Manufacturable Orthotropic Steel Deck Bridges

TRANSPORTATION ASSET AND INFRASTRUCTURE MANAGEMENT CONFERENCE

PENNSYLVANIA STATE UNIVERSITY

OCTOBER 25, 2019

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FHWA is the source for all images in this presentation unless otherwise noted.

U.S. Department of Transportation

Federal Highway Administration

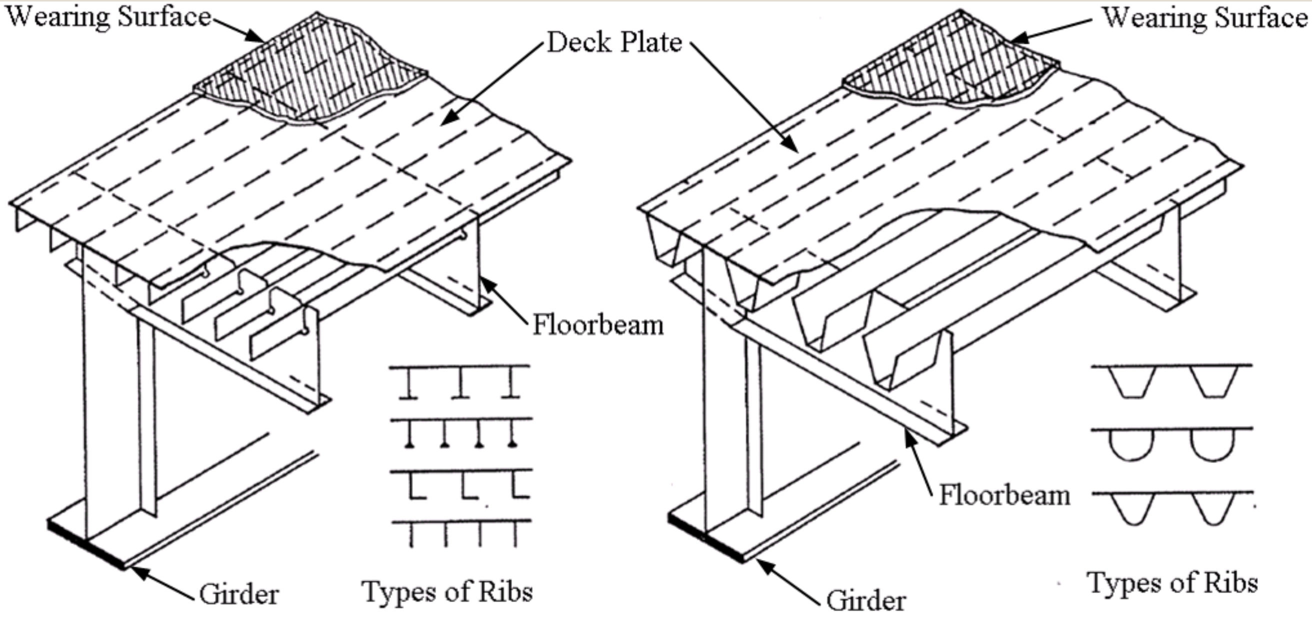
Office of Infrastructure

Motivation

- The bridge deck is the first line of defense against truck loads and environmental attack
- Many decks in U.S. designed for early replacement, but we need not accept that a bridge deck is "disposable"
- Orthotropic steel deck (OSD) is modular, manufacturable, lightweight, and durable
- OSD not widely used in the U.S. due to lack of experience and concerns of fatigue

Background

- What is "orthotropic steel deck?"
  - Steel deck plate with stiffening ribs and floorbeams to provide load distribution in 2 orthogonal directions



(a) Deck with Open Ribs

(b) Deck with Closed Ribs

Recent U.S. Bridges with OSD

- Carquinez Bridge (shown)
- New Tacoma Narrows
- Bronx Whitestone Redeck
- San Francisco Oakland Bay Bridge
- Verrazano Narrows Redeck
- Throgs Neck Redeck

U.S. Design References

- *FHWA Manual for the Design, Construction, and Maintenance of OSD Bridges (2012)*
  - Commentary, discussion, design examples
- *AASHTO LRFD Bridge Design Specs*
  - Expanded OSD specs in 2012
  - Strength, Service, Fatigue limit states
  - Detailing provisions

Publication No. FHWA-IF-12-027
February 2012

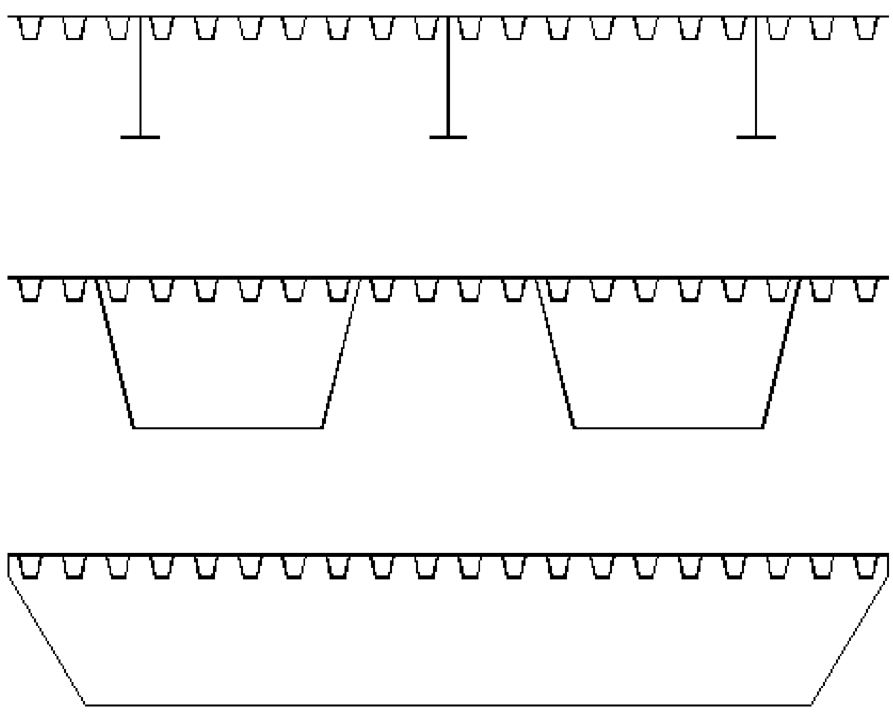
US DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

