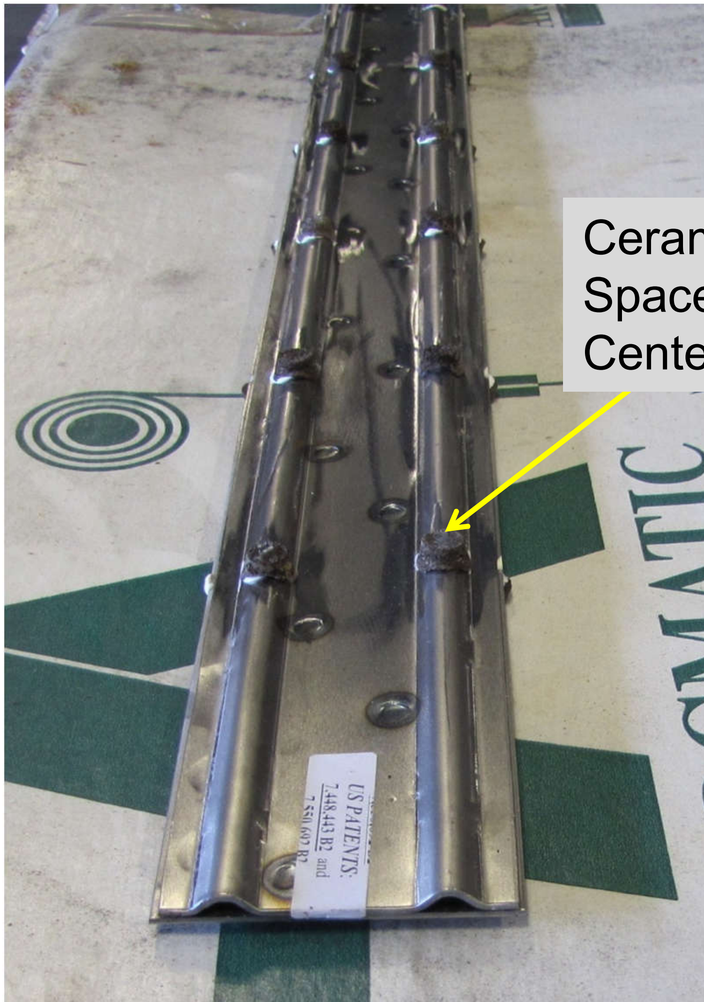
- Square Preparation
- Remove Mill Scale From Fusion Zone
- Sump at Bottom to Start Weld
- No Beveling or Turning of Plate
- Cast Weld Vertically in One Pass

Starting Sump

Final Preparation



Consumable Guide and Spacers



Ceramic Spacers to Center Guide

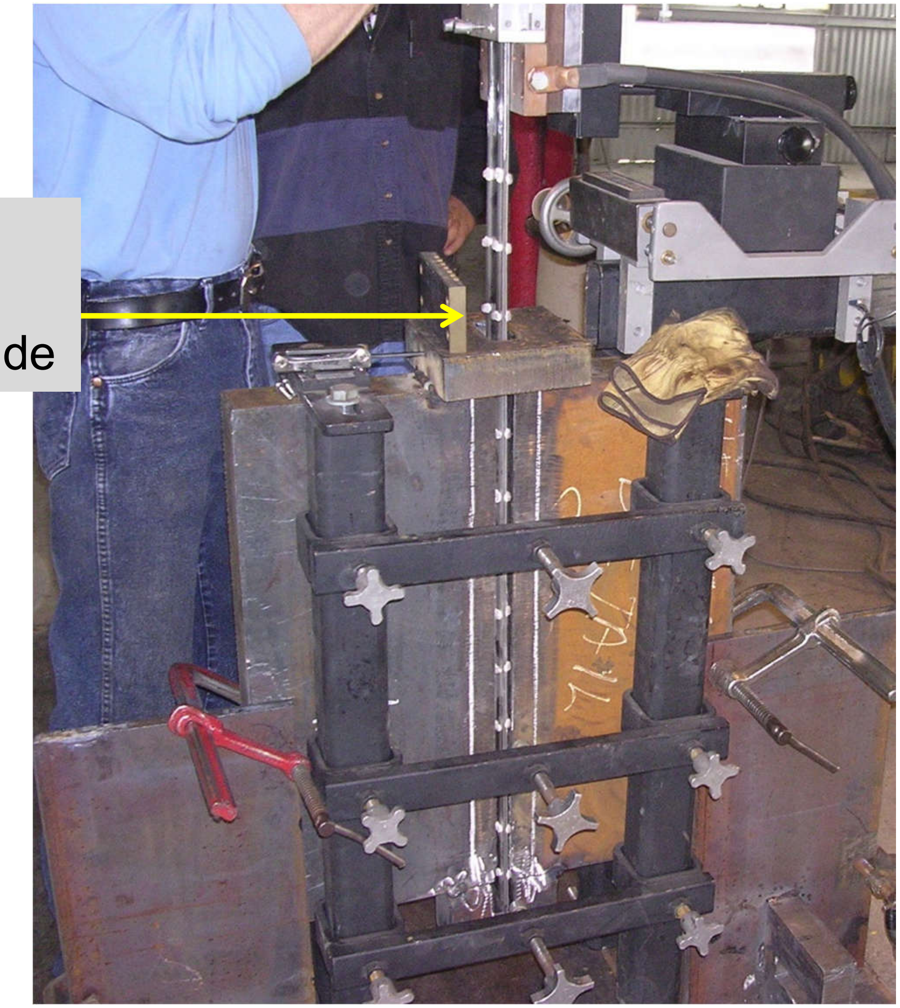
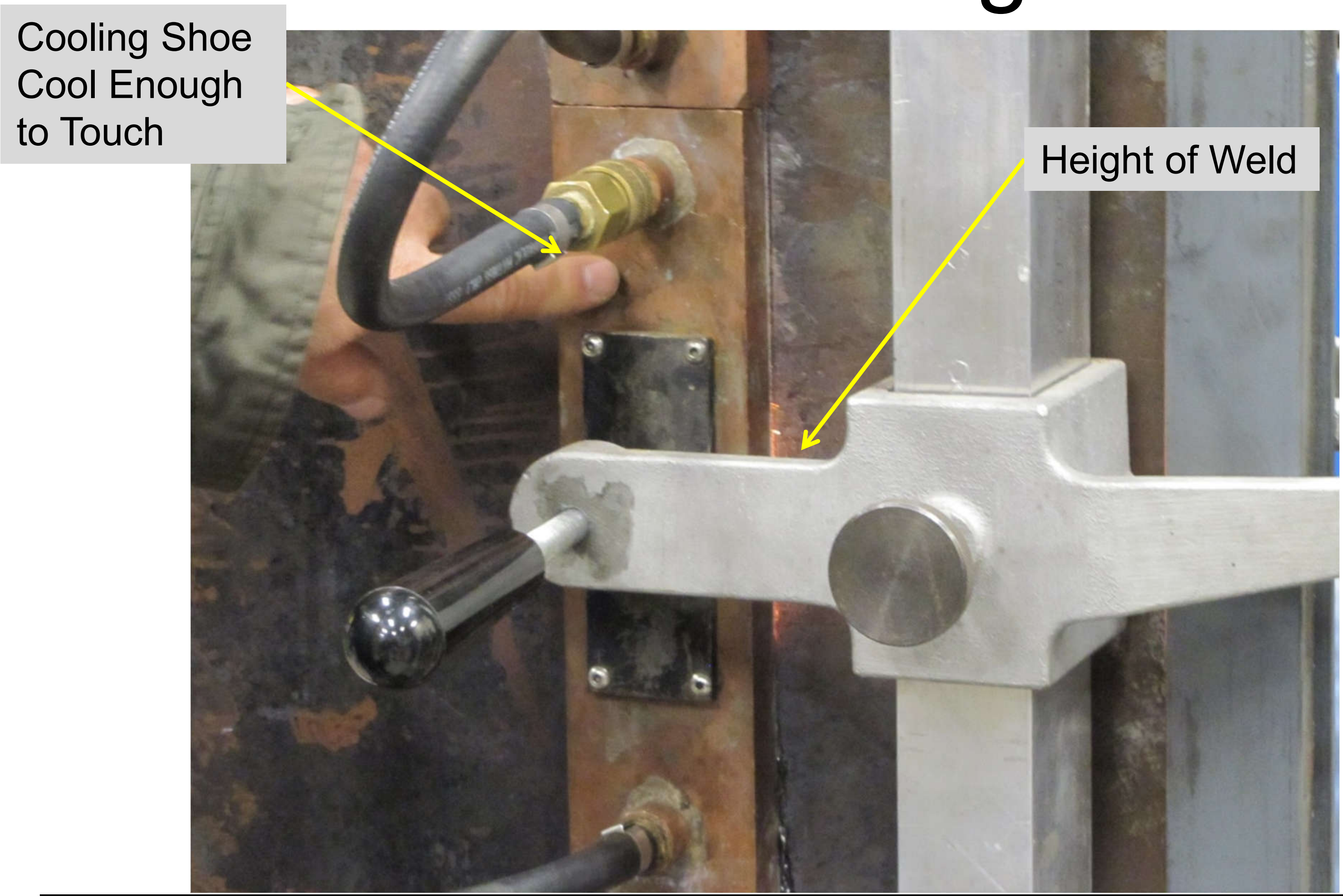


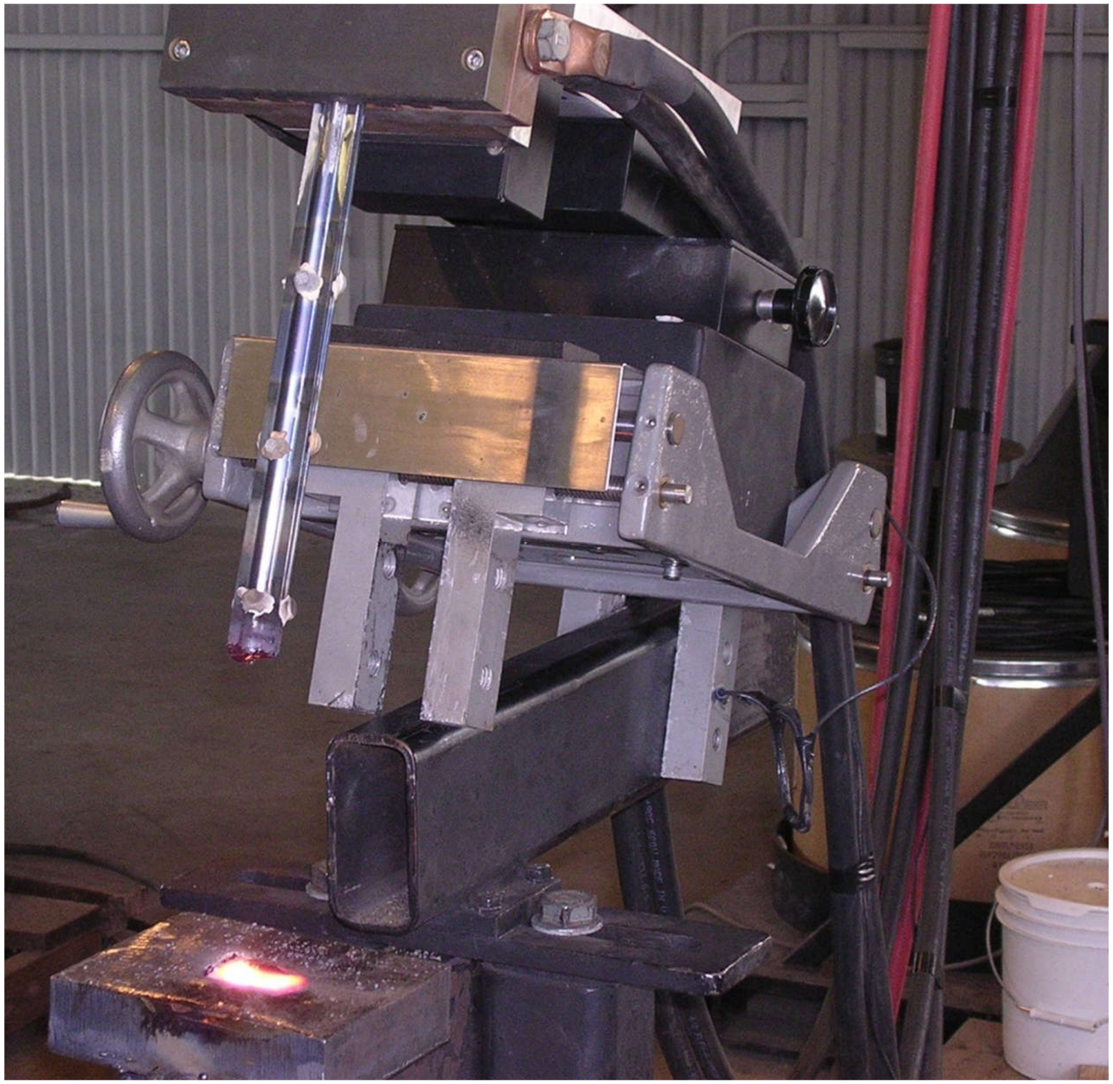
Plate Ready to Weld

- 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



End of Weld

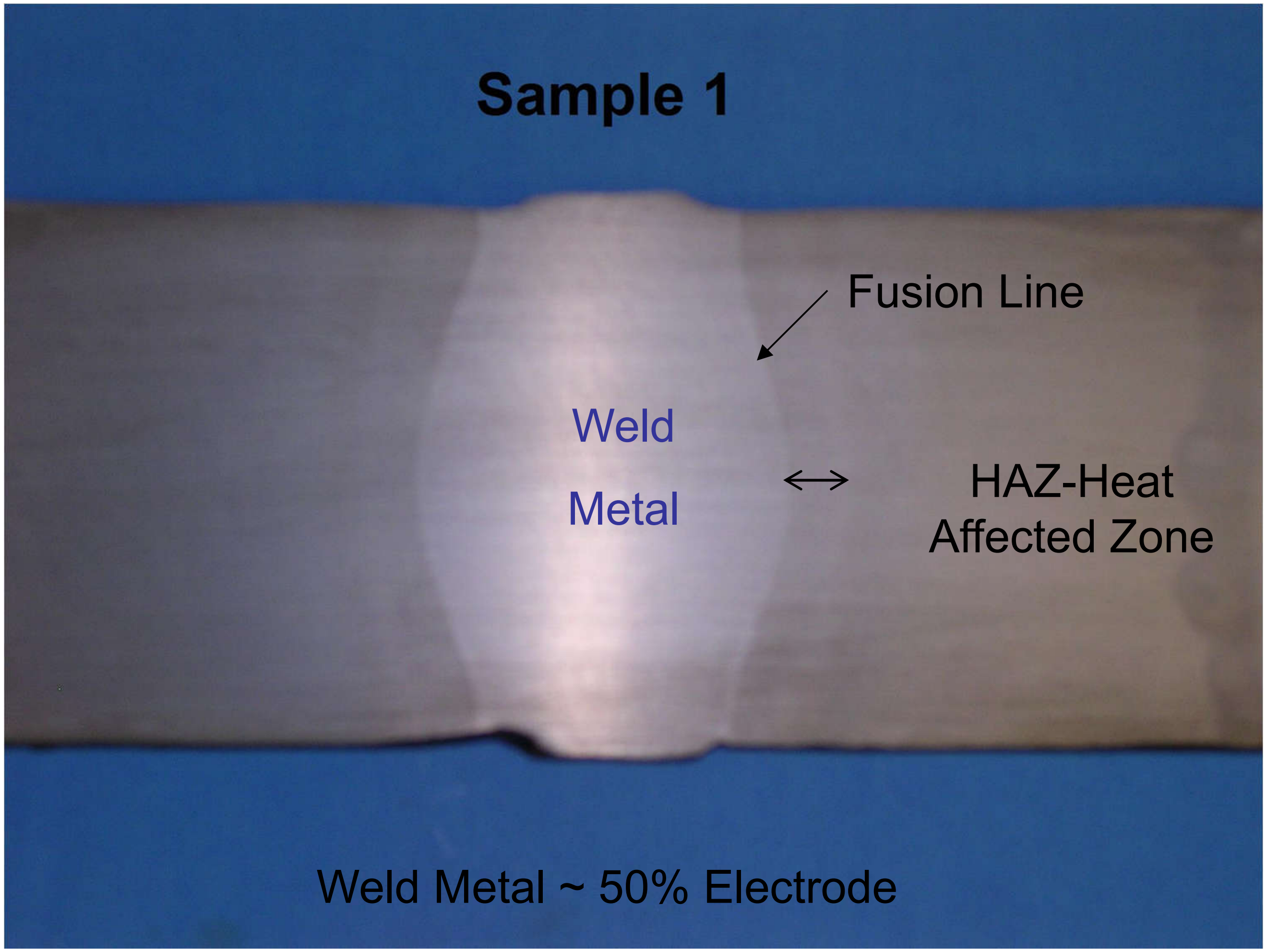


- Guide Consumed
- Note Molten Metal in Run Off Pad

Completed Weld

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

Weld Cross Section

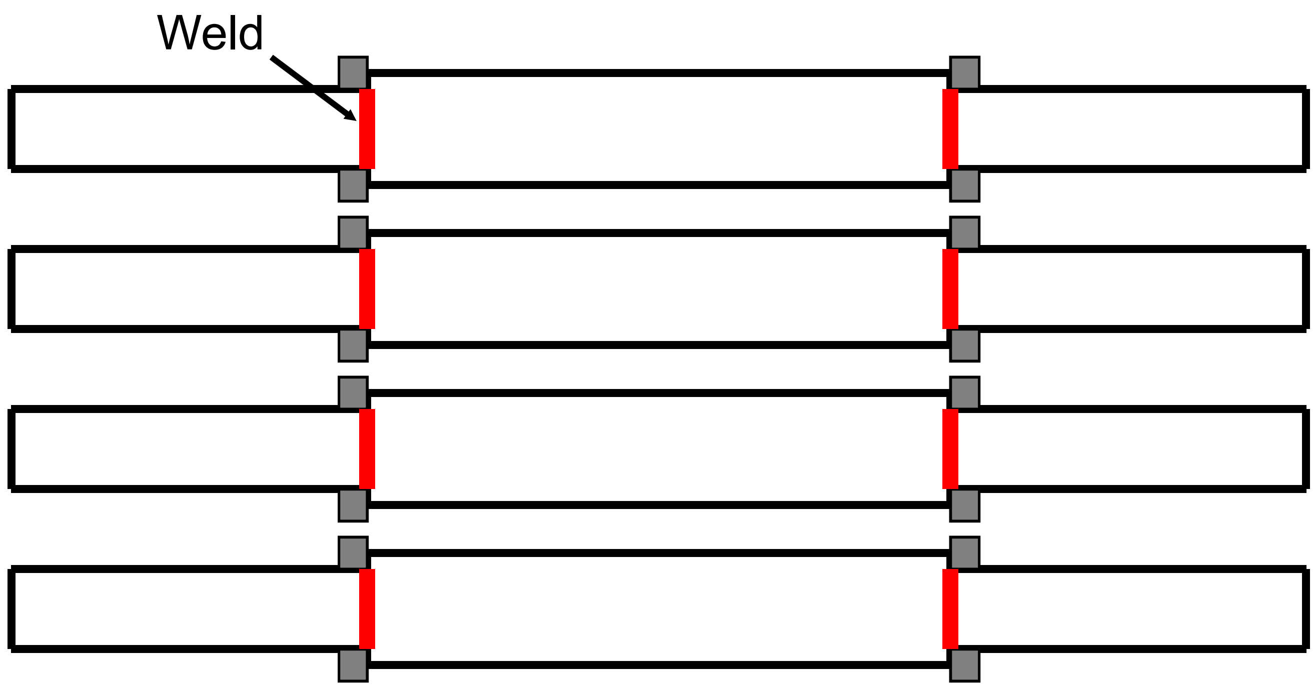


Efficient Flange Sizing

- 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.