MANUAL FOR DESIGN, CONSTRUCTION, AND MAINTENANCE OF ORTHOTROPIC STEEL DECK BRIDGES

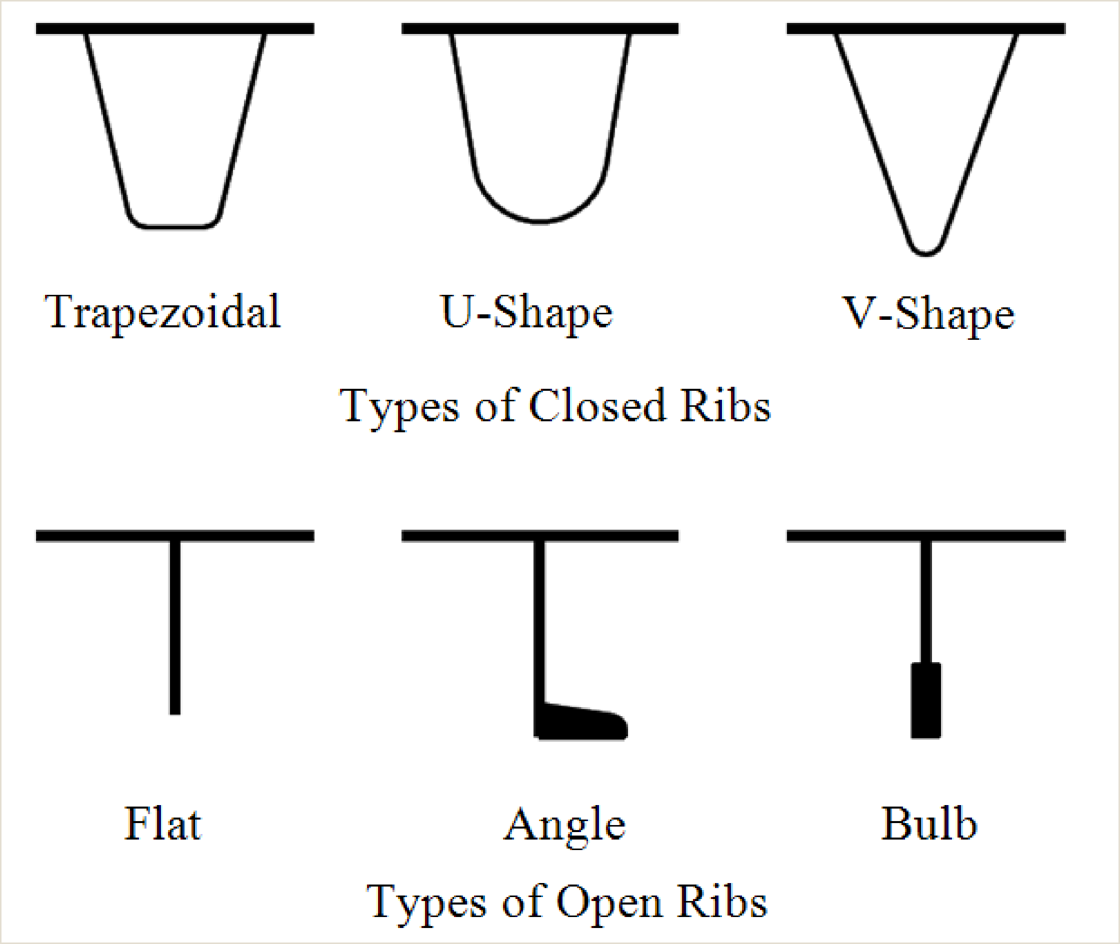
https://www.fhwa.dot.gov/bridge/pubs/if12027/if12027.pdf

Typical Bridge Sections

- Examples of OSD bridge cross sections
- Deck design is similar for each

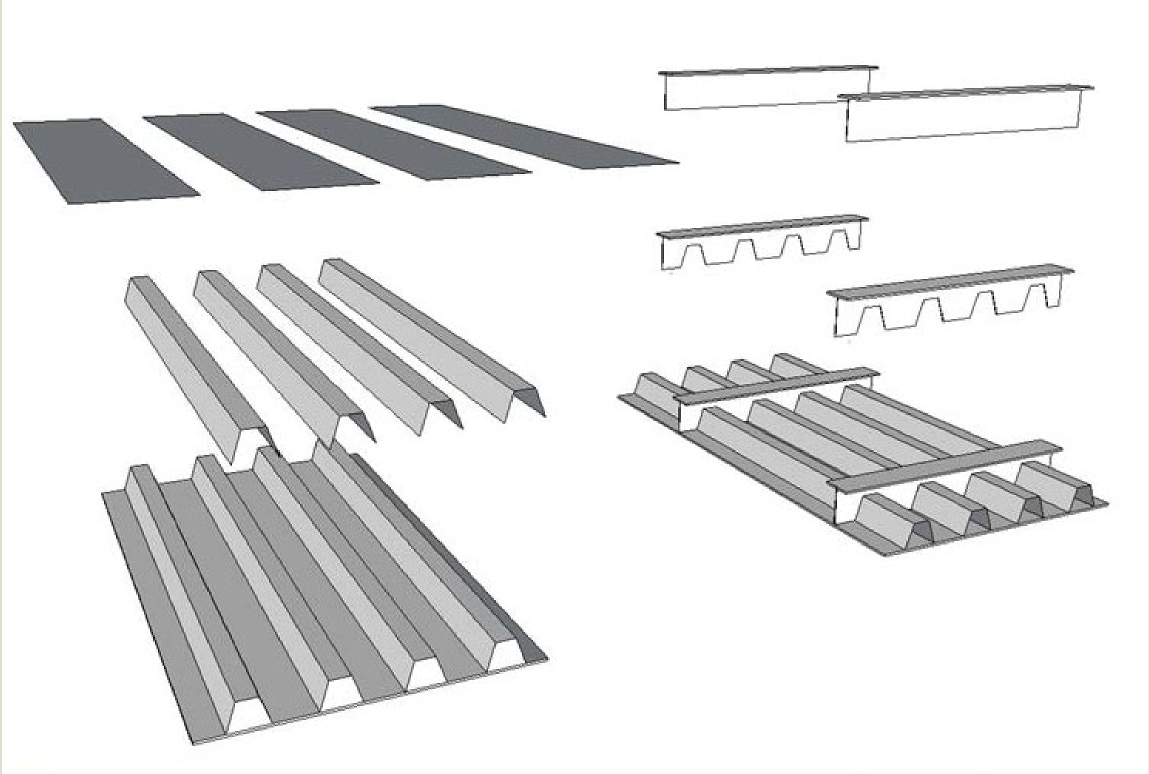


Typical Rib Sections



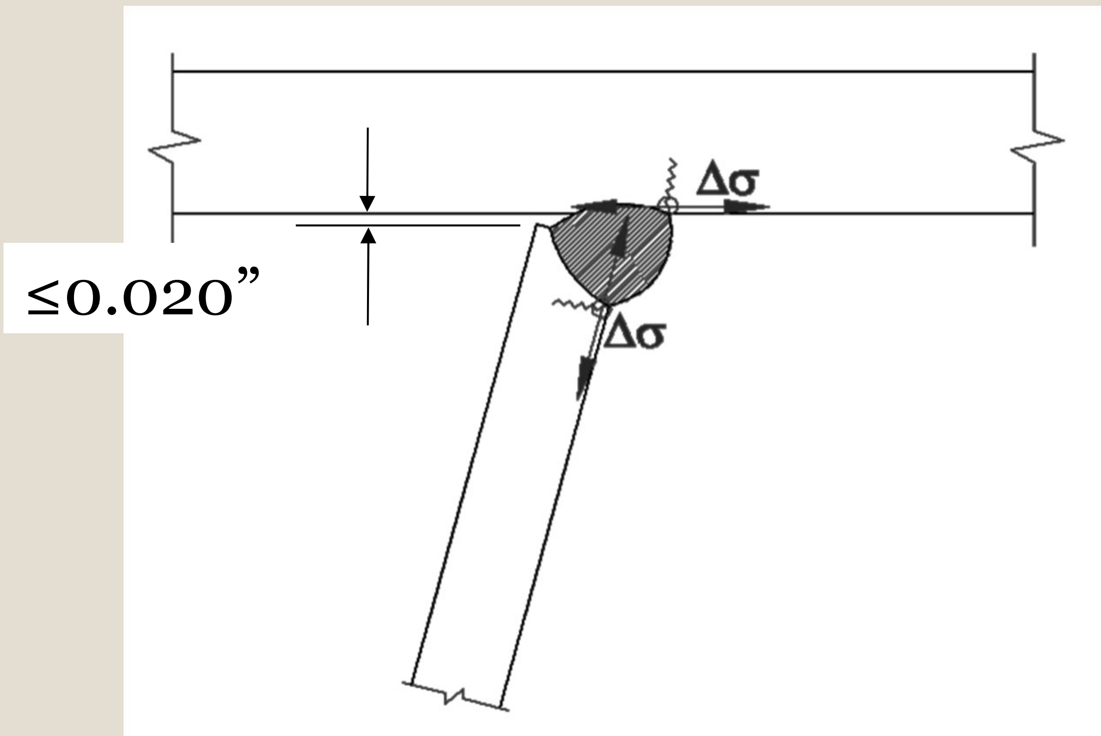
Fabrication

- Requires specialized techniques
- Tolerances often difficult to control



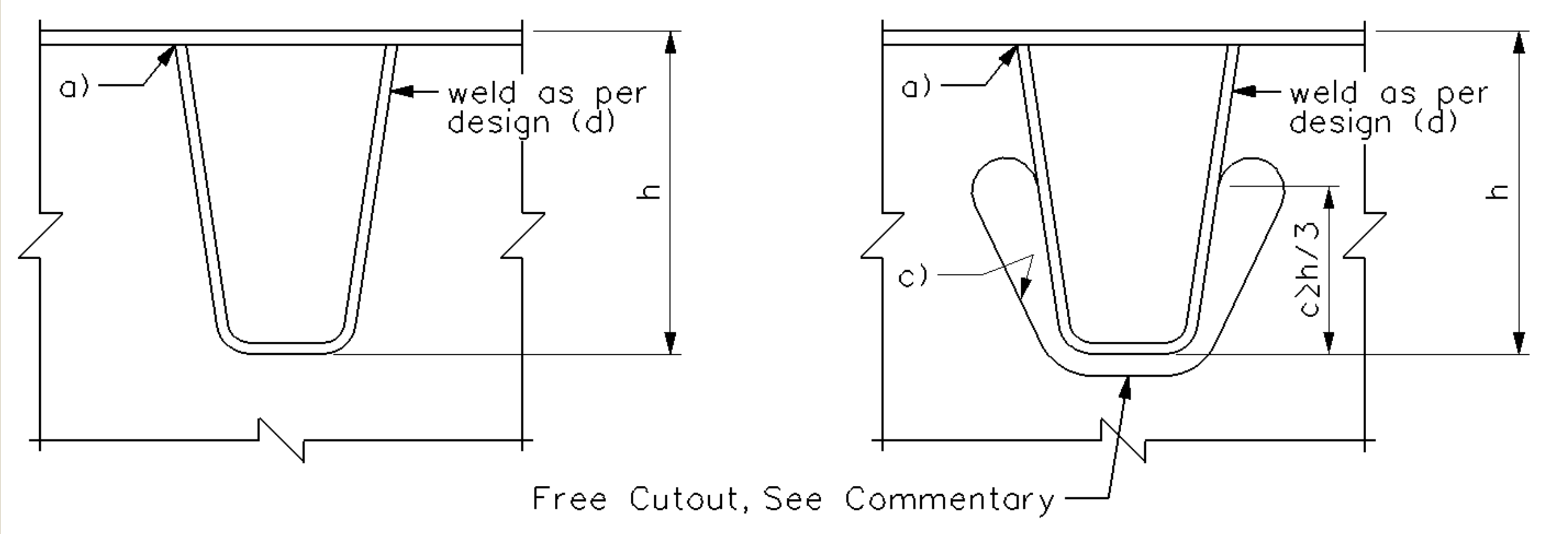
Details

- Rib to deck welding (closed rib)
  - One sided partial penetration
  - 60% min. penetration with 0.02” tight fit prior to welding



Details

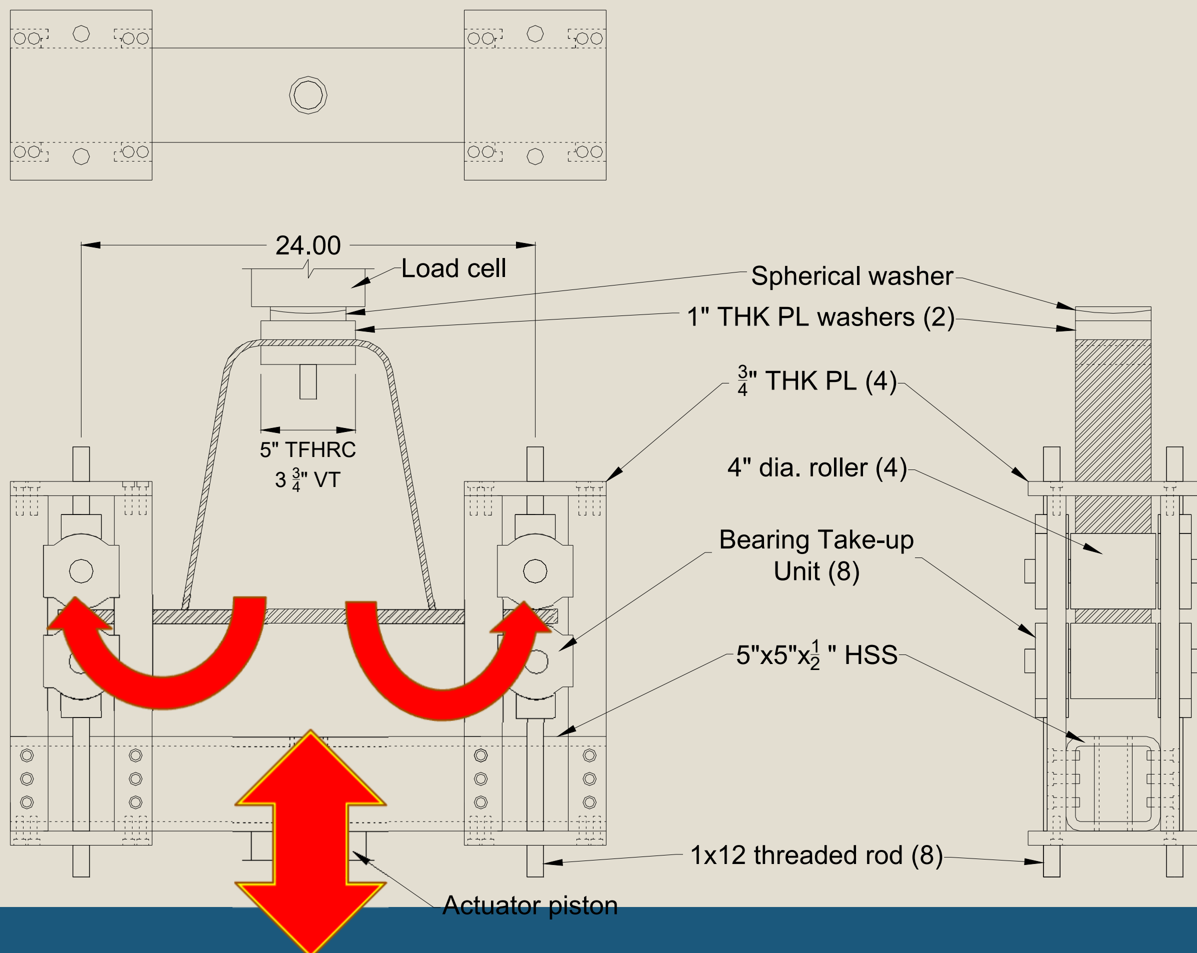
- Rib to floorbeam
  - Cutout AND no-cutout are viable options
  - Weld details by design