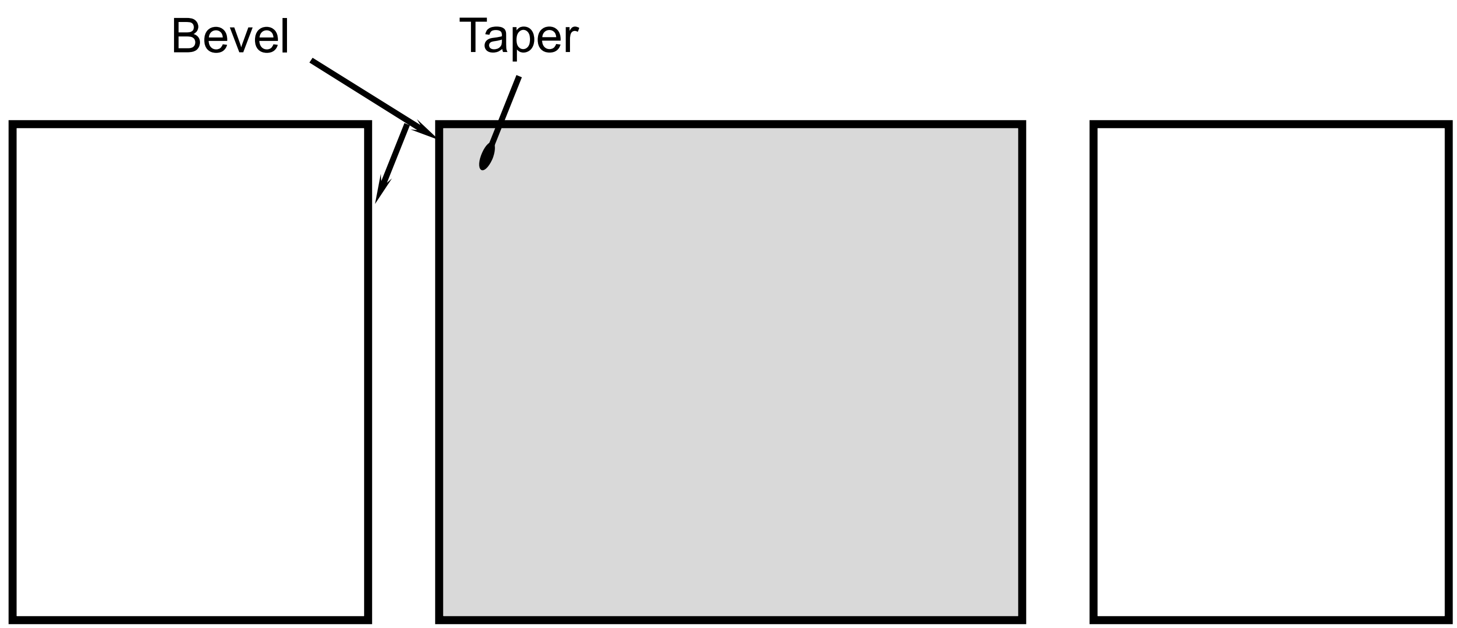
The Costly Method of Changing Flange Size by Changing Width

Weld and grind 8 splices



A Better Way- Change Flange Thickness

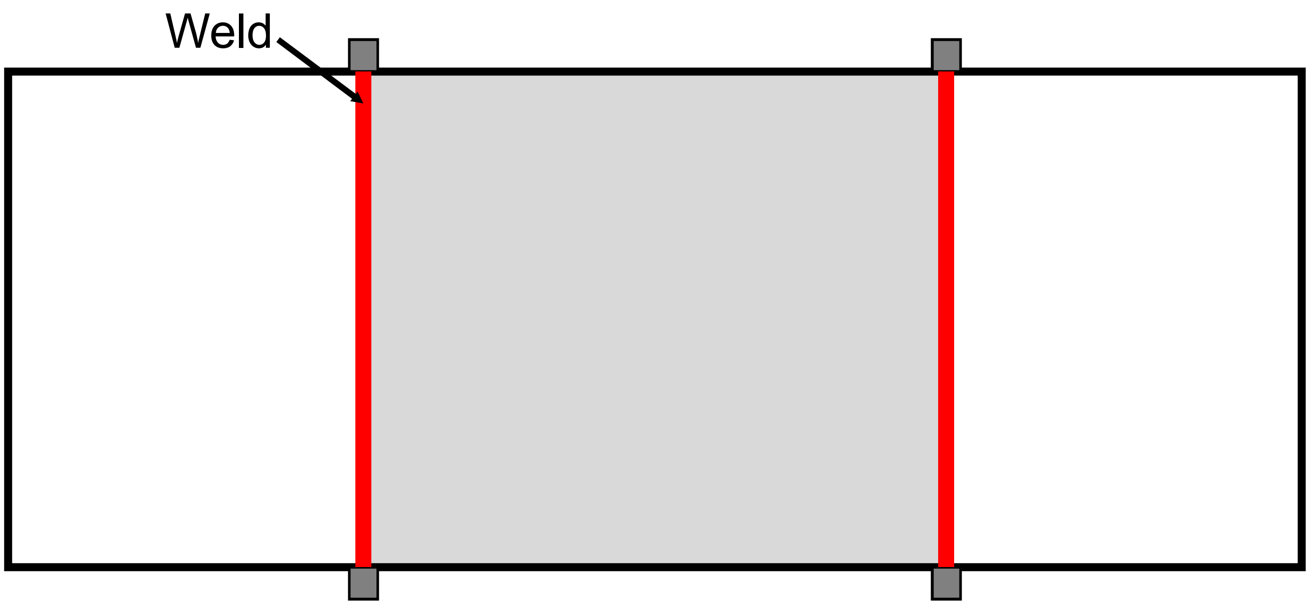
Bevel (4) and taper (2) plate edges



CHANGE THICKNESS

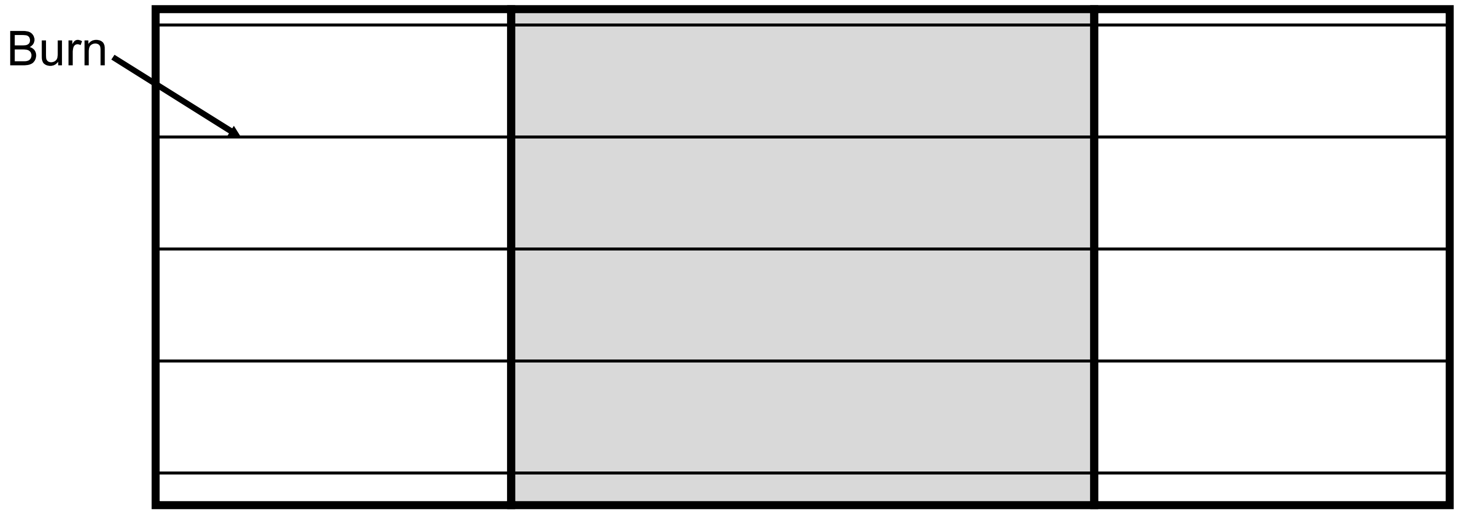
- Flange Sizing - change thickness

Weld and grind 2 splices



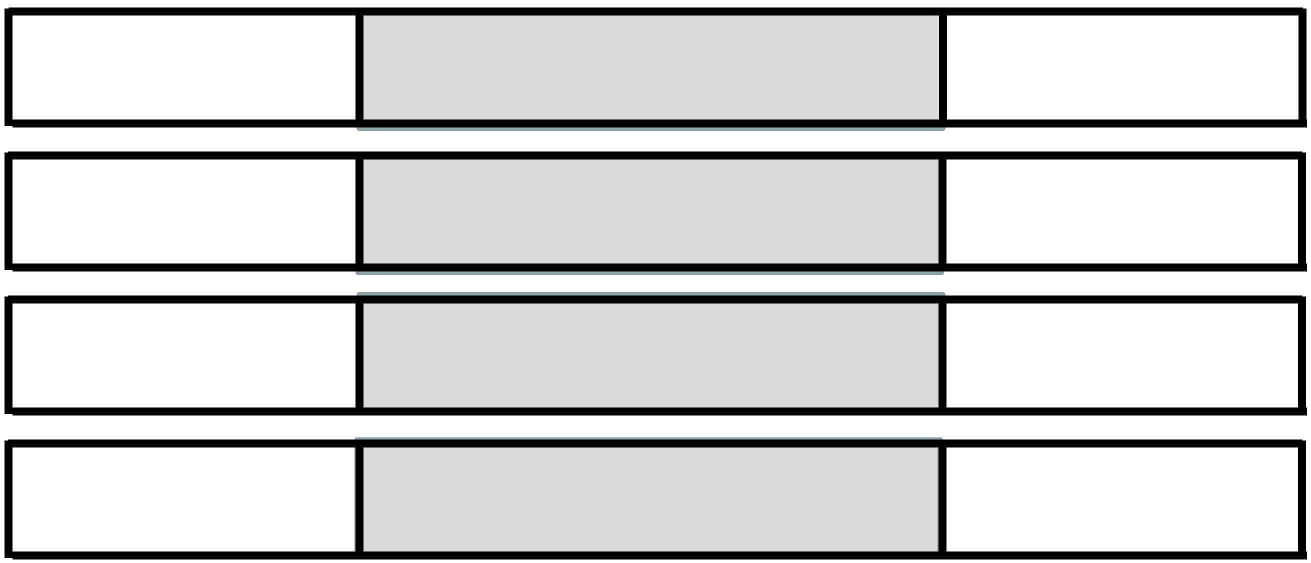
- Flange Sizing - change thickness

Burn 4 flanges from 1 assembly



- Flange Sizing - change thickness

4 flanges from 1 assembly

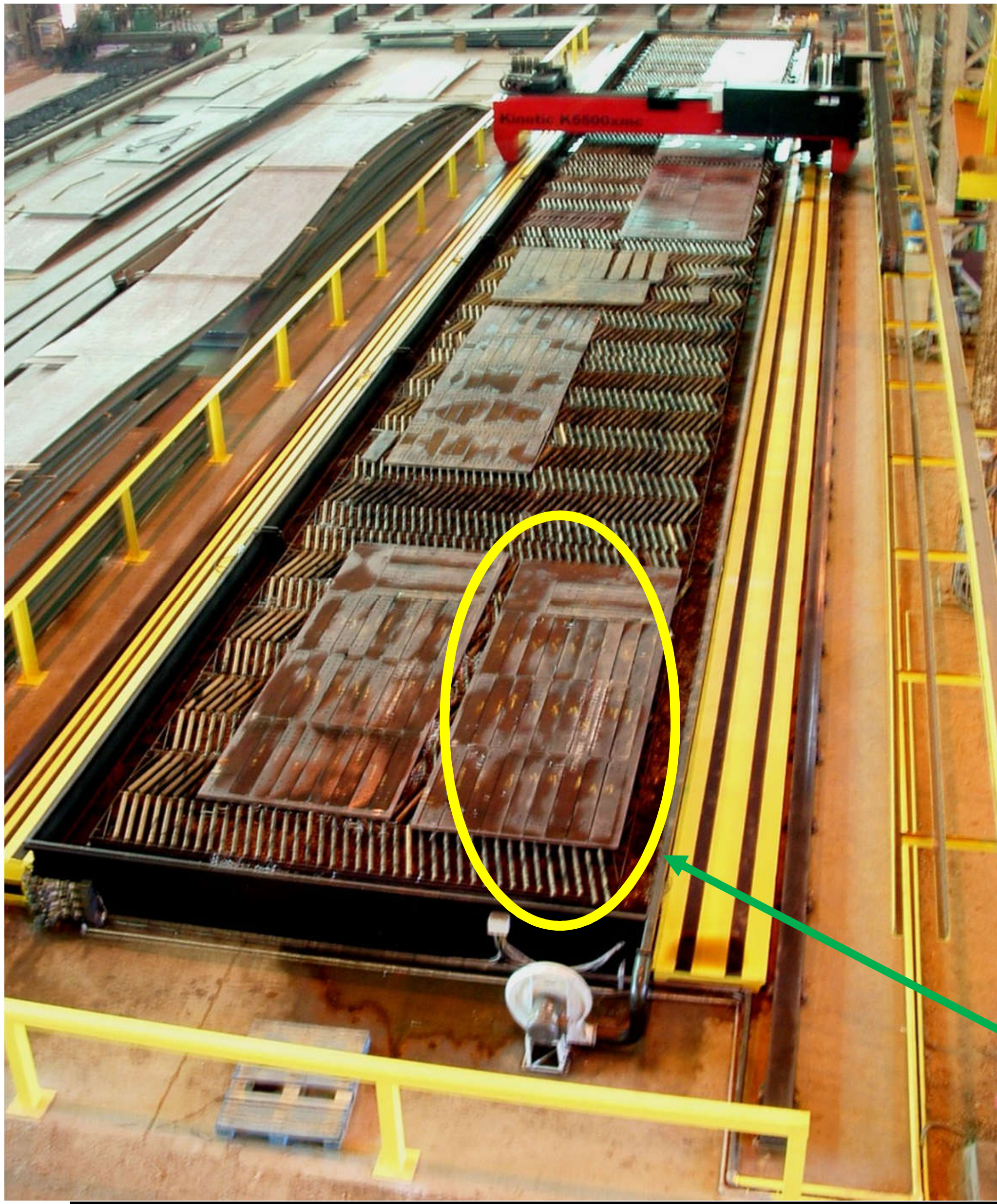


Good Practice

- 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…
  - <u>ONLY</u> when material cost saved > labor cost spent



CNC Cutting and Drilling Equipment

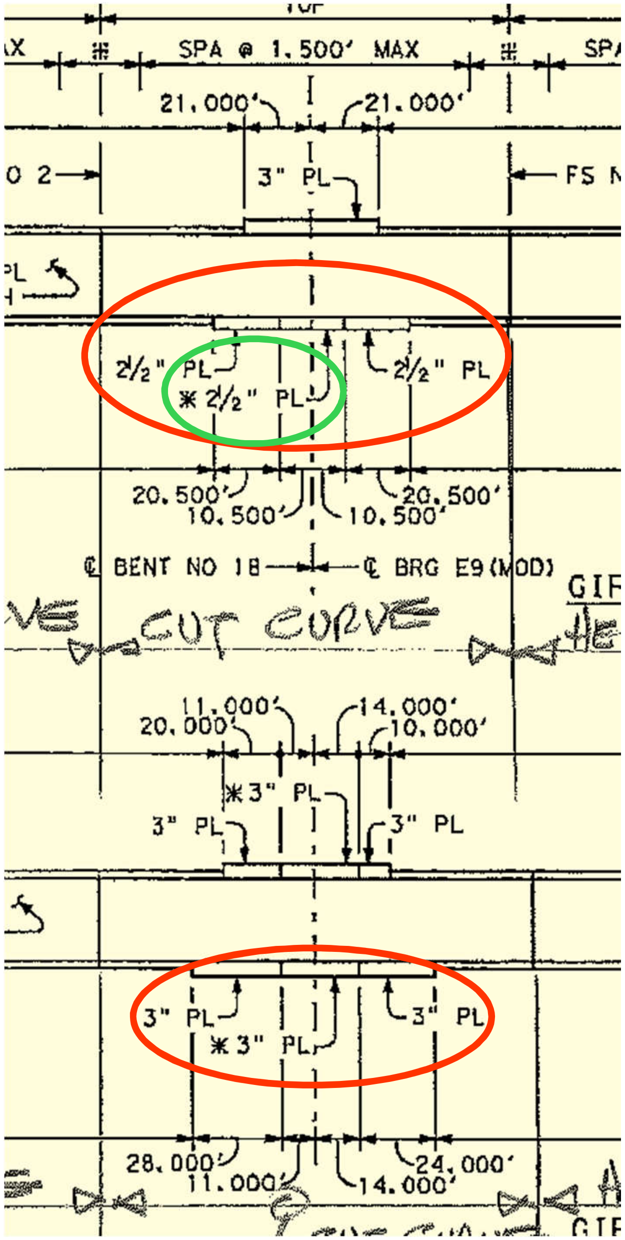
Equipment:
16.75 ft. x 165 ft. bed

2-48 HP Drill Heads
12 tool Changer station

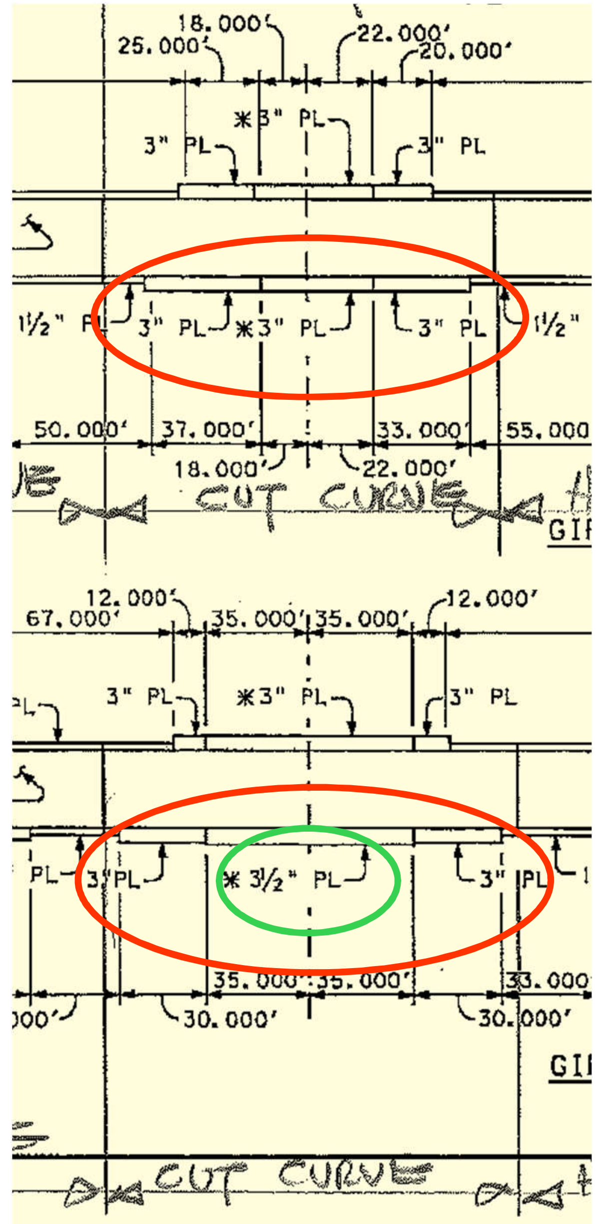
Plasma Automated Contour
Bevel Cutting System