FHWA OSD Research Efforts

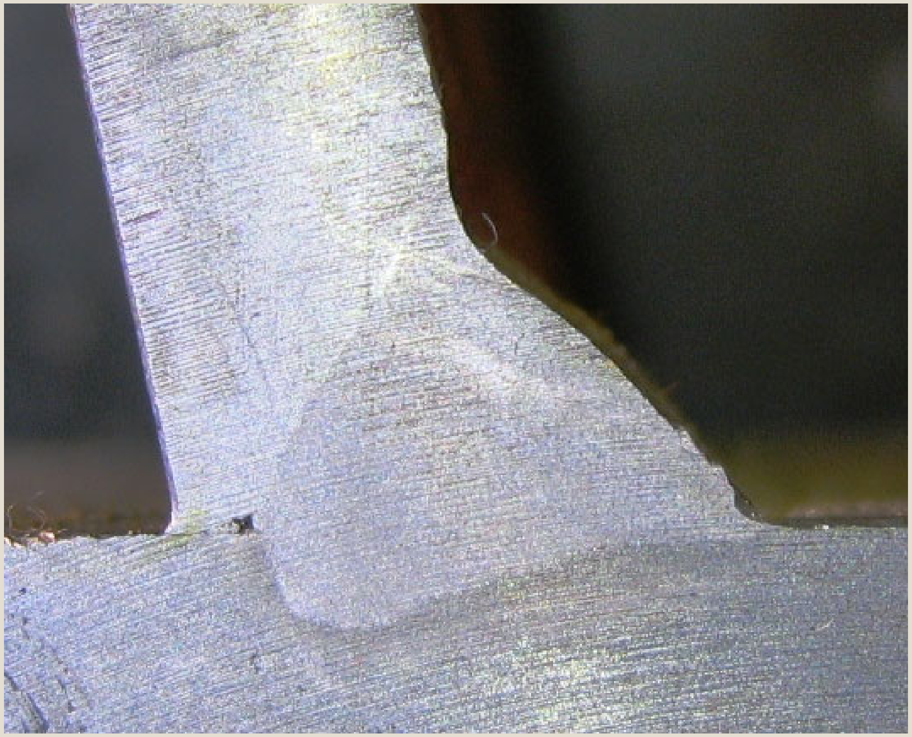
FHWA Rib to Deck (RD) Weld Research

- Tests run on full scale 4” sub-assembly

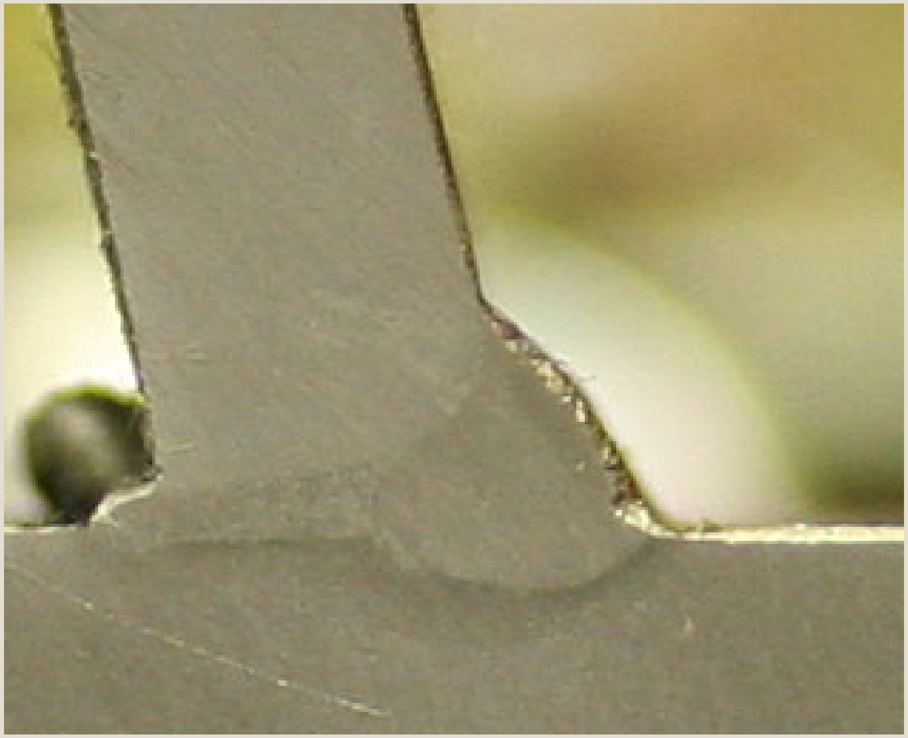


FHWA RD Weld Research

- 185 specimens tested with variations in penetration, root gap, weld process, etc.

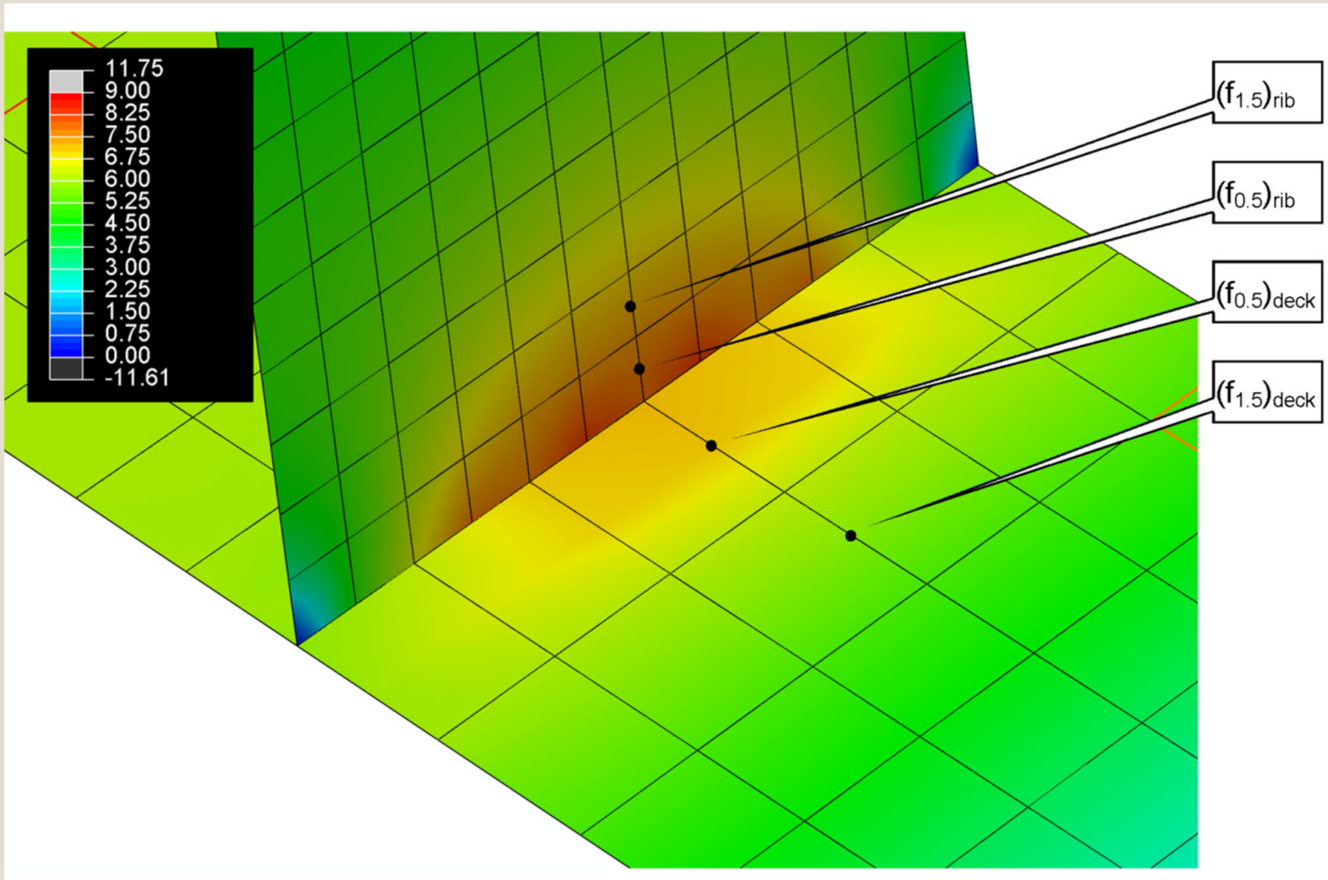


Gas metal arc welding (GMAW)



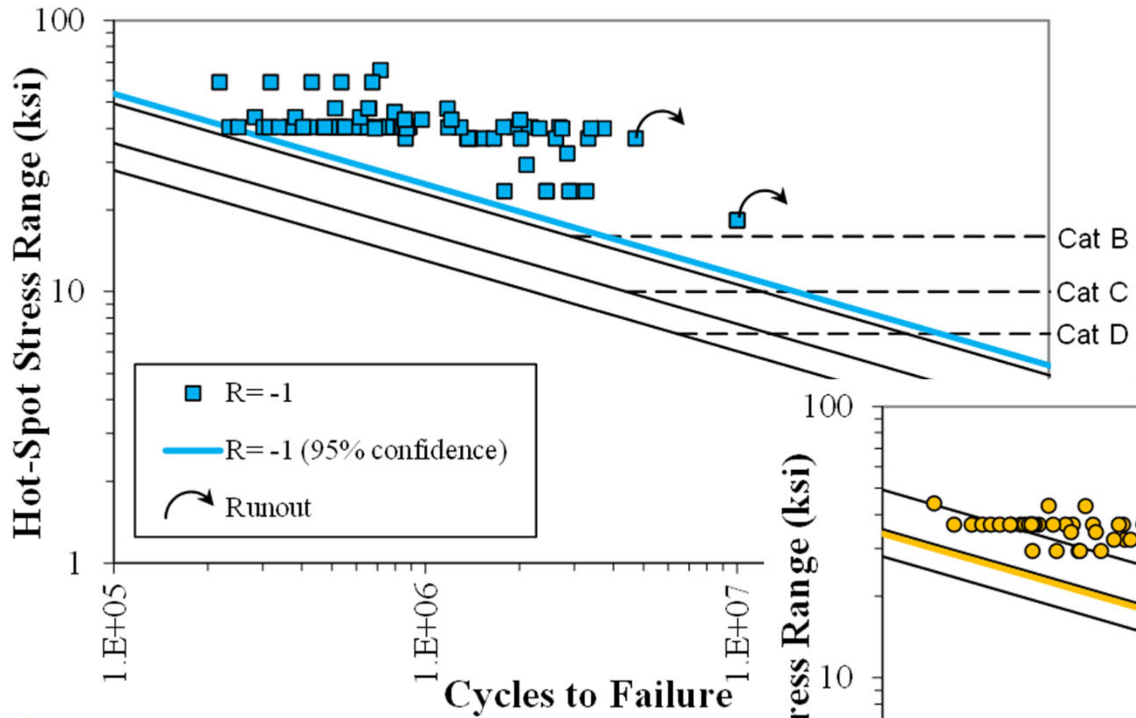
Hybrid Laser Arc Welding (HLAW)