6-Oxy-Fuel Torch Stations

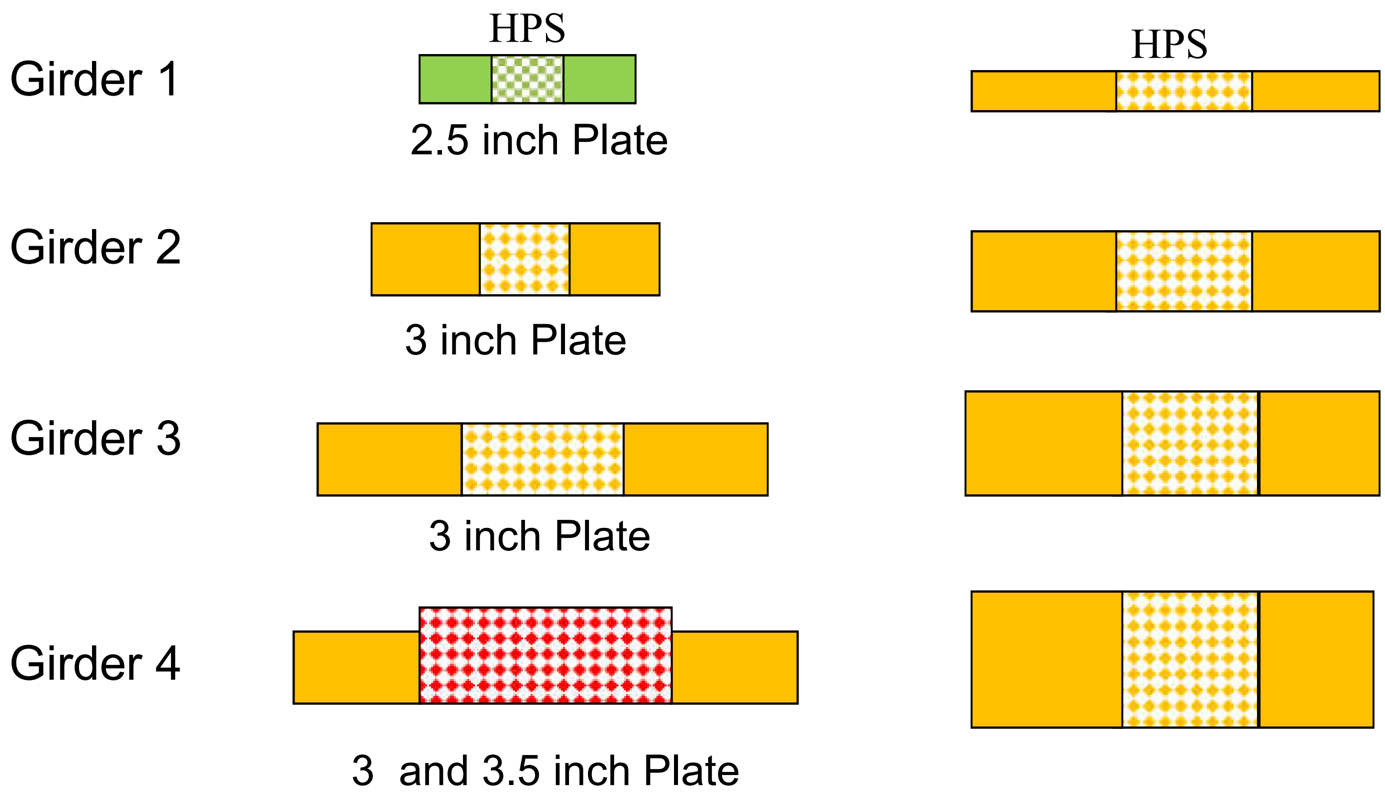
Flanges Stripped From Wider Plate



How to Prevent Slabbing of the Flanges



Bottom Flanges at Pier



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

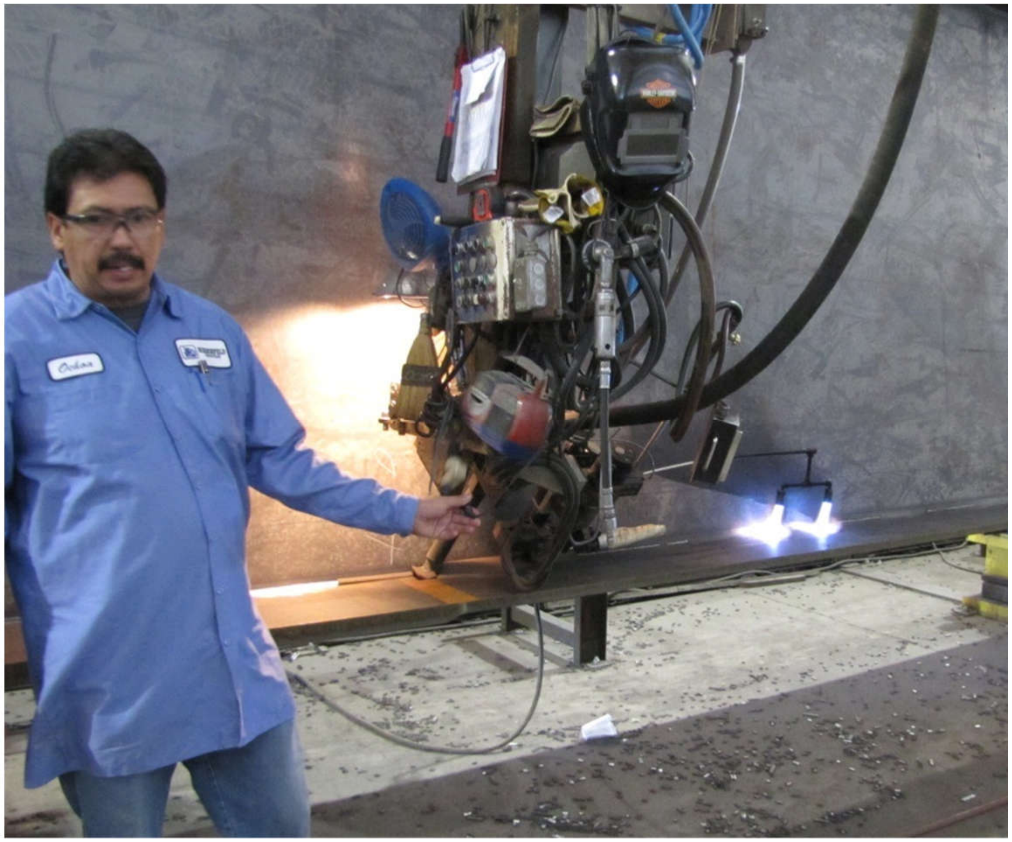
Camber Cut Into Web

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

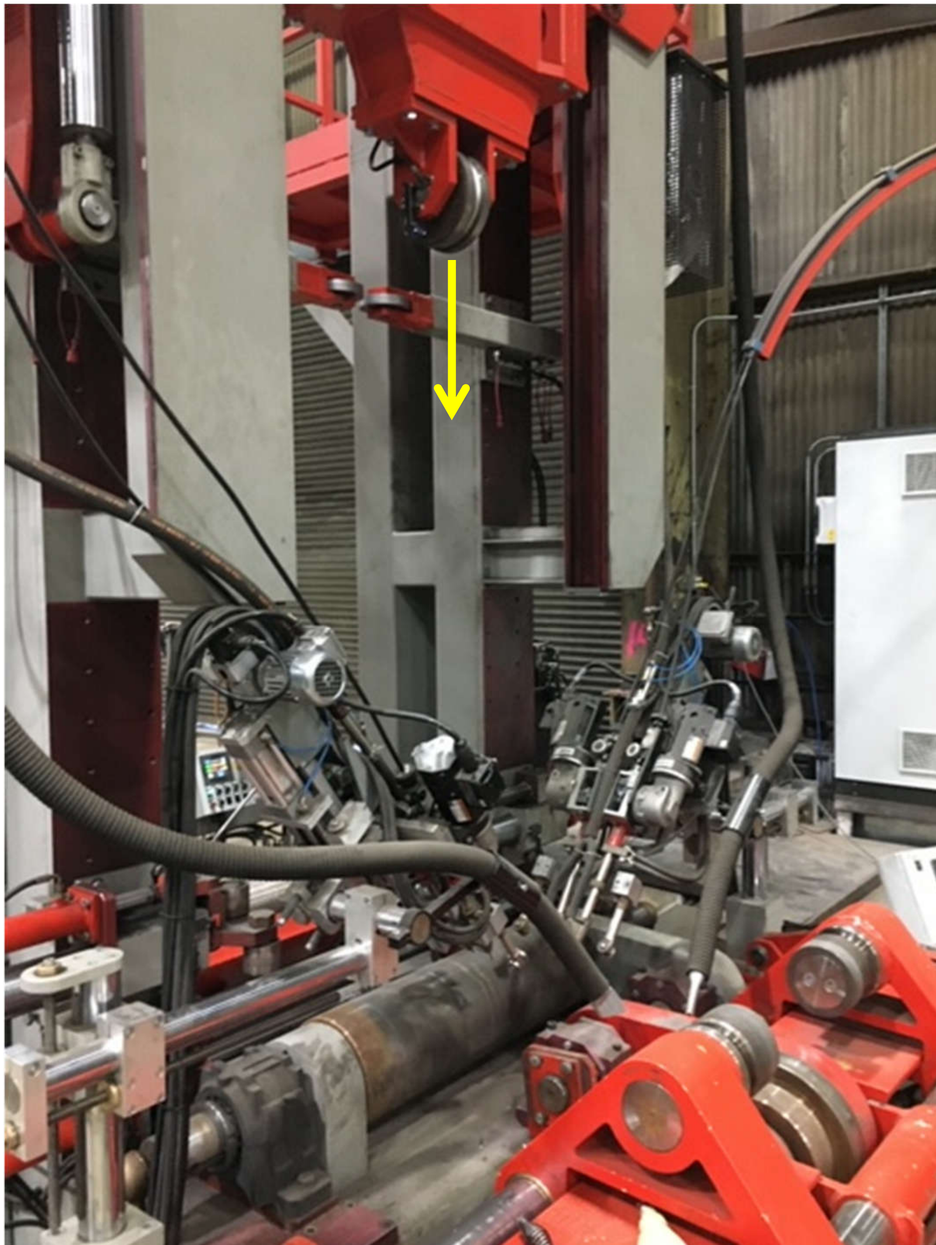
Weld Both Sides at Once

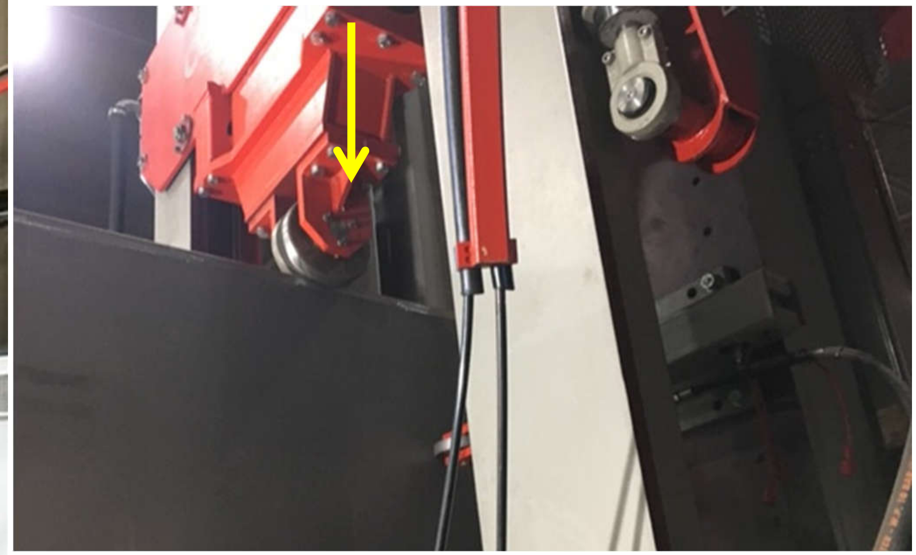


Welding Head and Preheat Torches

New Method of Assembly

- No Tack Welds
- Automated Welding Speed
- Preheat Built Into Fixture
- Welded T Assembly Flipped and Other Flange Welded

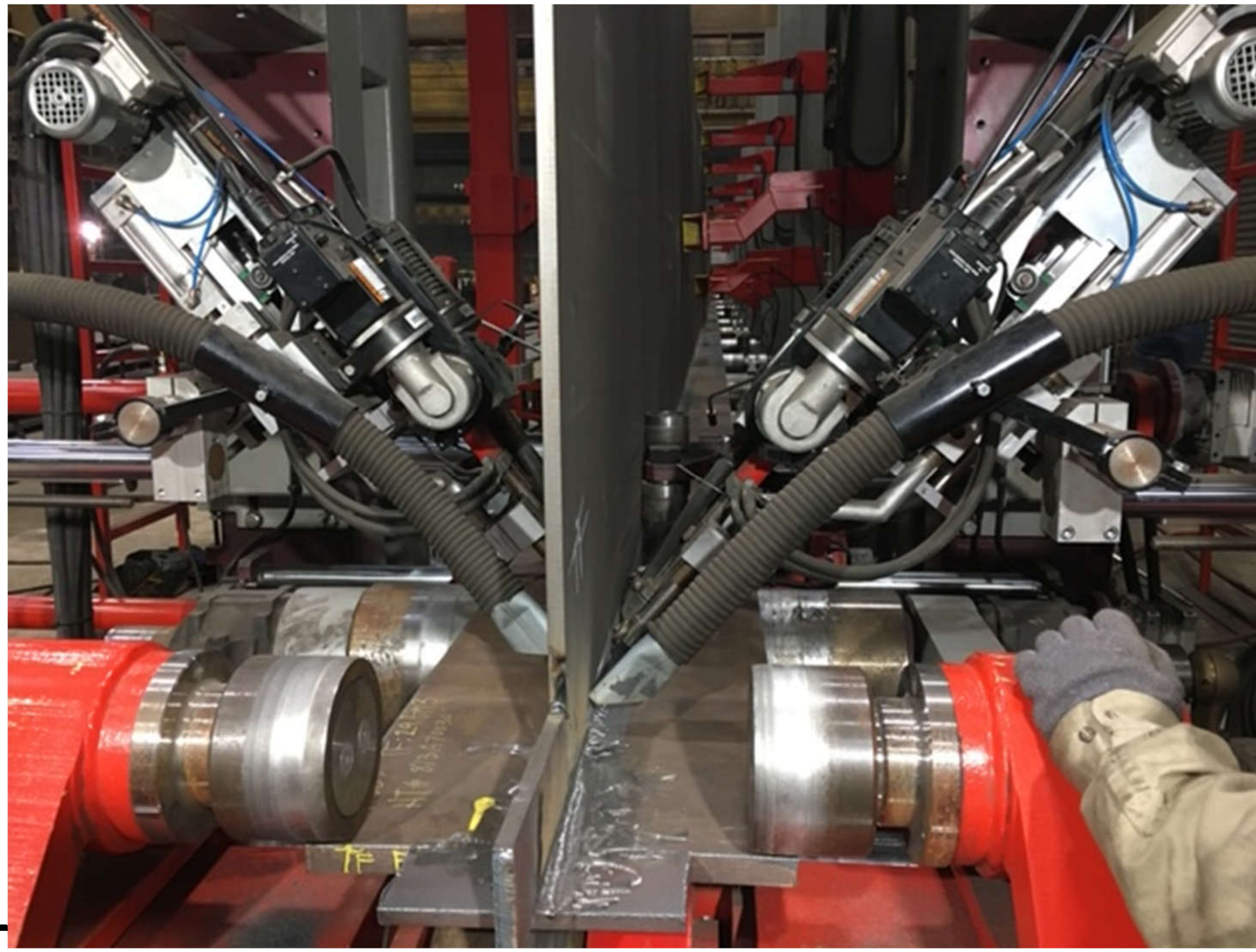




Clamping Force Applied by Roller at Top of Web

Web Centered on Flange Using Runoff Tab

Girder Fed Into Welding Head by Rollers



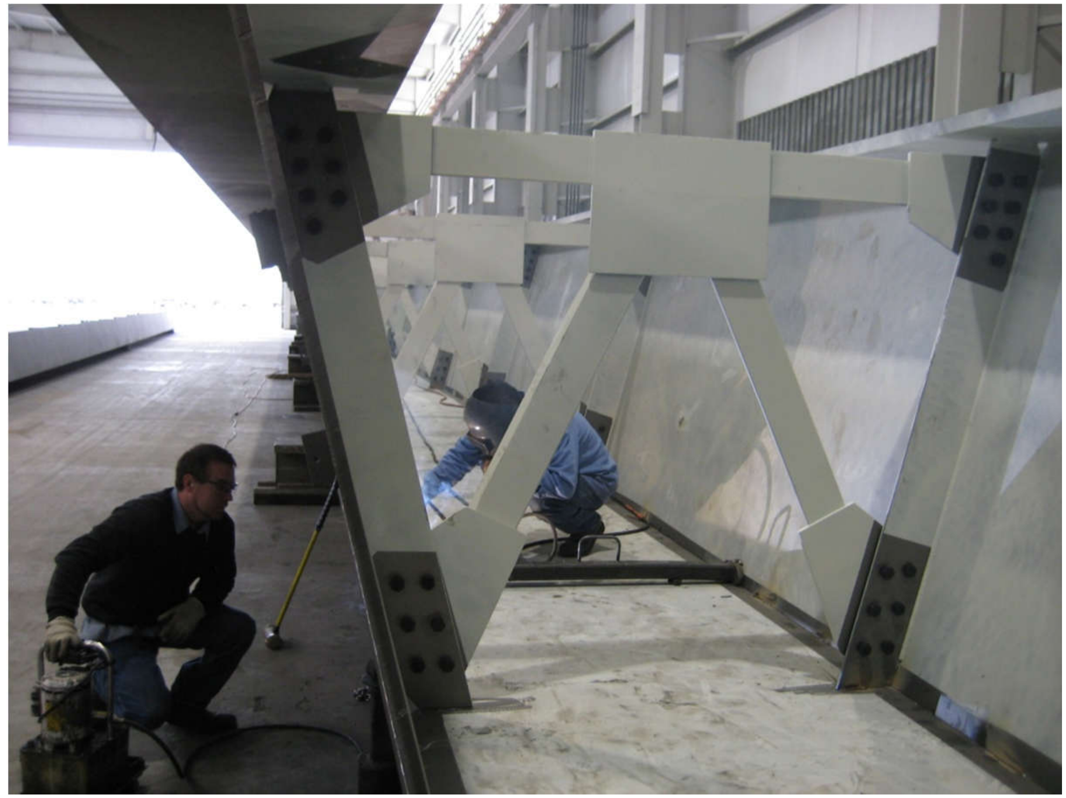
Frames to Steady Welded Section and Flip T Section