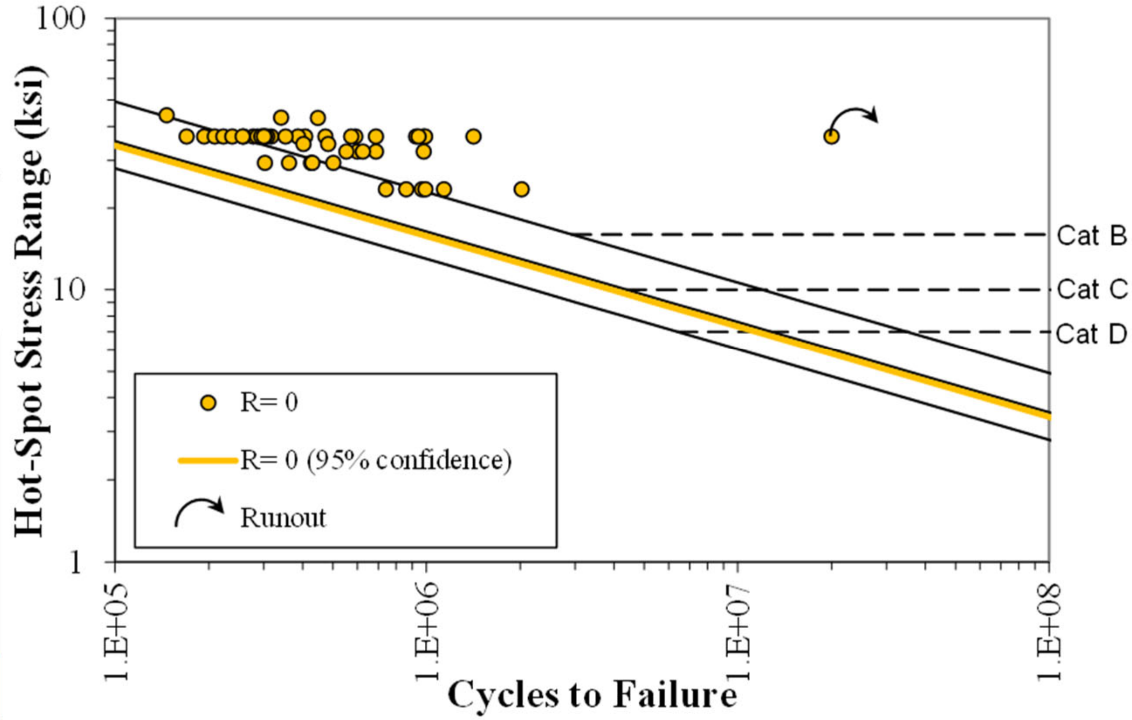
FHWA RD Weld Research



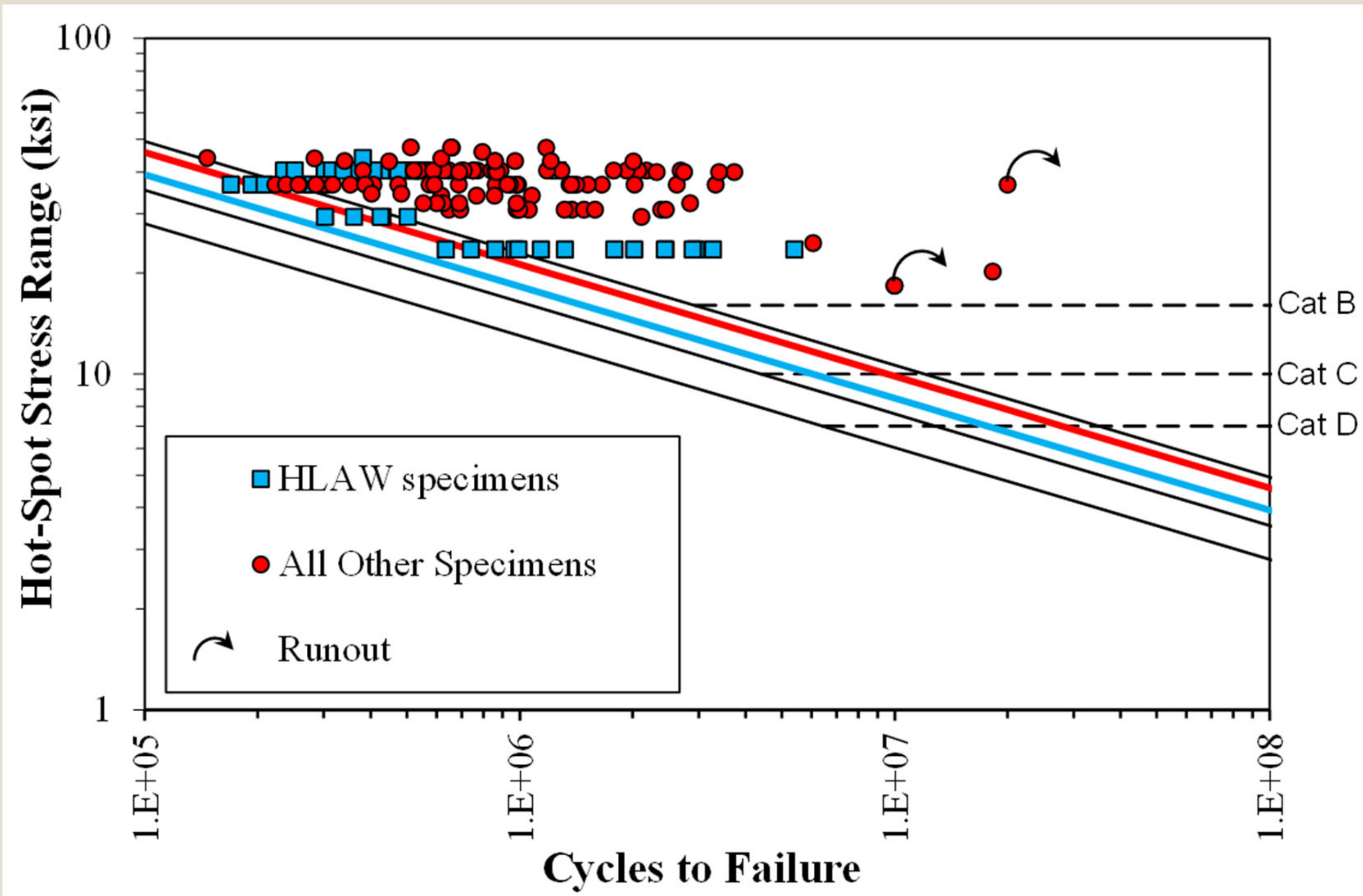
Used FEA to define local structural stress (Level 3 Design, Article 9.8.3.4.4)