Stiffener Fit

Stiffener Dart Welding SAW
Both Sides Welded at the Same Time

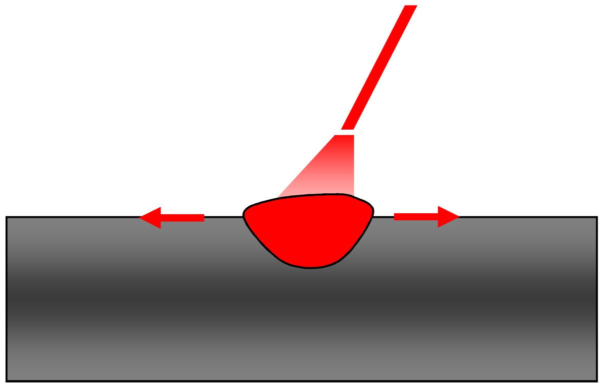
Tub (Box) Girders Hand Assembled

Flanges and Connection Plates Welded to Web

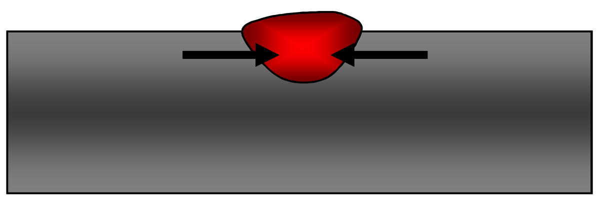


Cross Frames Used to Control Box Geometry

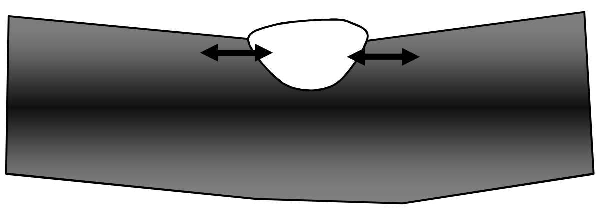
Residual Stress Due to Welding



Thermal expansion due to heat input from welding

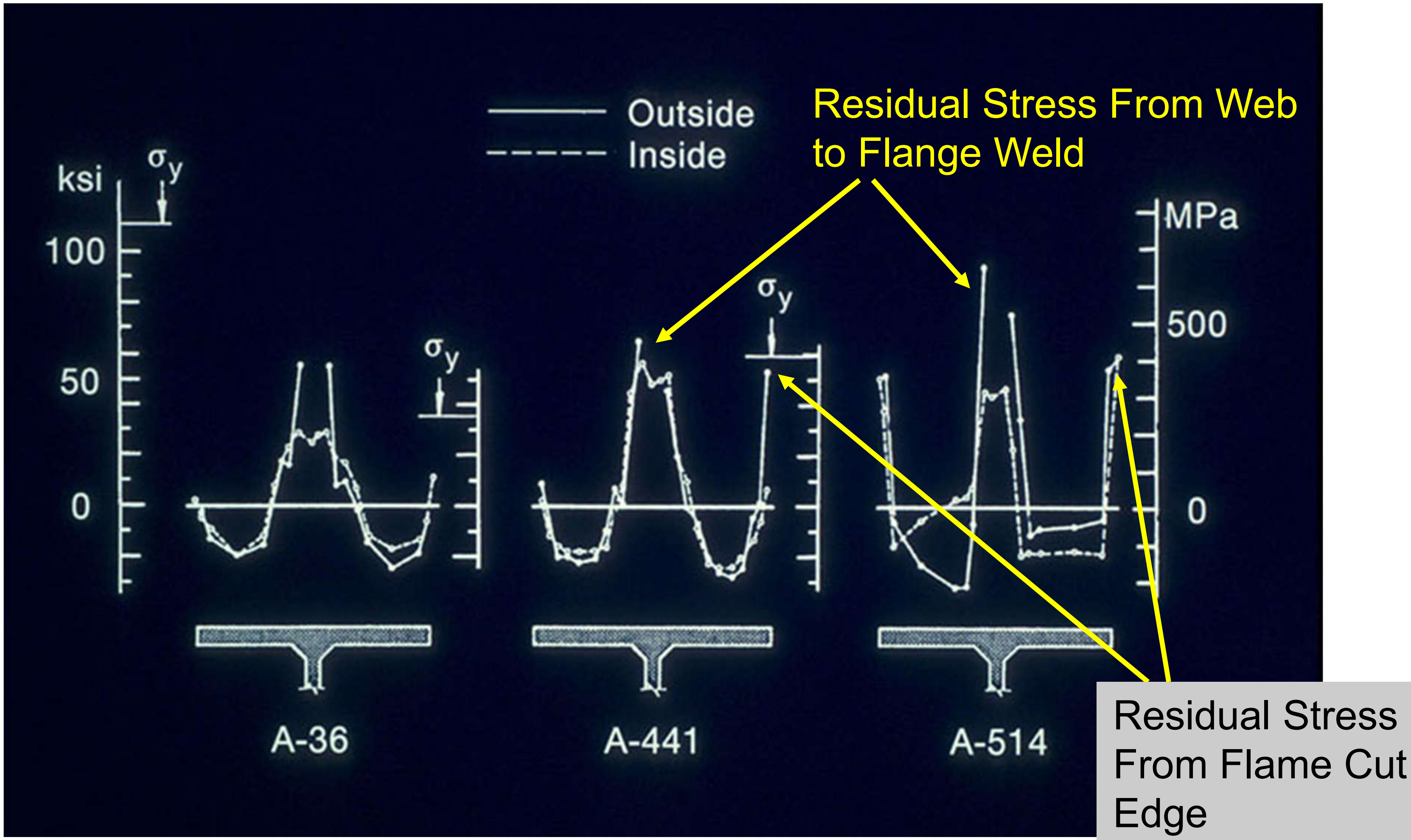


Shrinkage of beads due to cooling and solidification



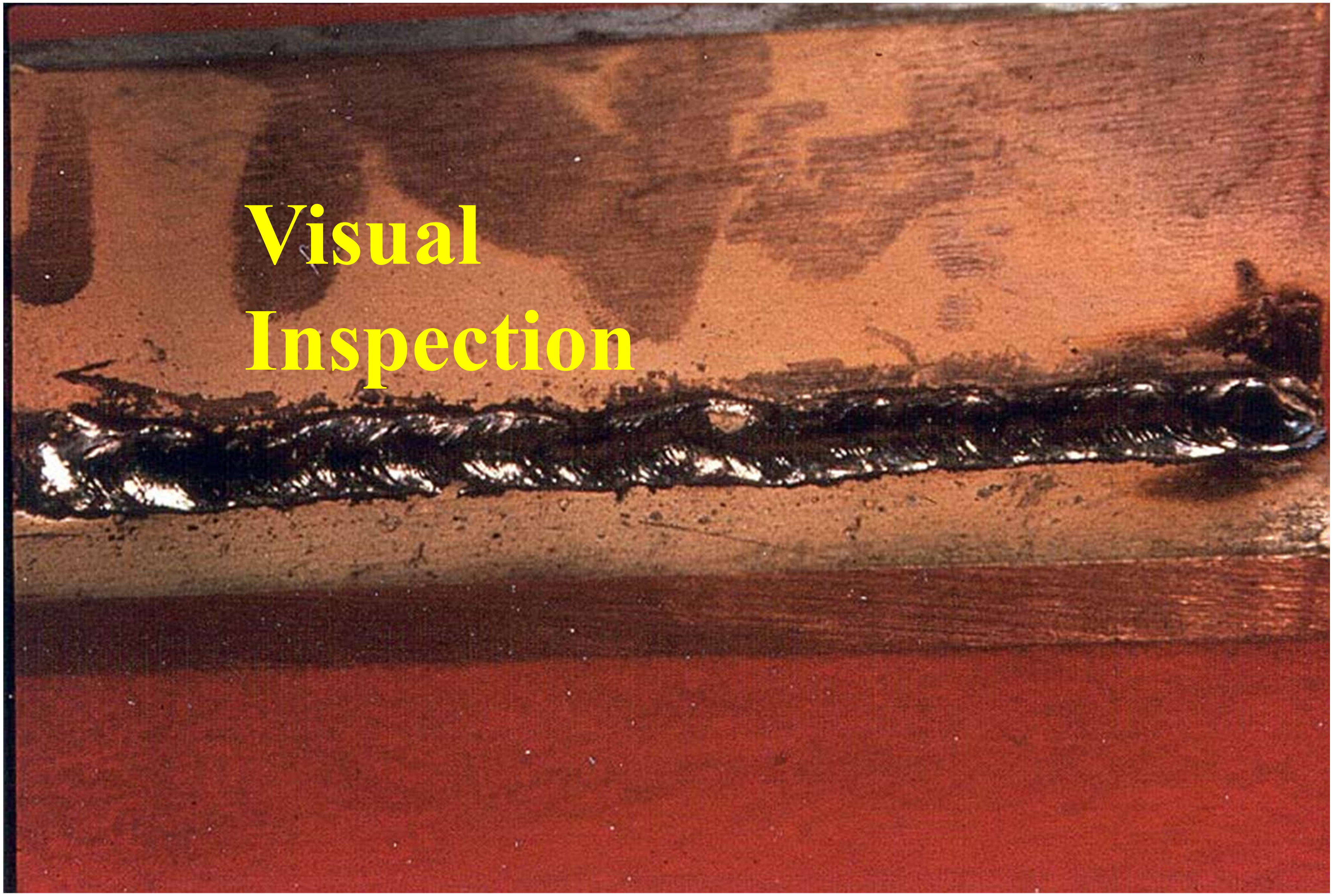
Tensile residual stress in the vicinity of weld

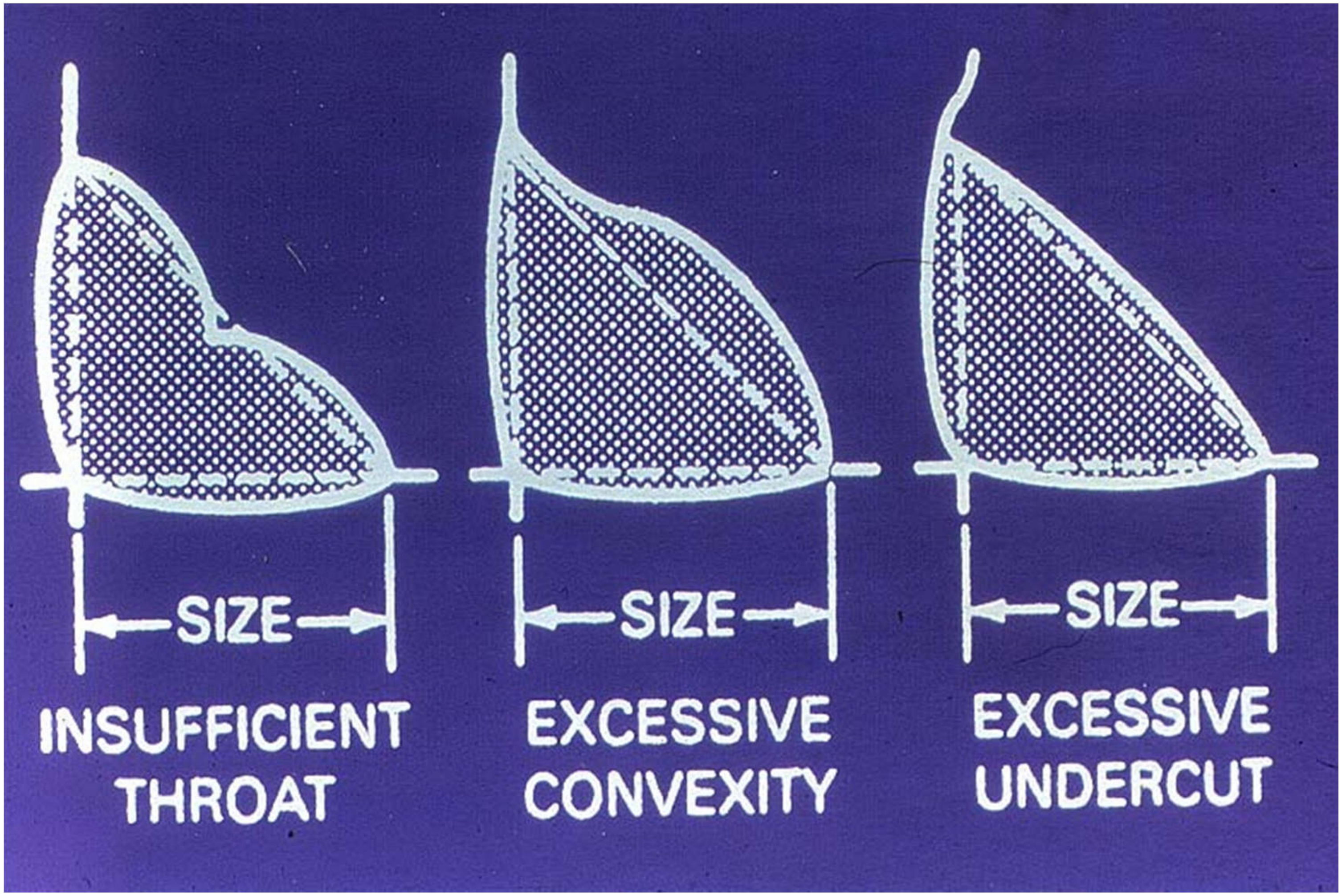
Residual Flange Stresses in Welded Shape

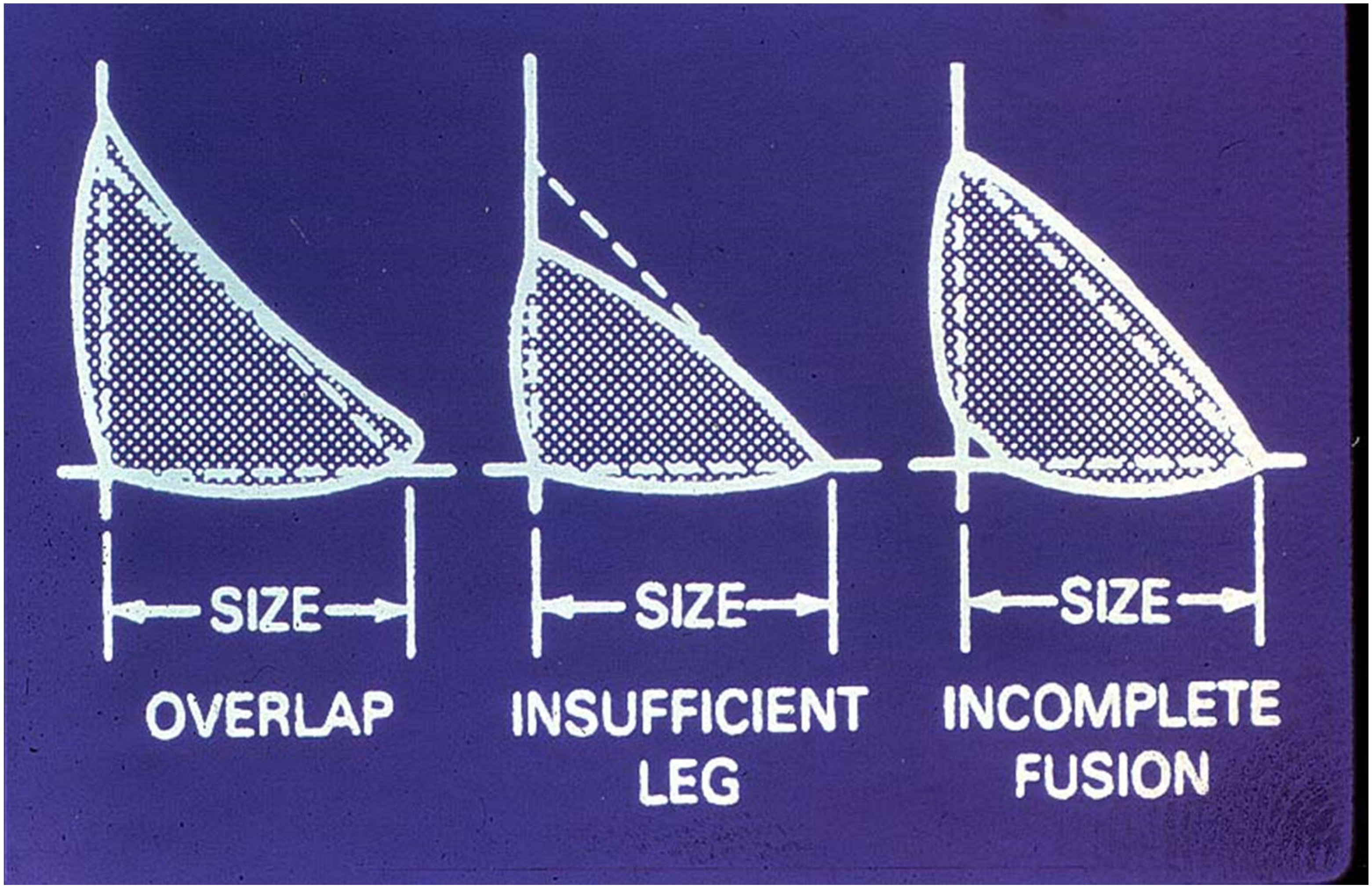


Weld Inspection

- Fillet Welds
  - Visual
  - Magnetic Particle
- Butt Welds
  - Ultrasonic
  - Radiography