RD Weld Fatigue Test Results

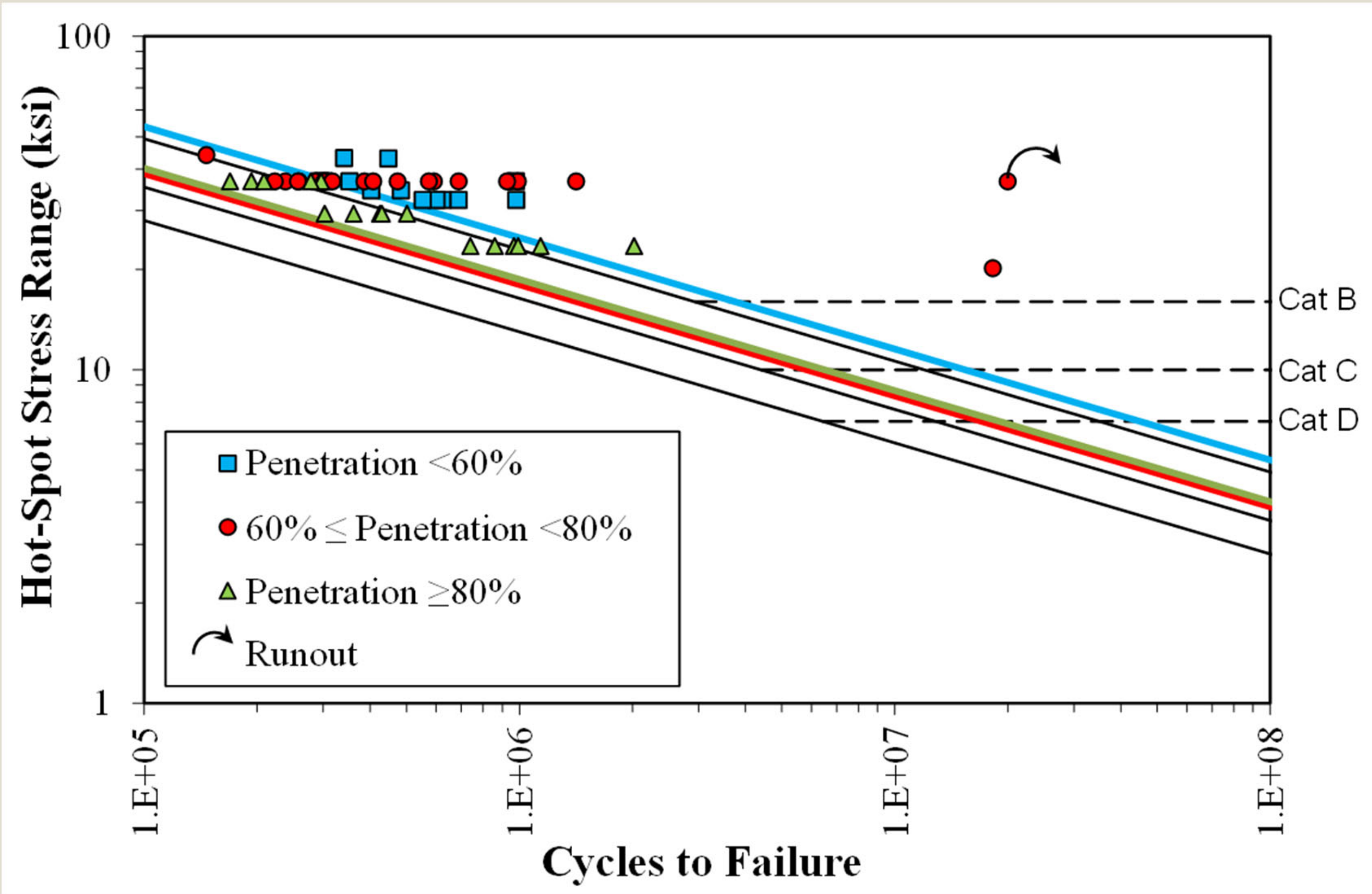




RD Weld Fatigue Test Results

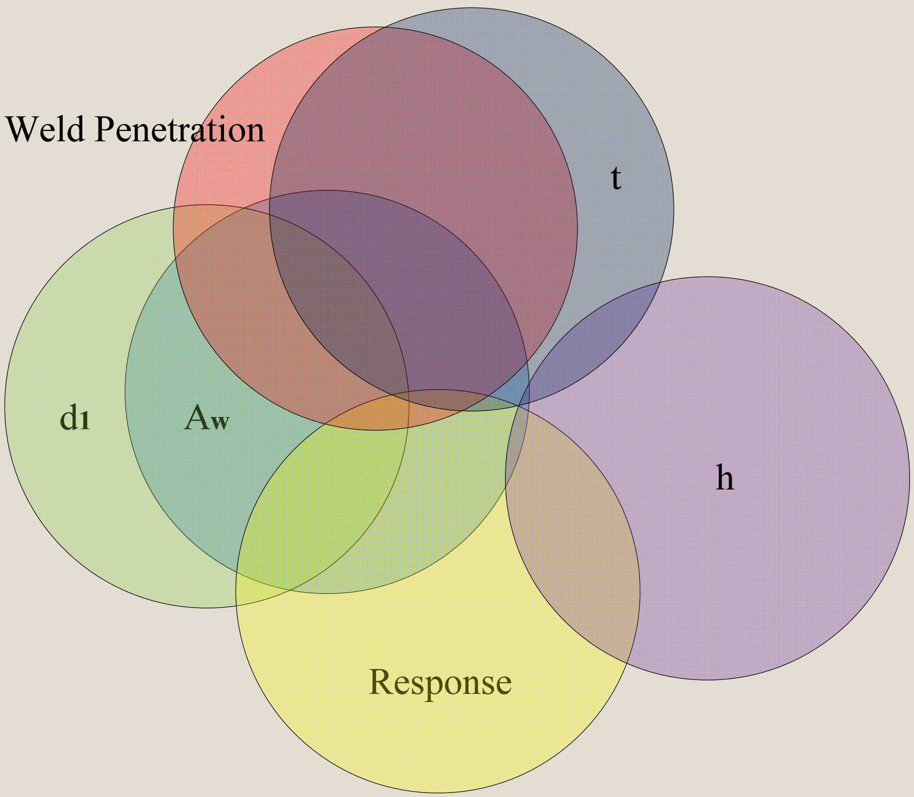


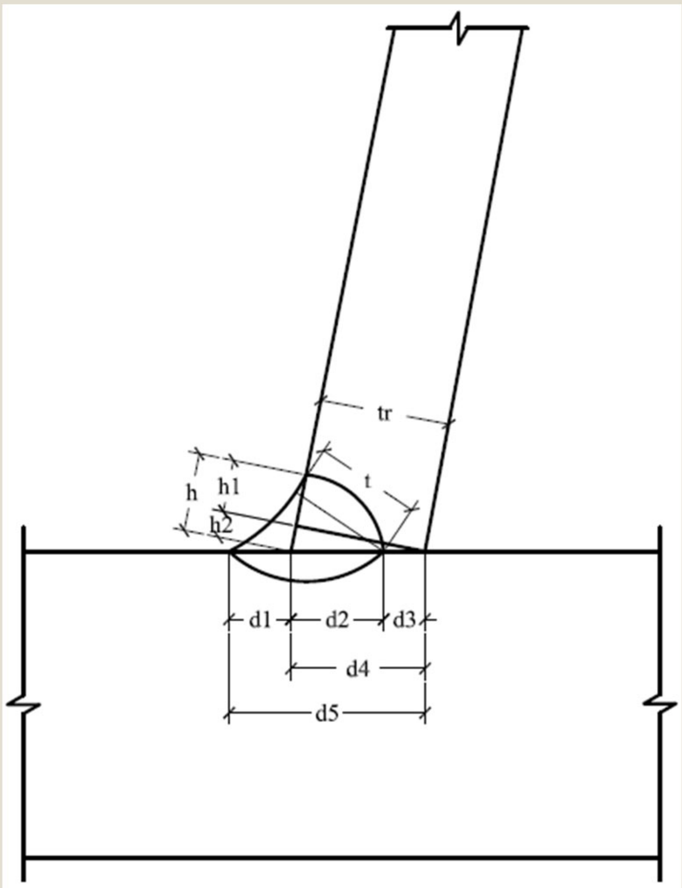
RD Weld Fatigue Test Results



RD Weld Parameter Study

- Correlation to resistance determined through regression





RD Weld Geometry Recommendation

- Tests on rib-to-deck (RD) weld safely show AASHTO Category C performance
- RD weld penetration is less important; weld area, throat, and leg size are more important to fatigue performance
- RD weld root gap is important to control. 0.02” provides closure to root after welding

RD Weld Geometry Recommendation

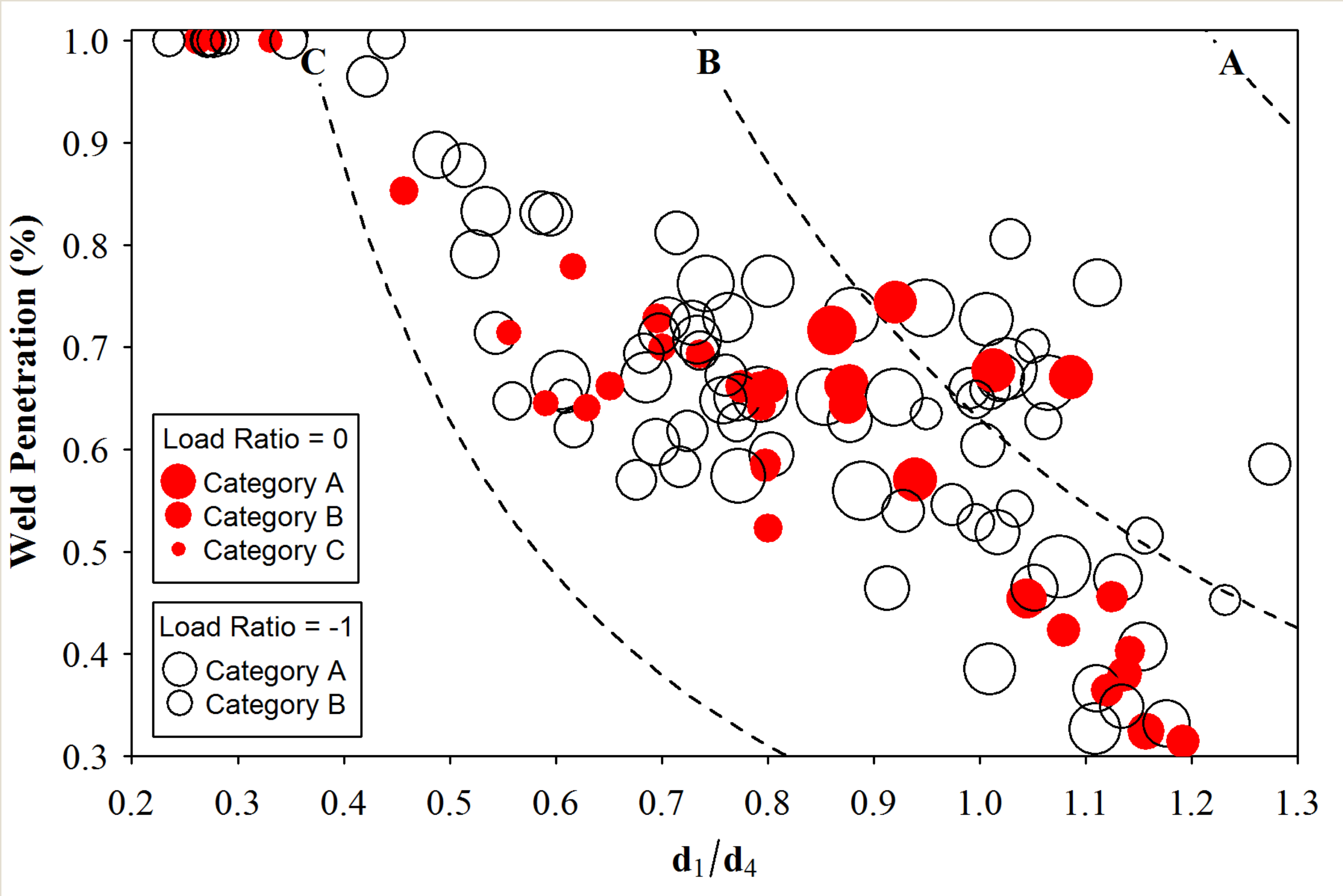
- After lots of hand cranks and simplifications:

$$\mathbf{0.222}\left(\frac{d_1}{d_4}\right)^{-1.50} \leq \left(\frac{d_2}{d_4}\right)$$