Visual
Inspection

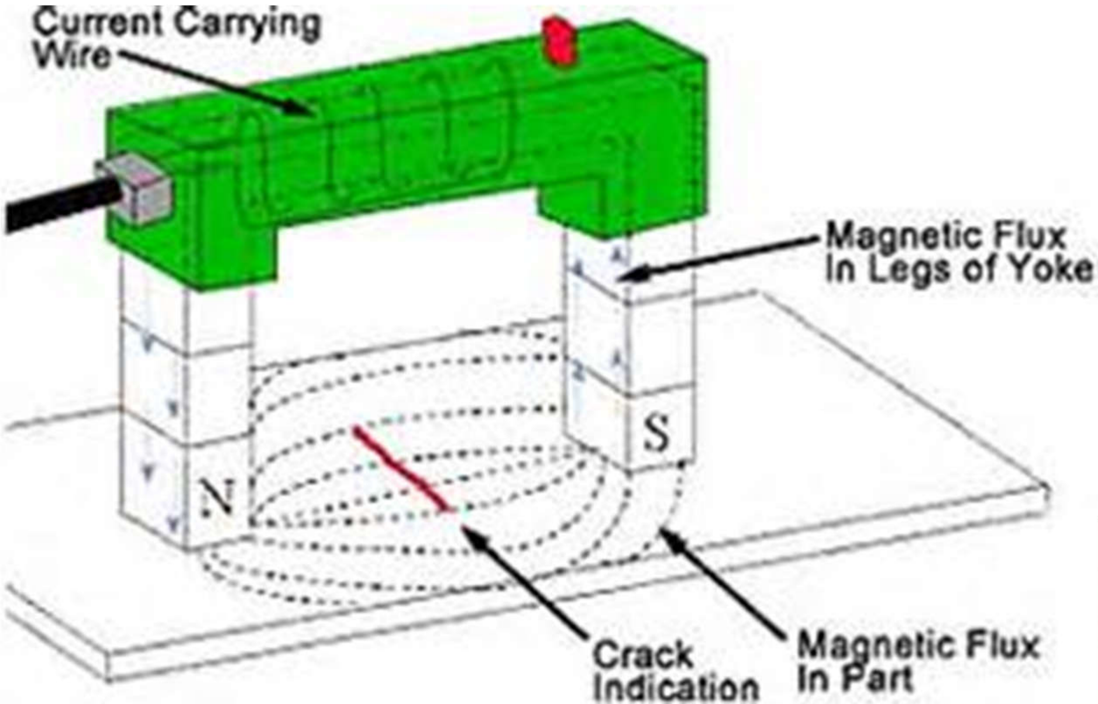

SIZE
SIZE
SIZE
INSUFFICIENT THROAT
EXCESSIVE CONVEXITY
EXCESSIVE UNDERCUT


SIZE
SIZE
SIZE
OVERLAP
INSUFFICIENT LEG
INCOMPLETE FUSION

Magnetic Particle

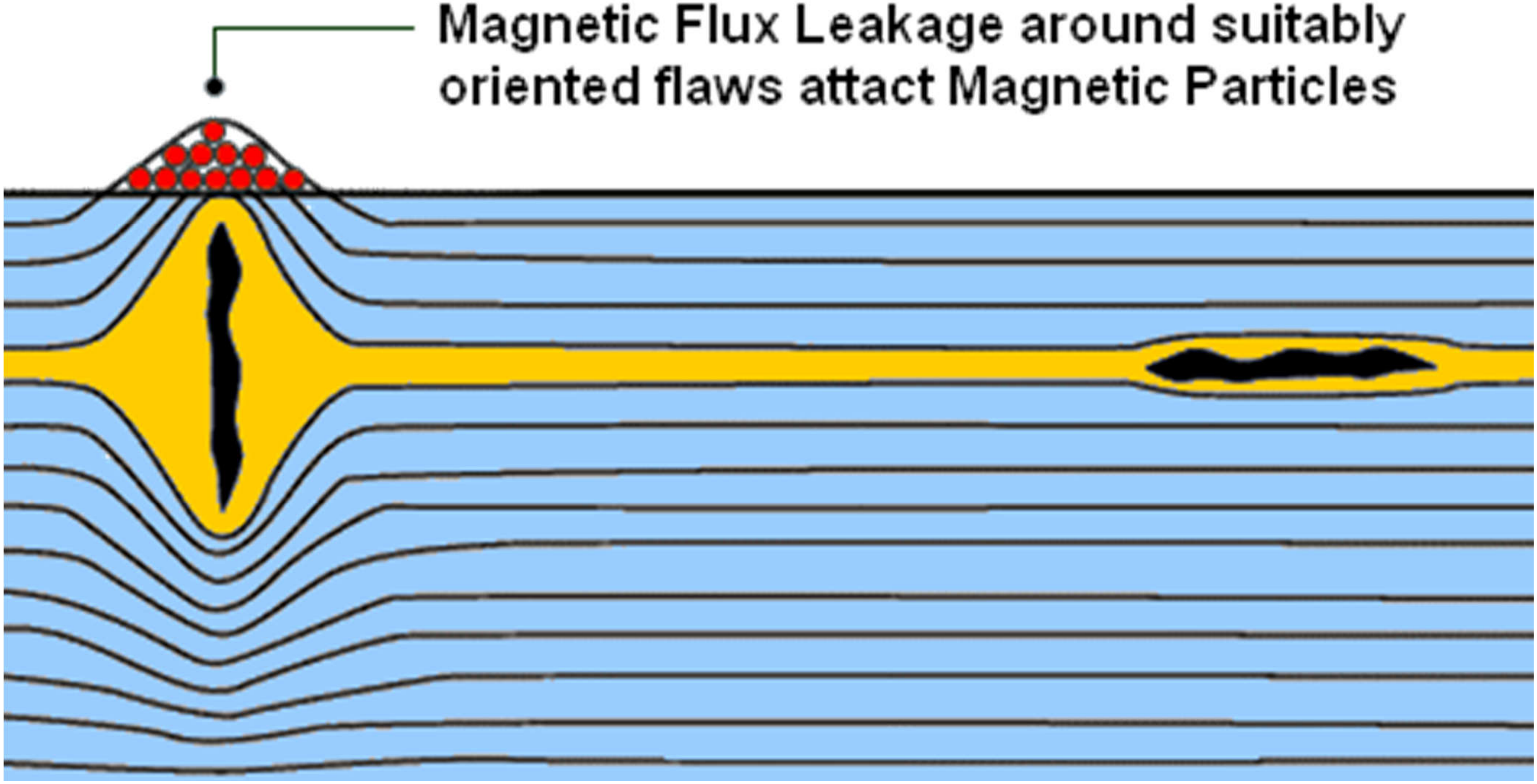
- Inspection of Web to Flange Fillet Welds and Other Fillet Welds
- Surface or Near Surface Inspections

Magnetic Particle (MT)



Fish & Associates

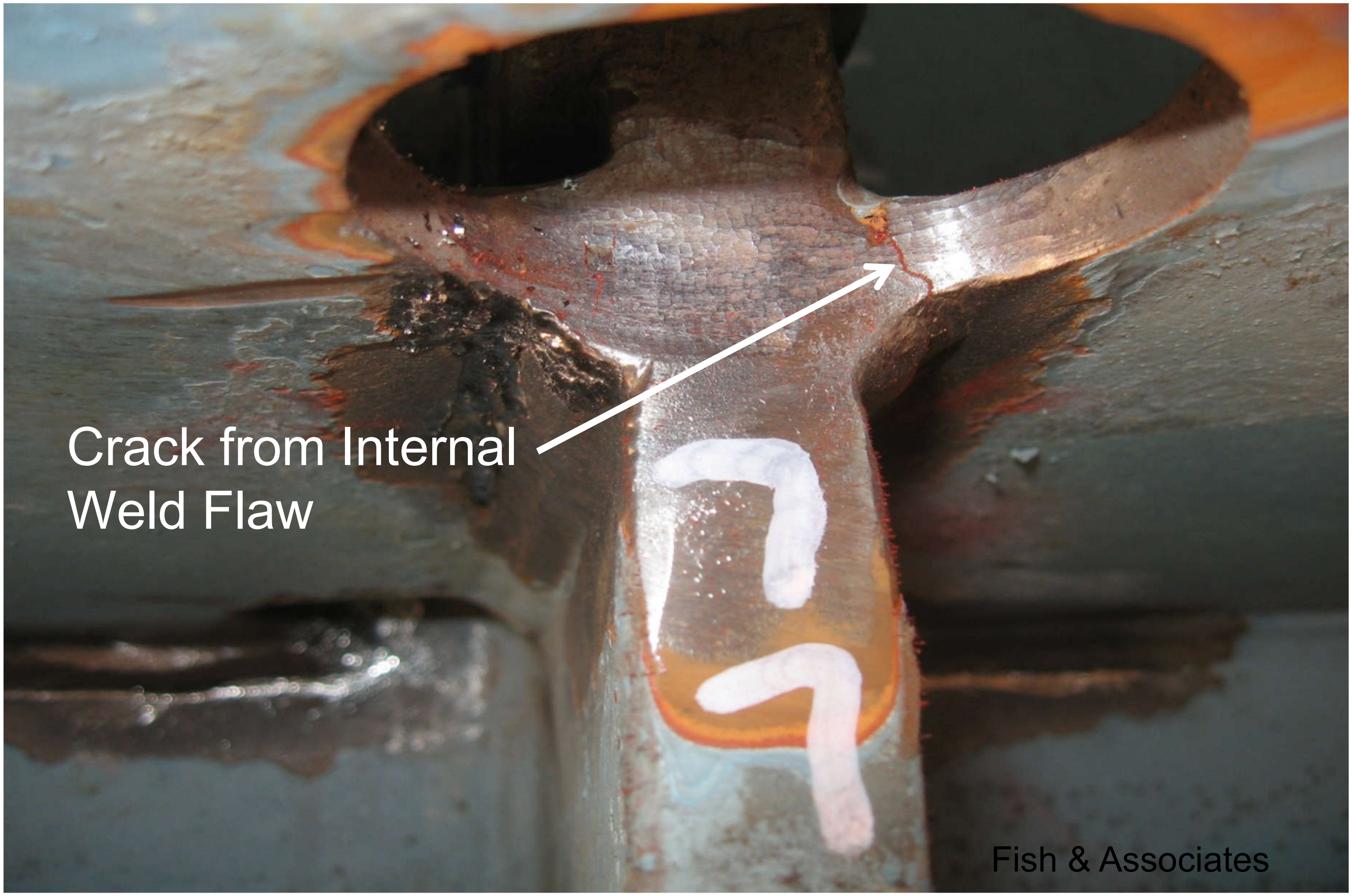
Magnetic Particle (MT)



Fish & Associates

Magnetic Particle (MT)

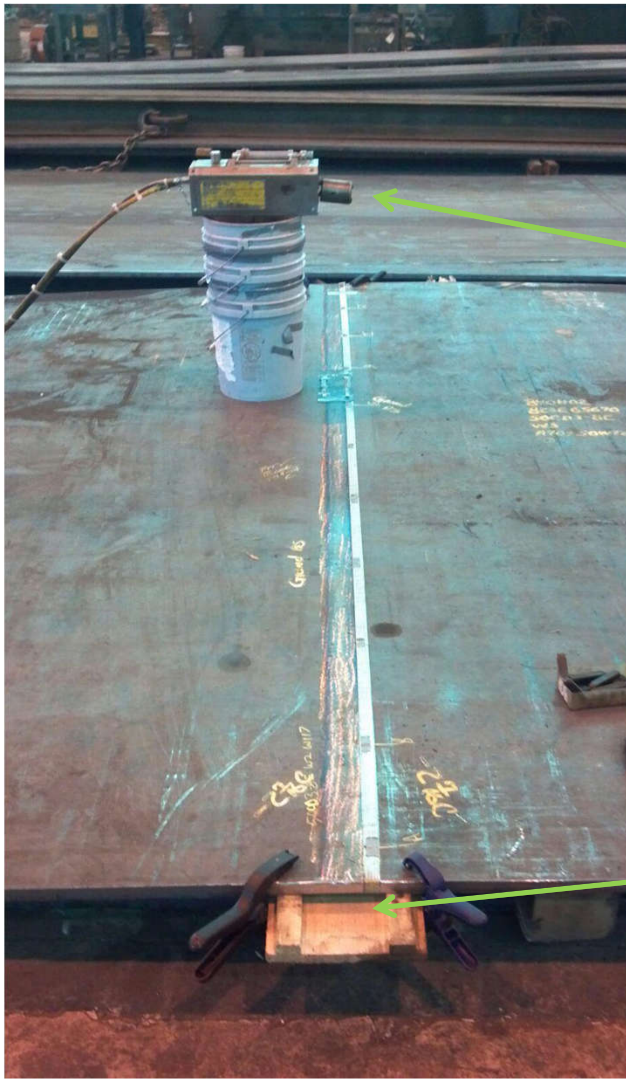
Magnetic Particle (MT)



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



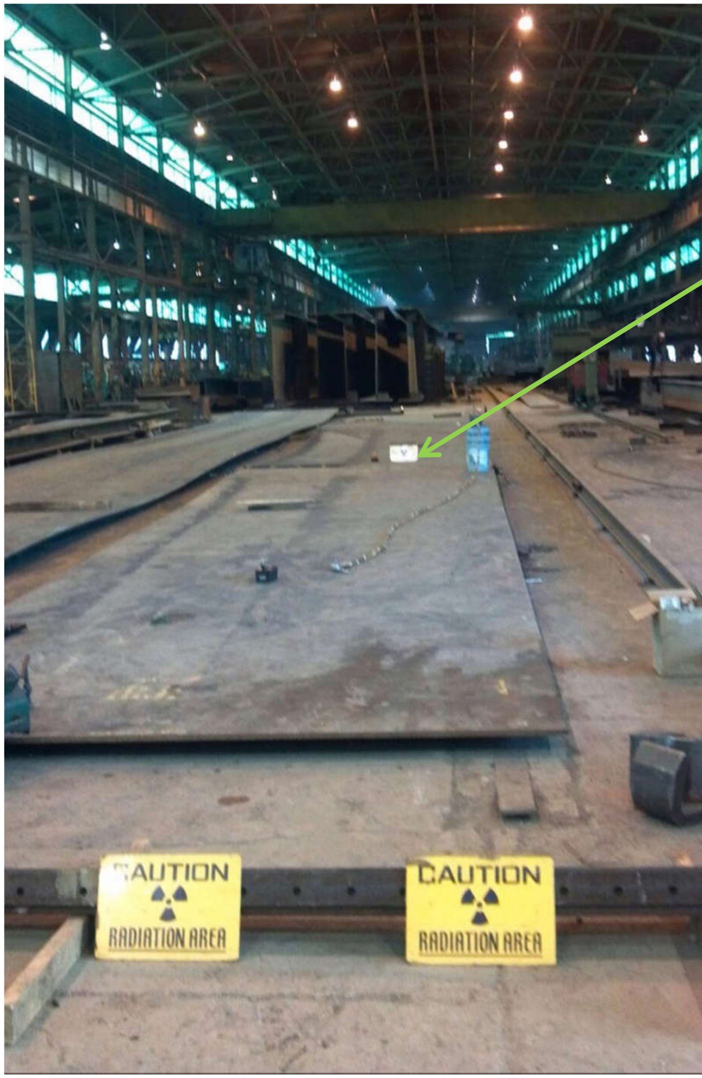
Gamma Ray Source

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

Measures Density Along Ray Path

Film Holder

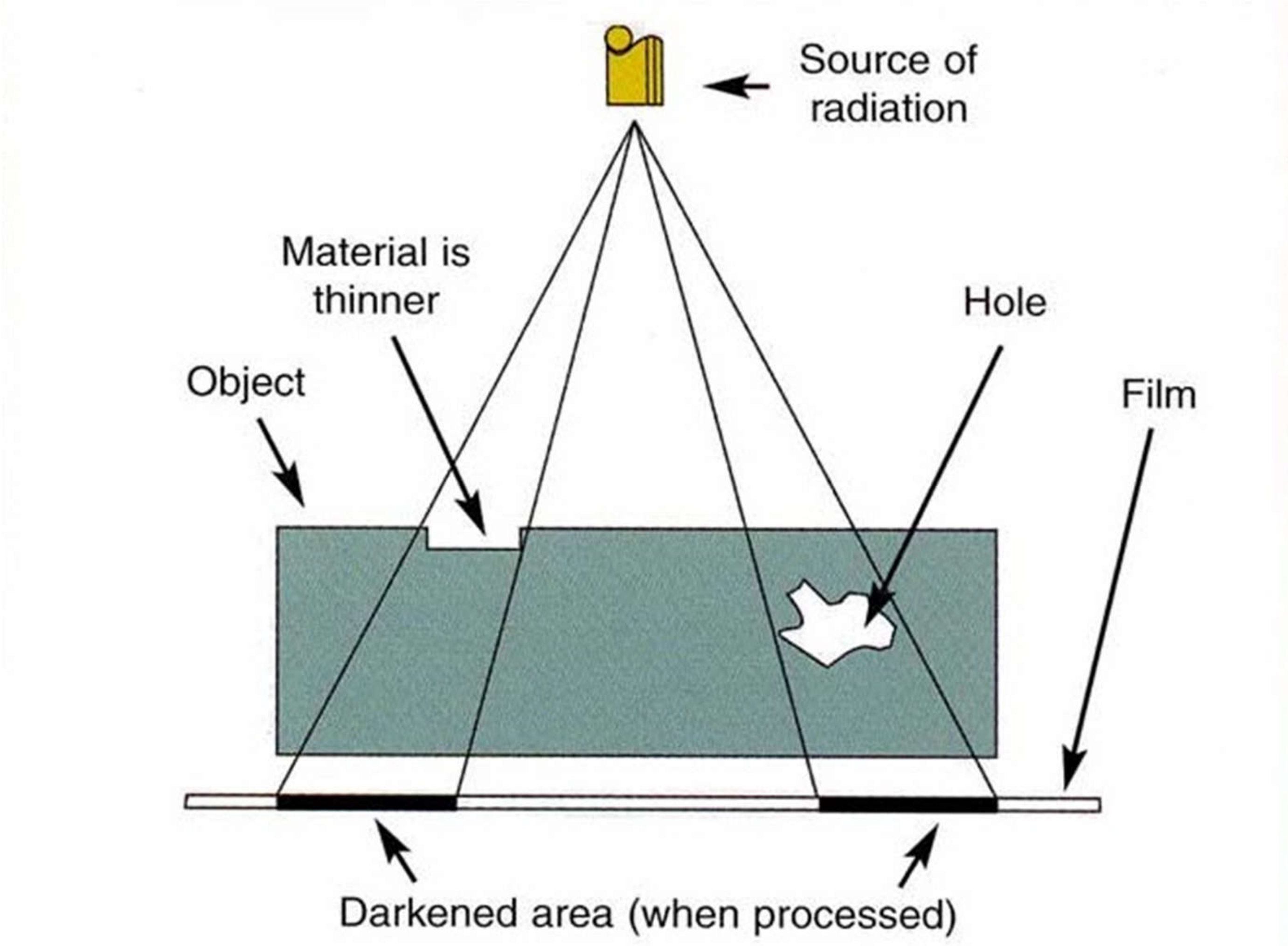
Radiation Hazard



Weld

Inspect at Night
Or Move Plate
Out of Shop

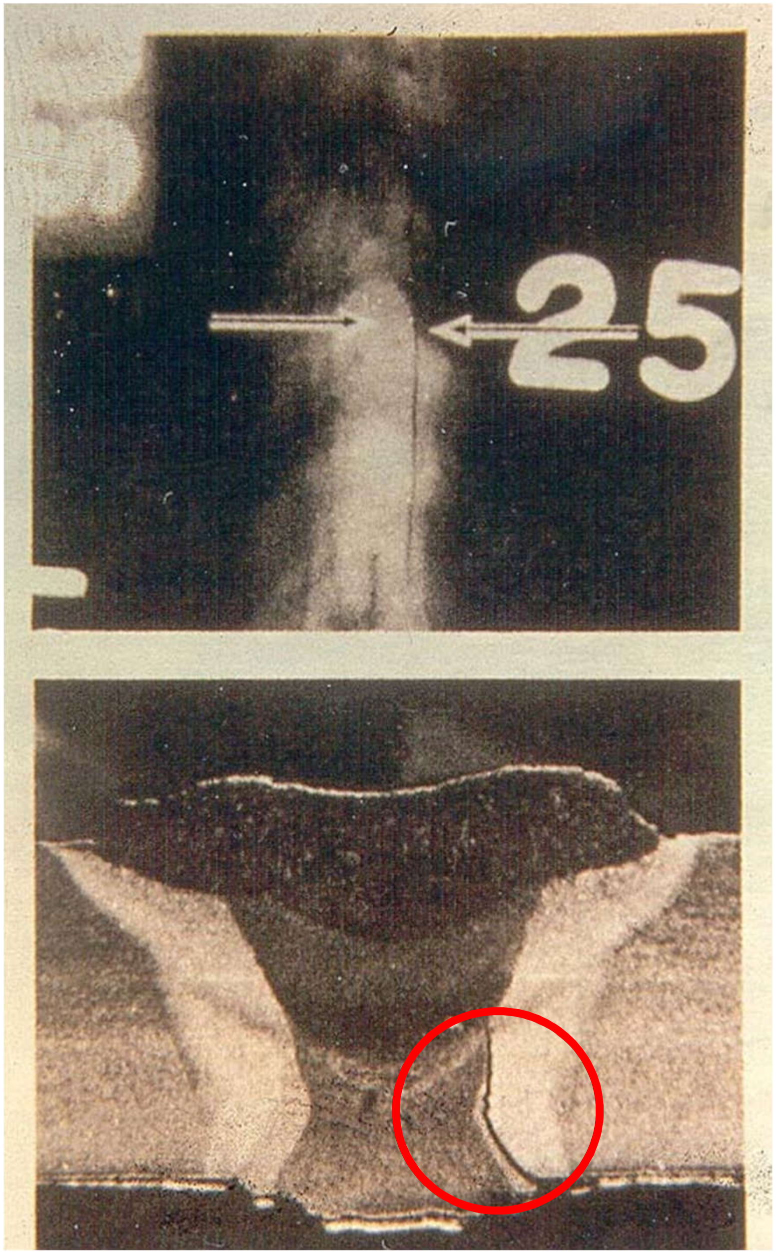
Radiography (RT)

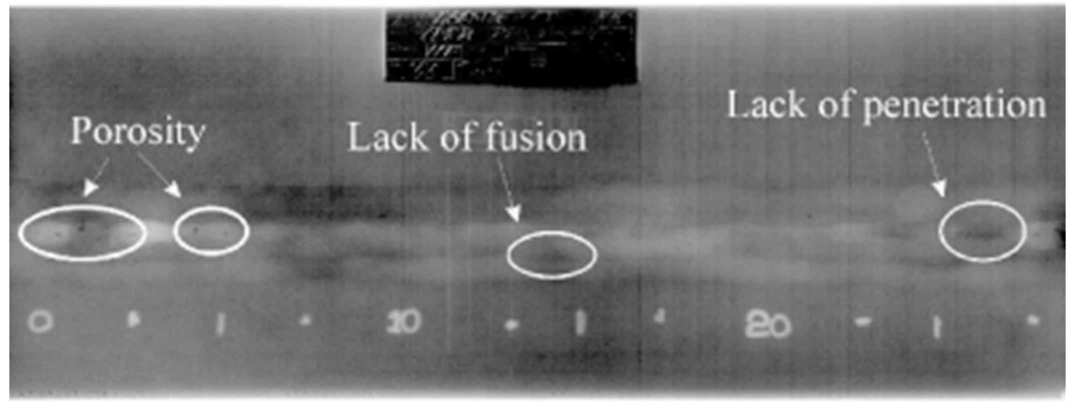


Fish & Associates

Approximate Thickness Limitations

Radioisotope	Thickness, in.
Iridium-192	0.5-2.5
Cesium-137	0.5-3.5
Cobalt-60	>3

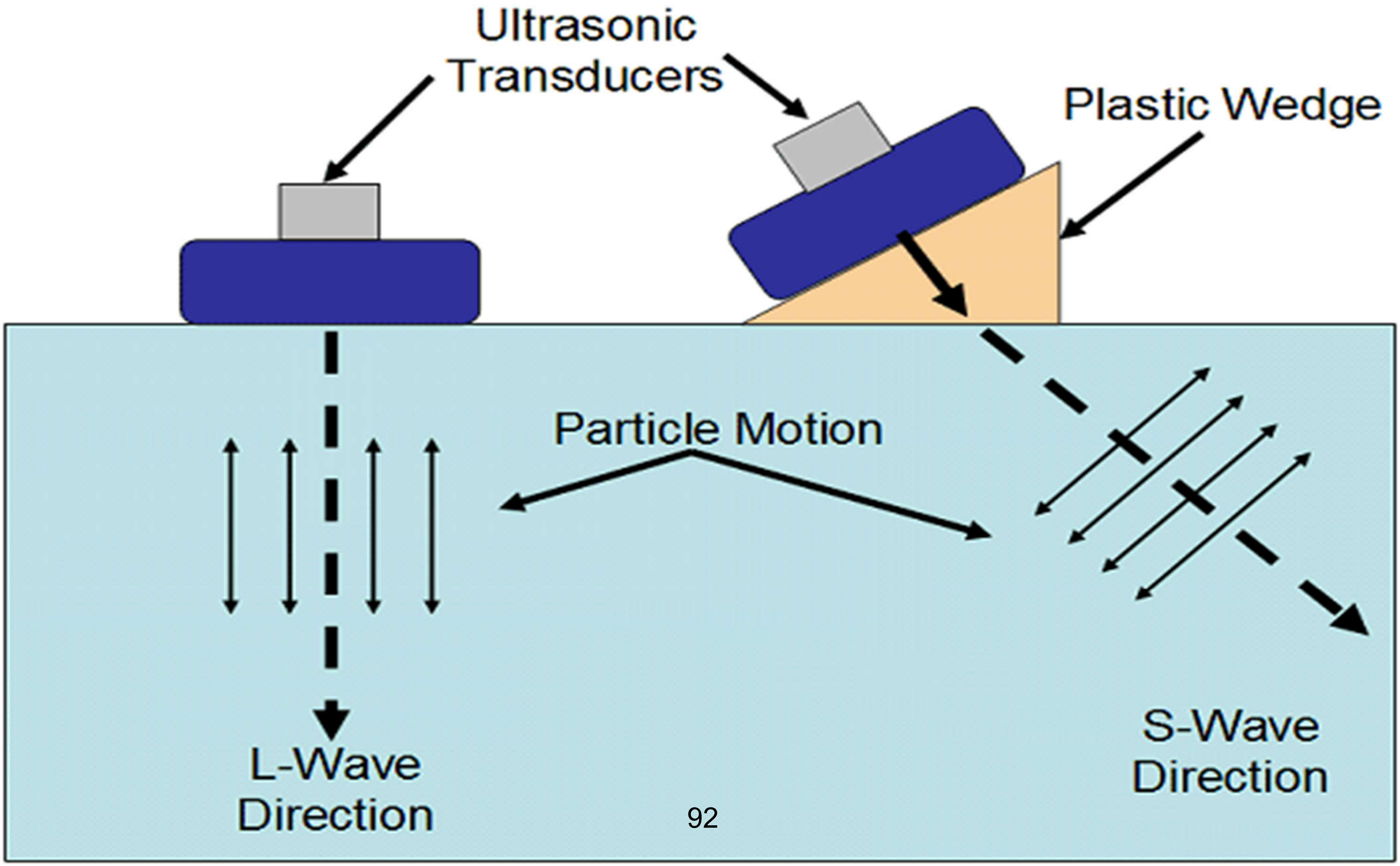

25


Porosity
Lack of fusion
Lack of penetration

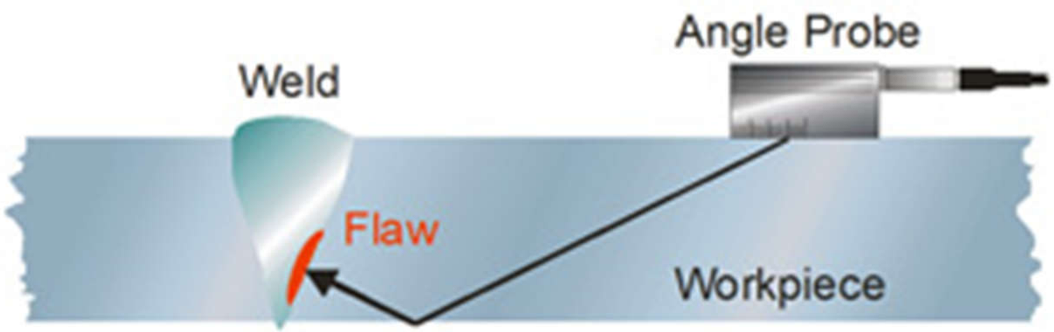
Ultrasonic Inspection

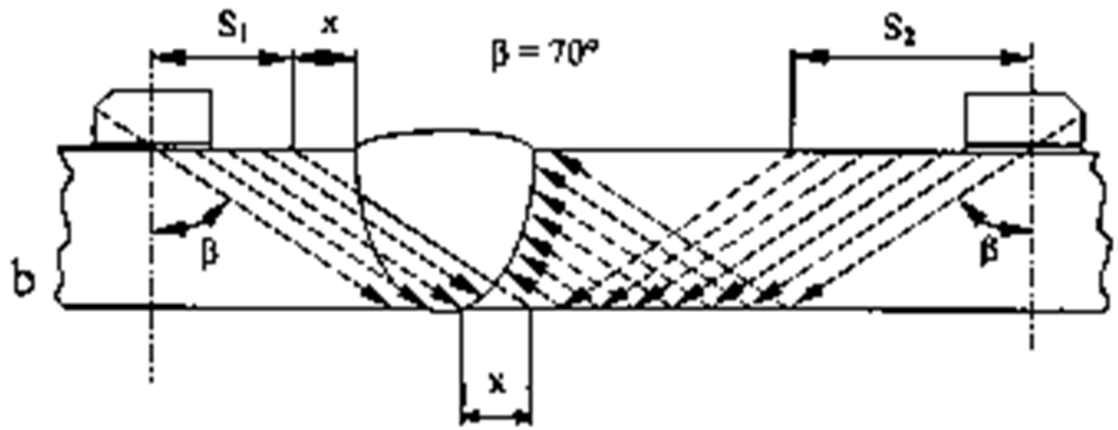
- Similar to Radar and Sonar
- Interrogate Weld Using High Frequency Waves (2-5 MHz)
- Sound Reflected Back to Transducer by Metal Air Interface (Defect)
- Portable and No Radiation Hazard

Conventional Ultrasonic Testing



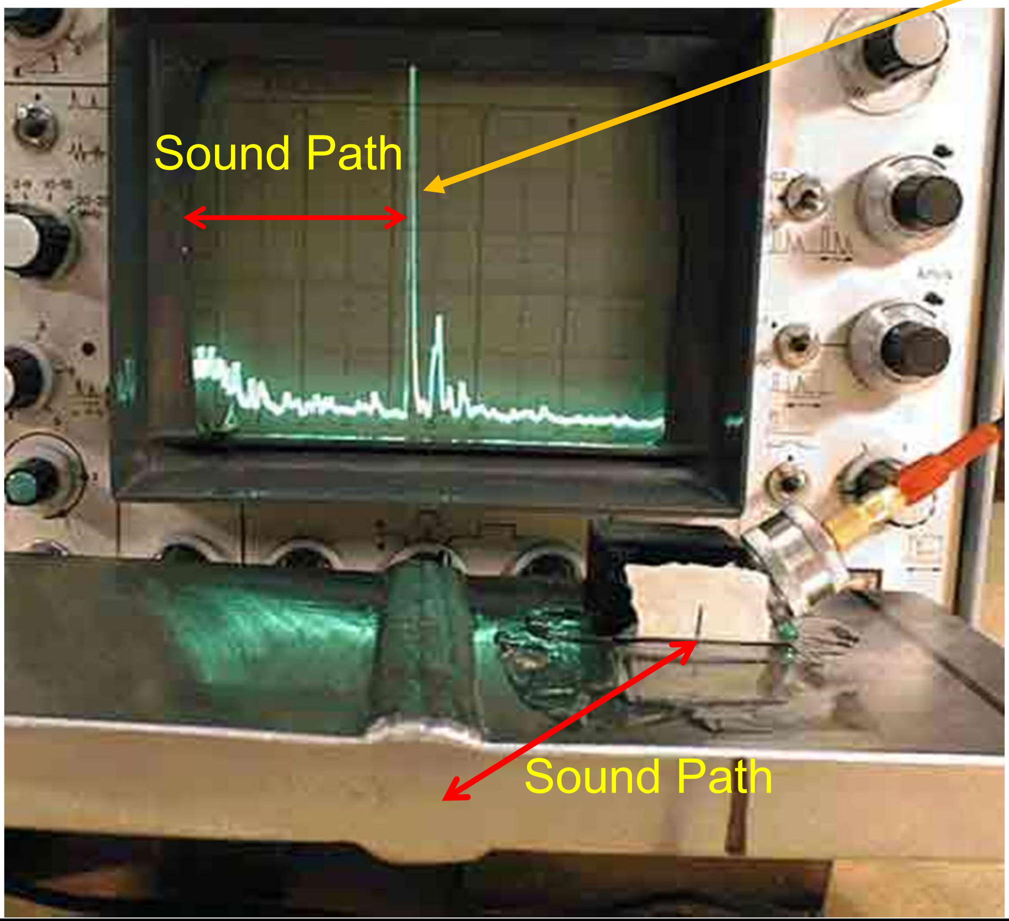
Ultrasonic Inspection



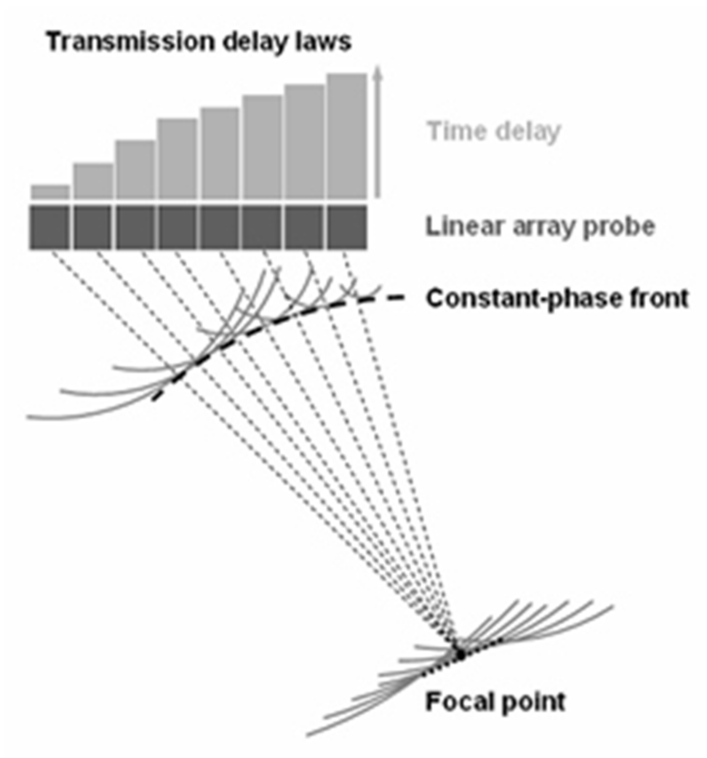


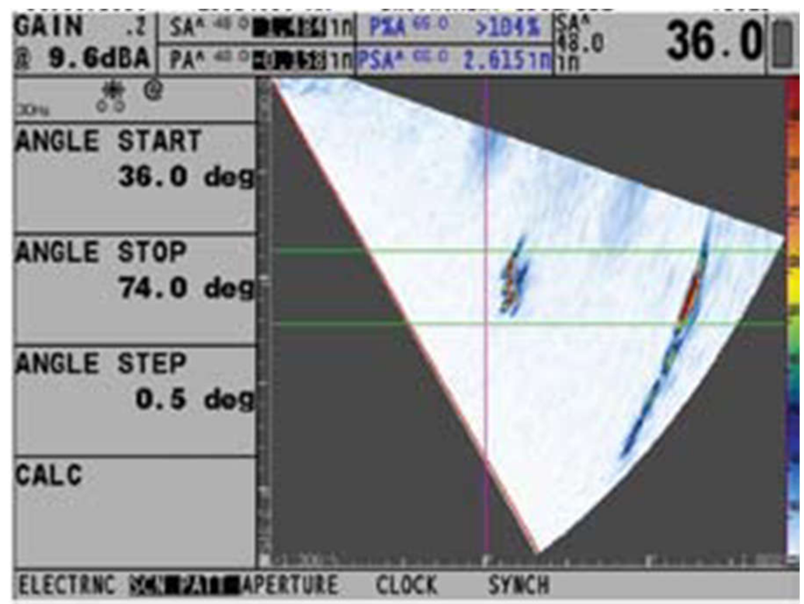
Angle Beam Testing of Weld

Amplitude of Reflected Sound Indication of Reflector Size



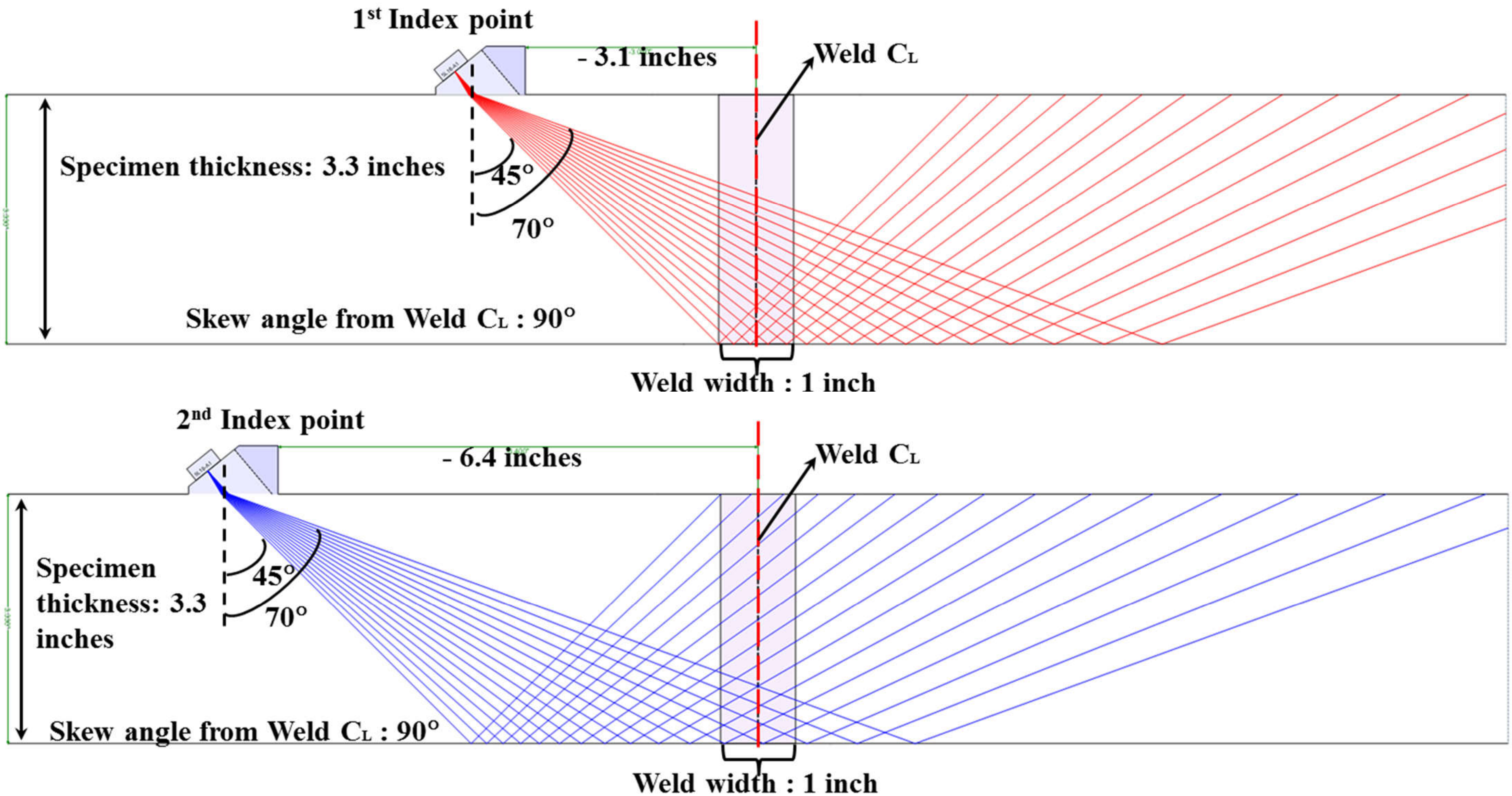
A New Technology
Phased Array Ultrasonic Inspection



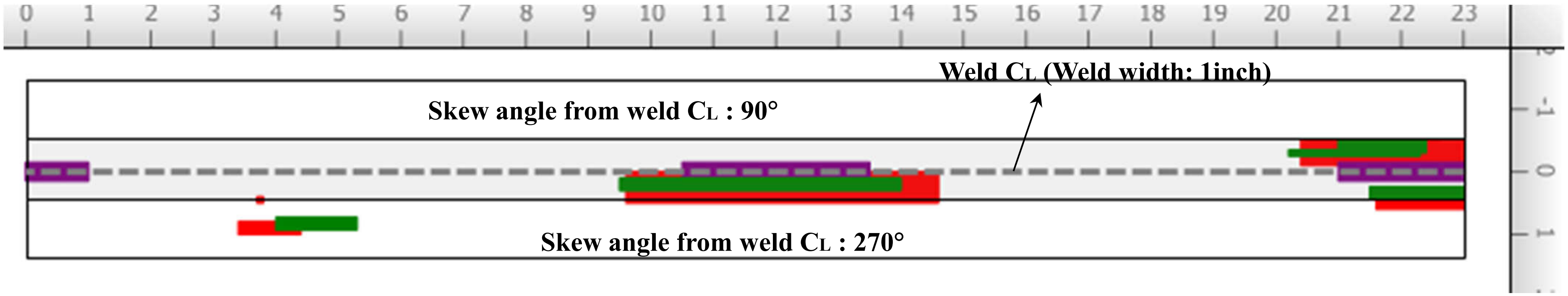


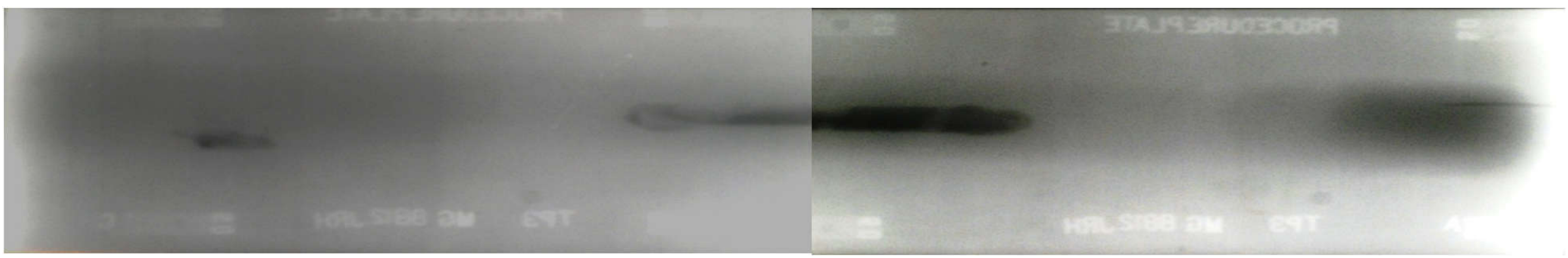
Transducer Contain Multiple Elements

Typical Scan



UT Vs RADIOGRAPHY: SPECIMEN TP3 (TOP VIEW)



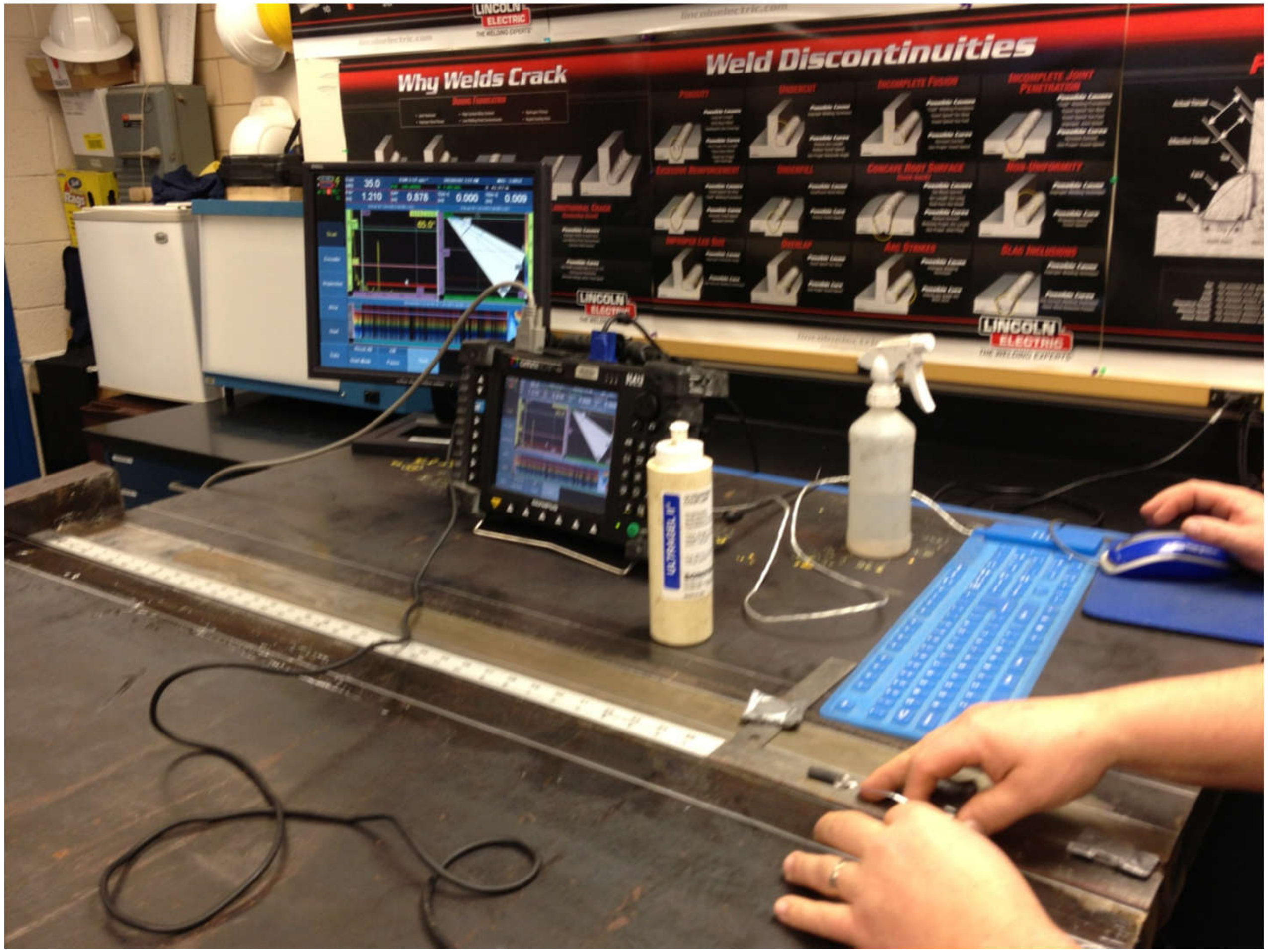


: PHASED ARRAY ULTRASONICS MEASUREMENTS AT TFHRC

: 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 Recorded Digitally

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

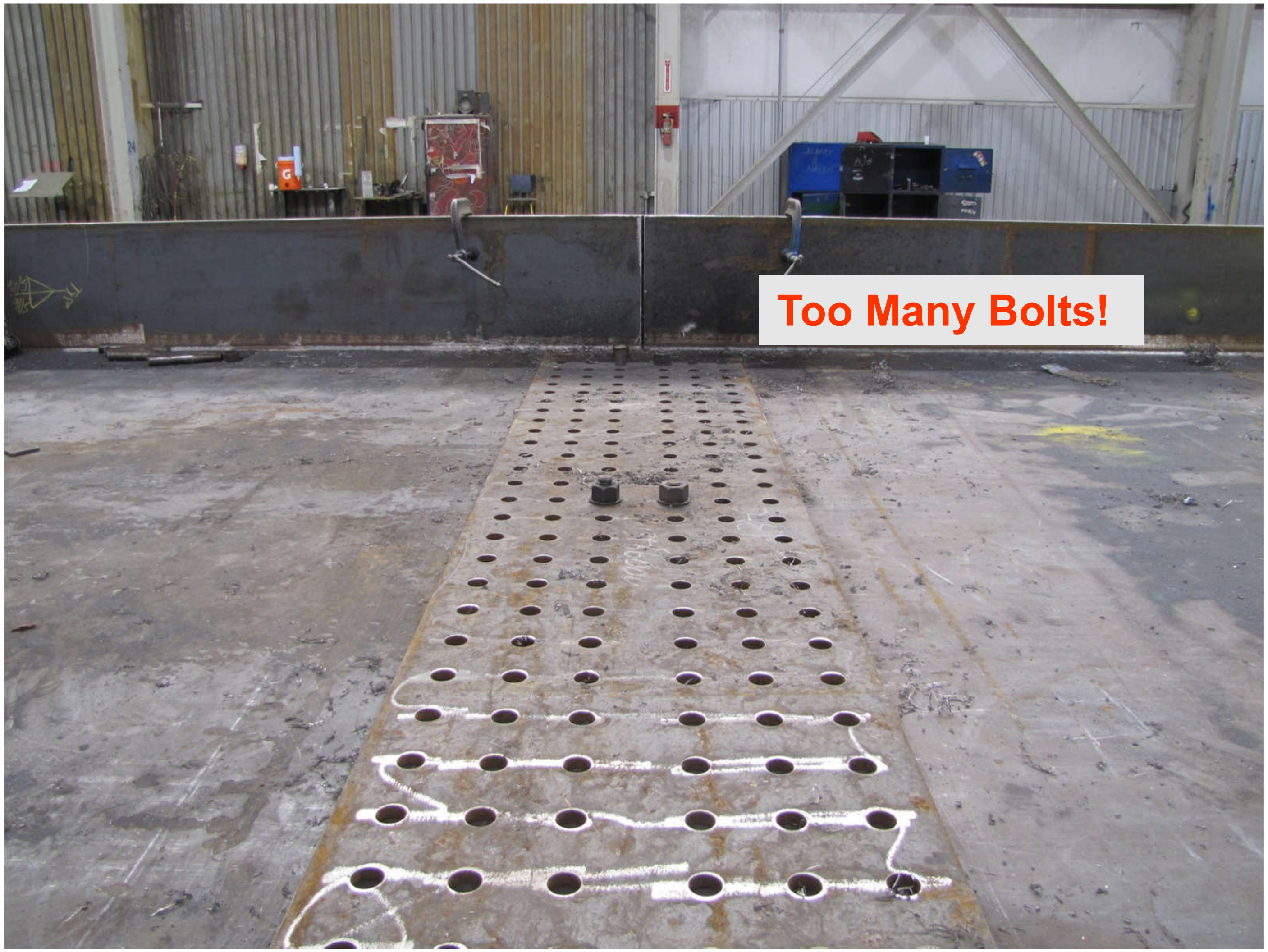
In Process Inspection

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

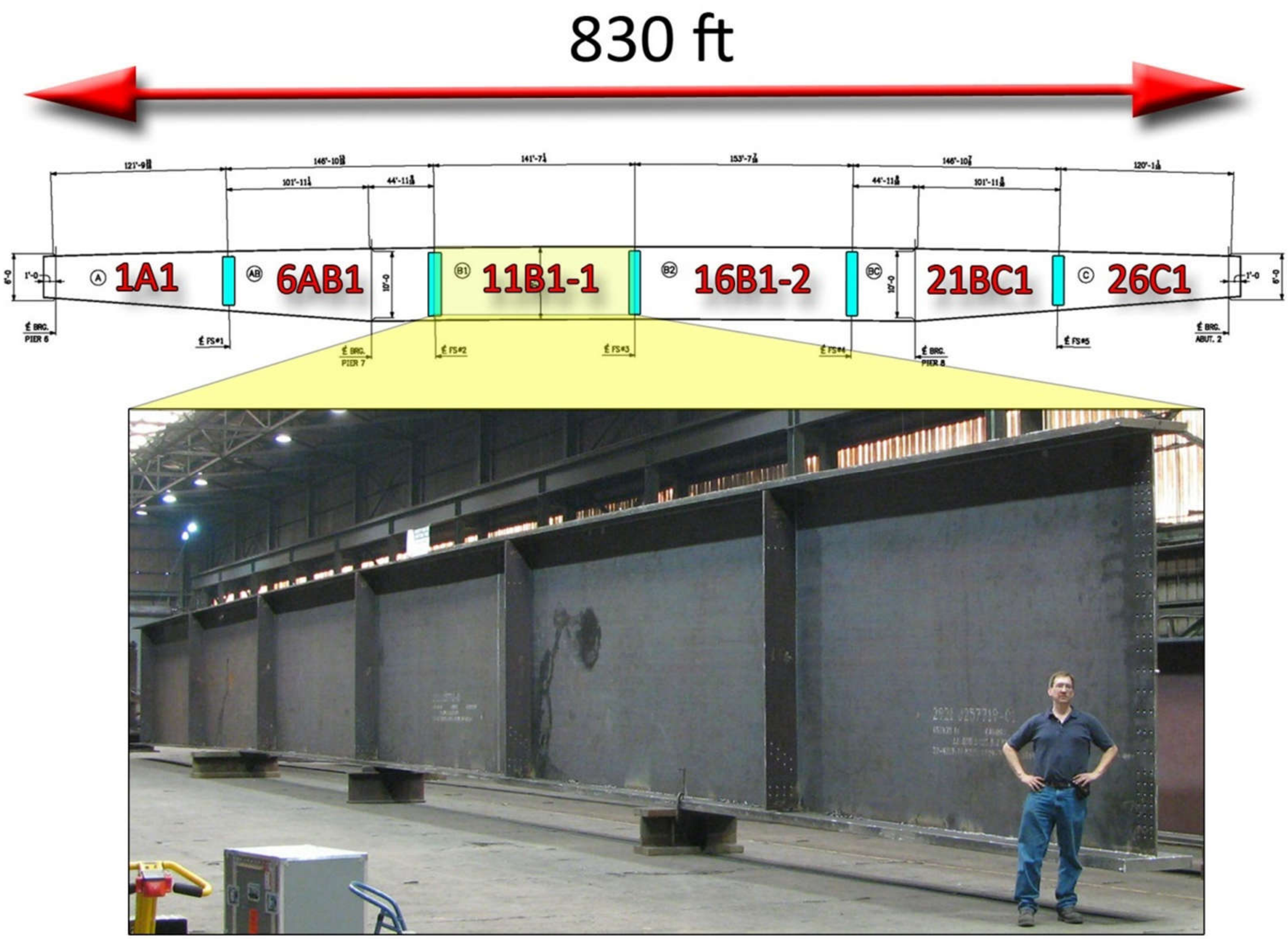
Operations:

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

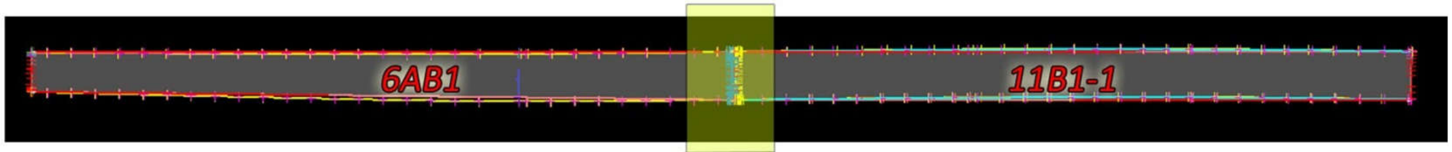
First Implementation

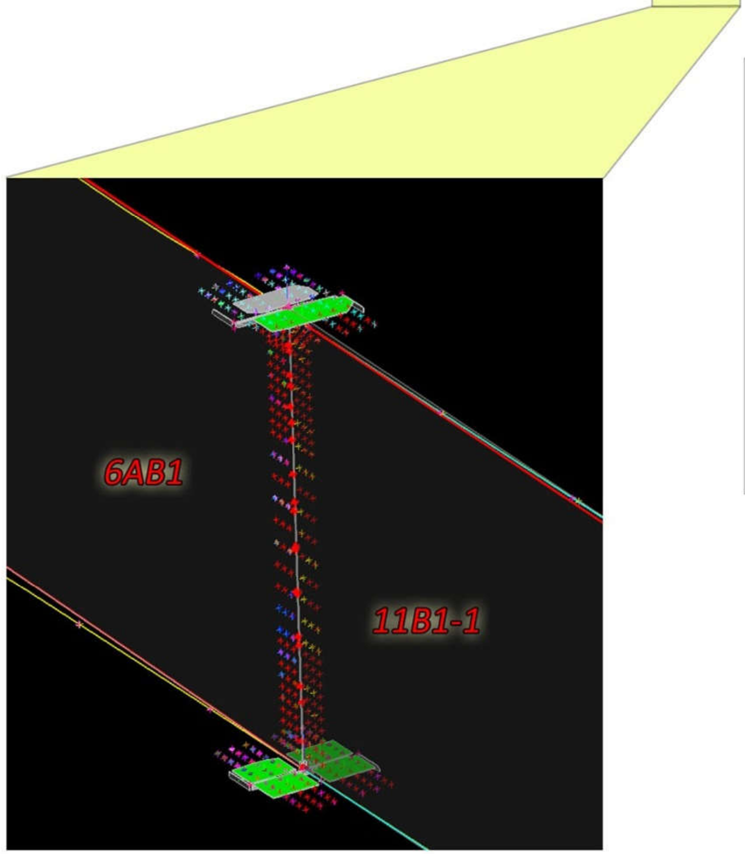
- Implemented in Virginia Sponsored Pooled Fund Study
  - Principal Investigator- Paul Fuchs (Fuchs Consulting, Inc.)
  - Tennessee DOT Bridge
  - Girder Fabrication by Hirschfeld Industries

Tennessee DOT Bridge Job

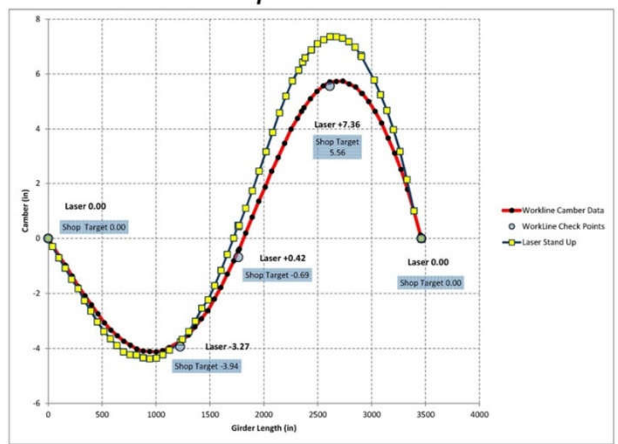


Virtual Assembly Software

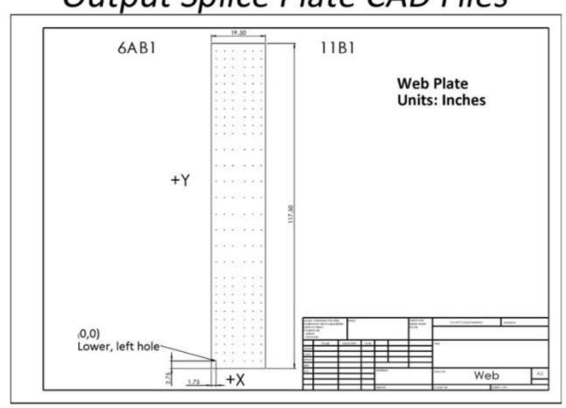




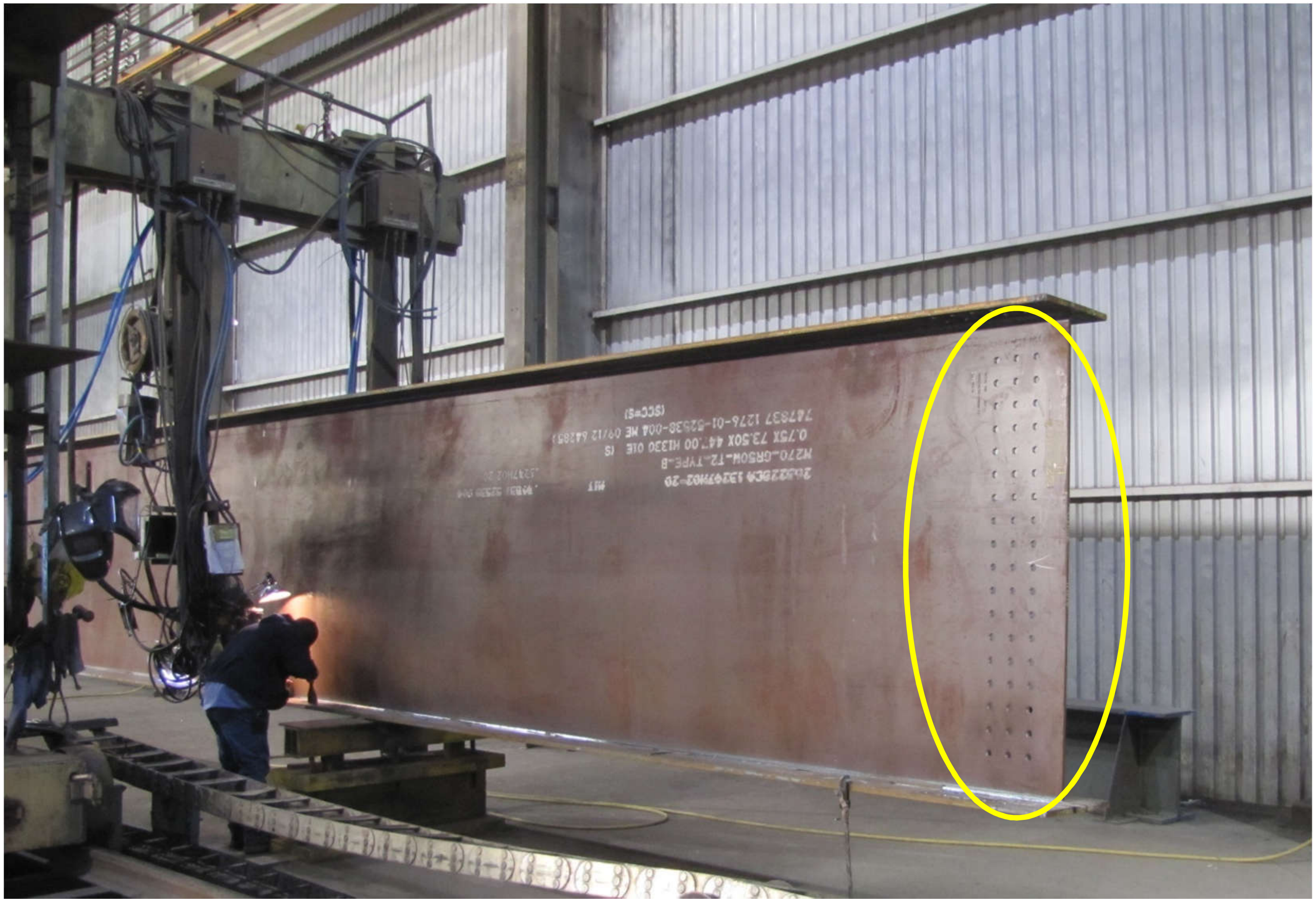
Fit-Up Work Line



Output Splice Plate CAD Files



Welding of Girder With Splice Holes

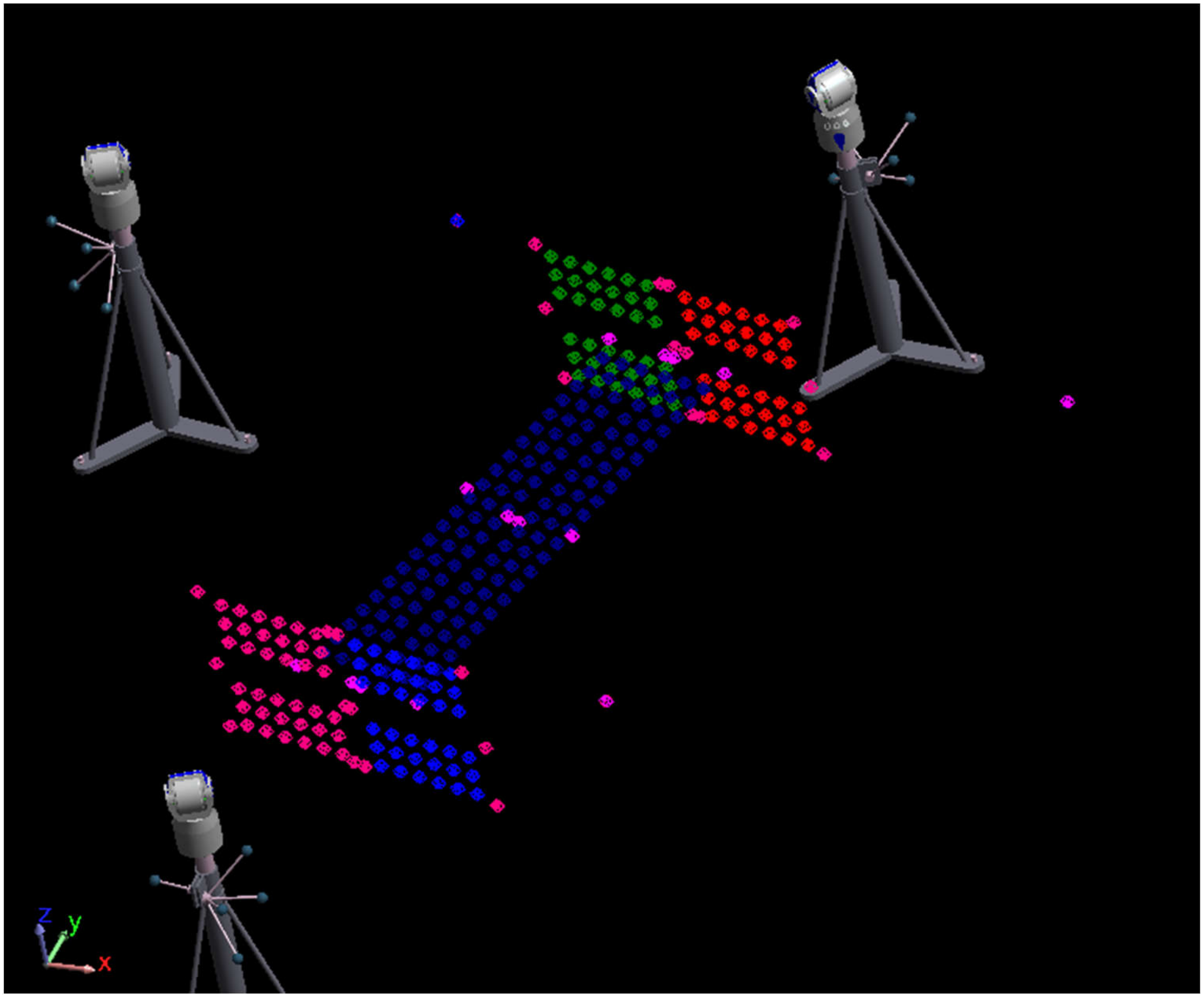


Predrilled Girders Trimmed and Adjusted for Correct Length and Camber

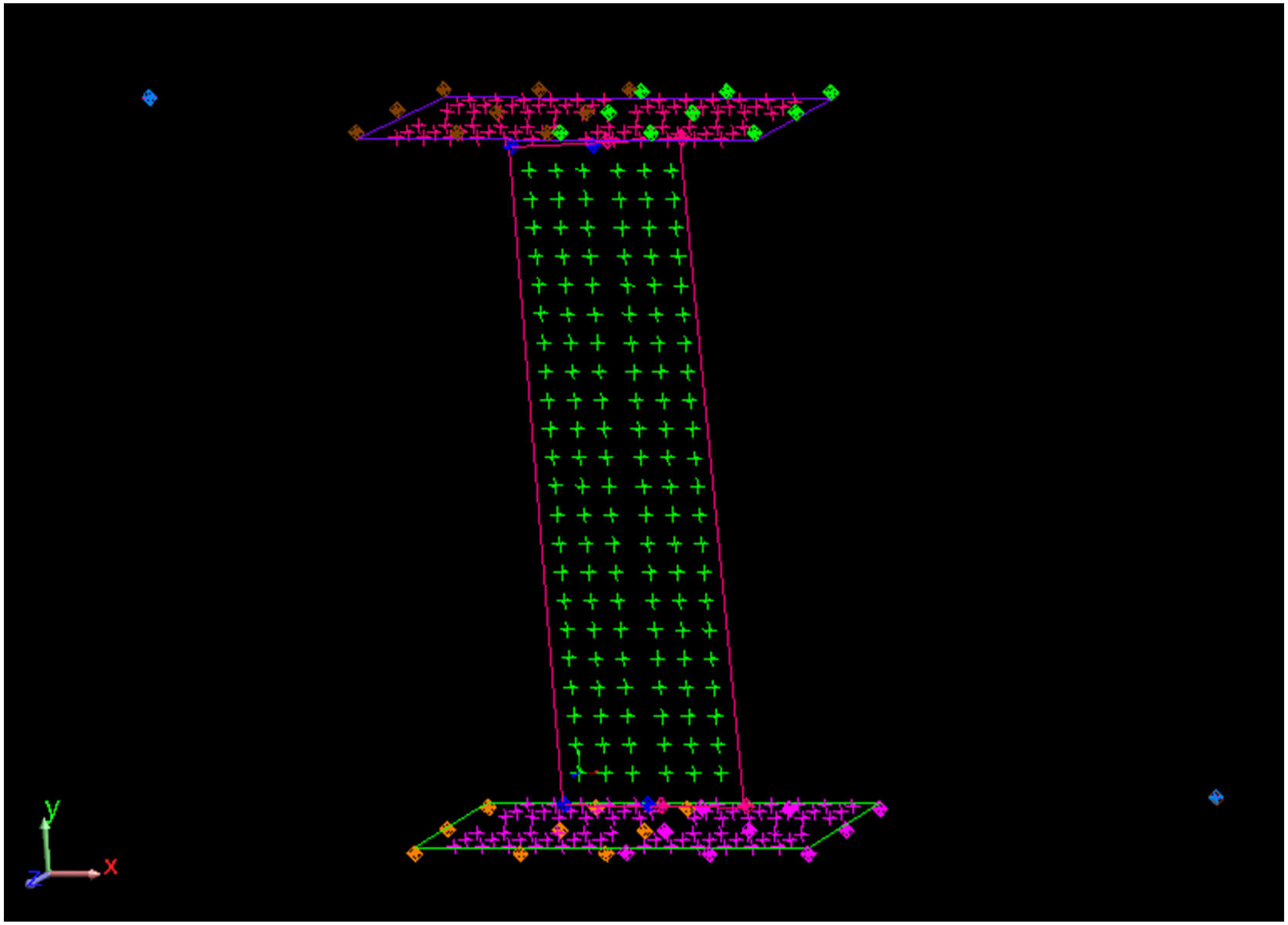
Hole Location Measurement Using Laser

The Target-SMR
Spherically Mounted Retroreflector

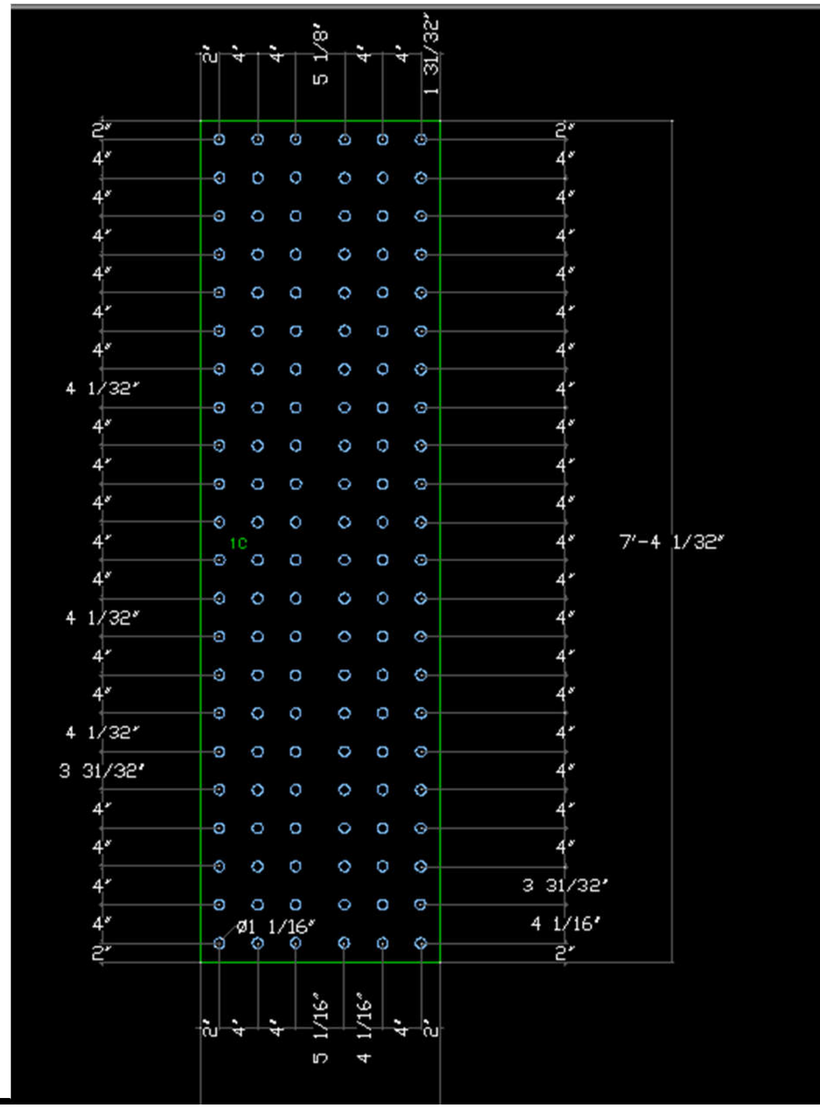
Scan Ends of Girders in Lay Down



Development of Splice Plate Geometry

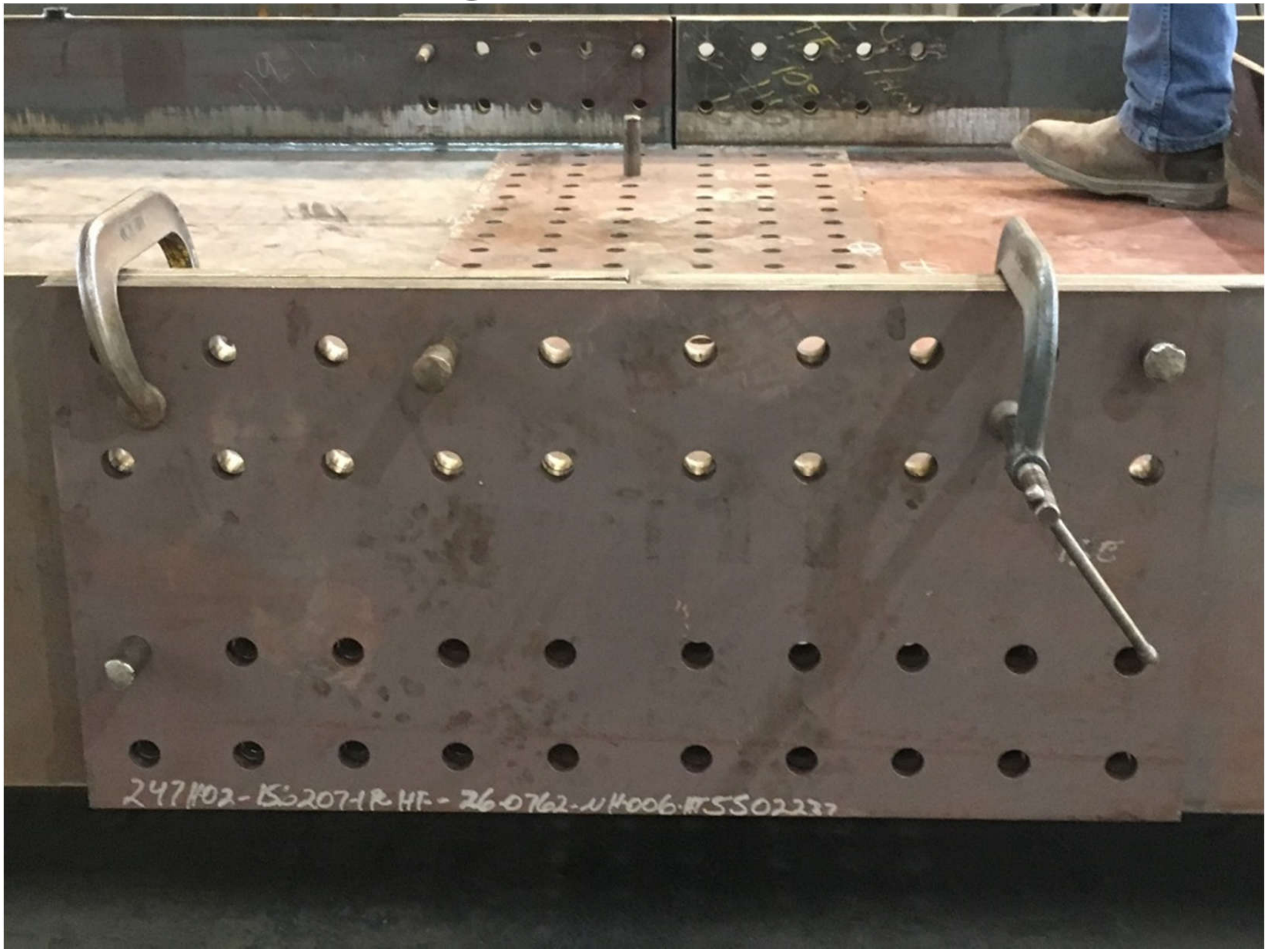


Splice Plate Detailed in Autocad



Check of Splice Plate Fitup

Flange Splice Fit



It Fits!

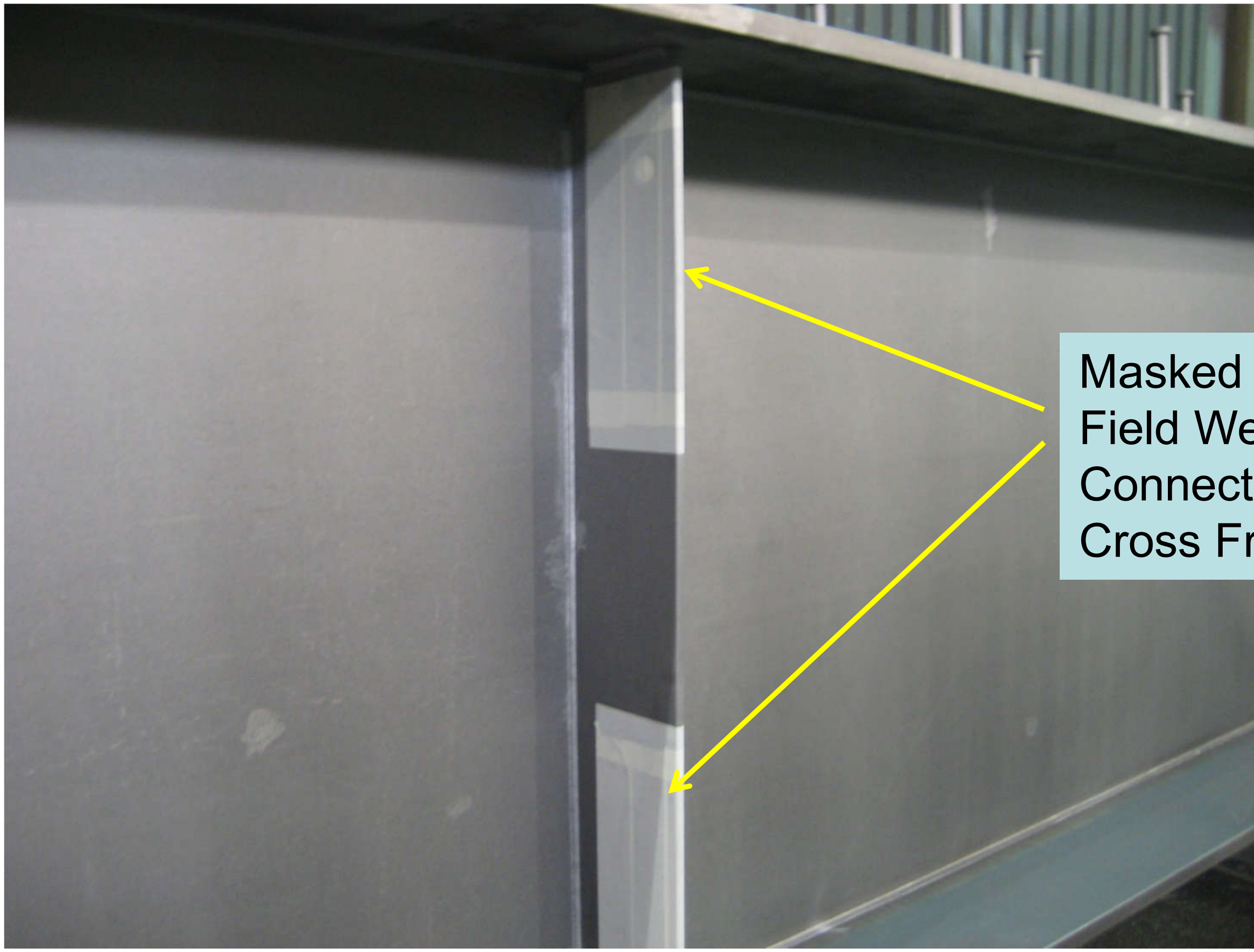
State of the Art

- 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?