Leg Length on Deck Plate

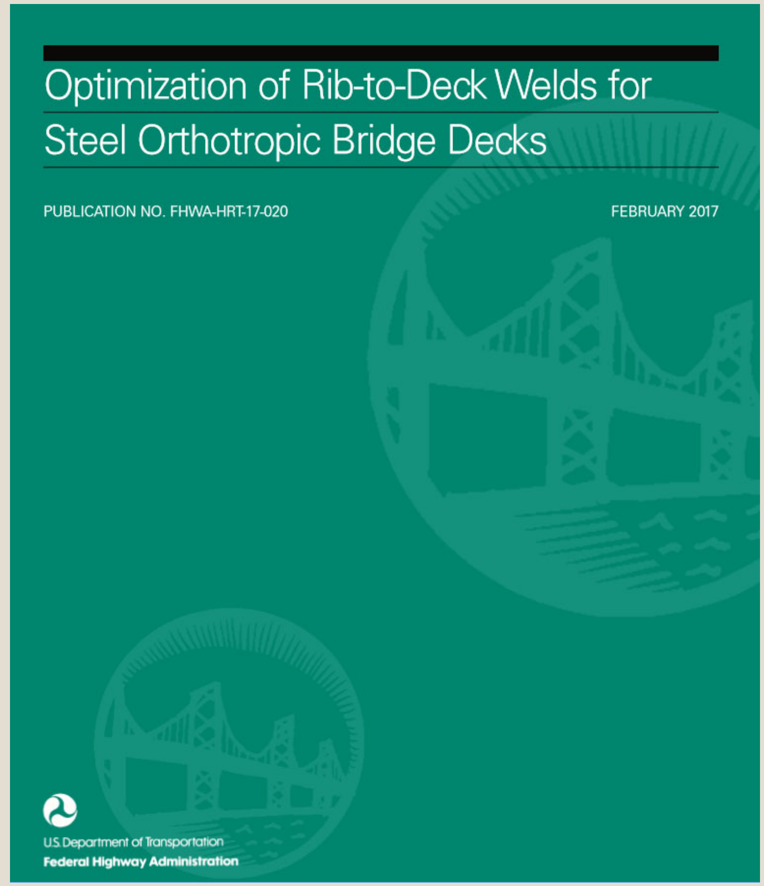
Penetration

Regression Results



FHWA Research Report

- The results of testing and recommendations are published in FHWA report



https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/17020/17020.pdf

Specification Recommendations

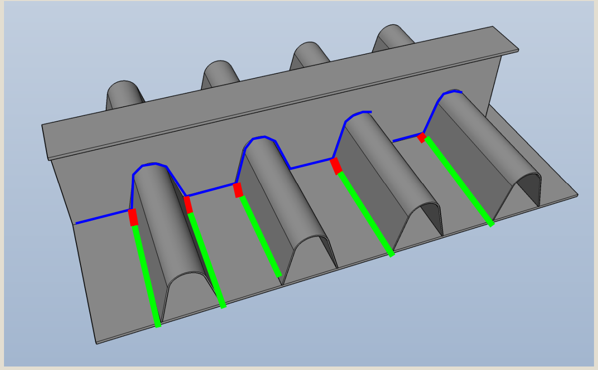
LRFD Article 9.8.3.6.2 – Closed Ribs. The one-sided weld between the web of a closed rib and the deck plate shall have a minimum penetration of *60* percent and no blow-through, and shall be placed with a tight fit providing less than or equal to a 0.02 in. gap prior to welding. *The weld throat shall be greater than or equal to the rib wall thickness*.

Could still be loosened up more:

- 30% < Penetration < 90%
- $0.222(d_1/d_4)^{-1.5}$ < Penetration to determine leg length on deck.
- $0.40 < d_1/d_4 < 0.80$

FHWA Research on Rib to Floorbeam (RFB) Connection

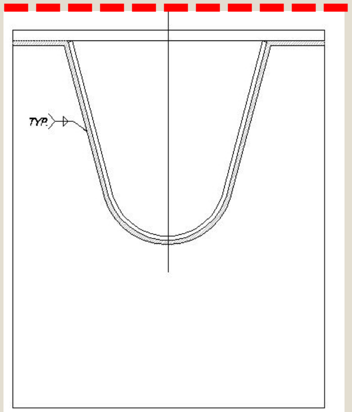
- Investigate potential for automated fabrication of rib-to-floor beam (RFB) connections
- Assess fatigue performance of RFB connections made by these processes using FEA and full-scale laboratory testing
- Develop recommendations for RFB connections

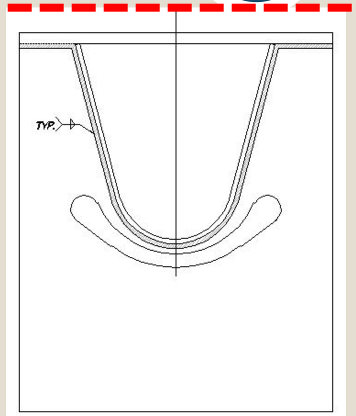


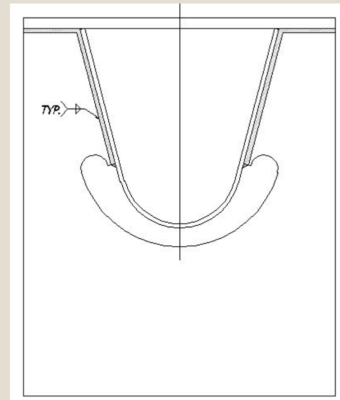
Research being done by Lehigh University

Image courtesy of Lehigh University.

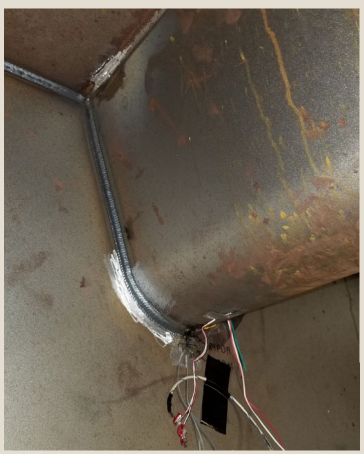
RFB Connections Studied

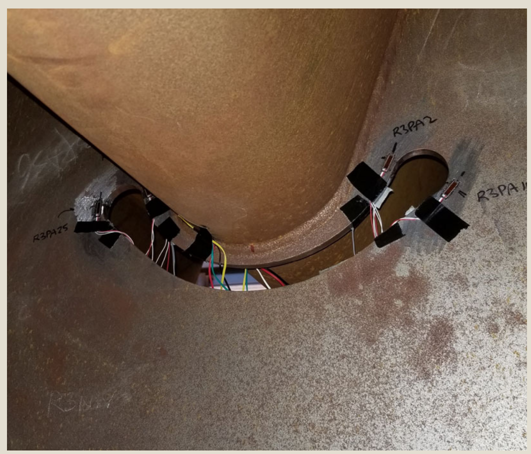






Extended Cut-out

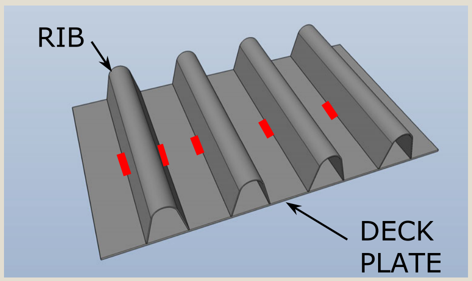




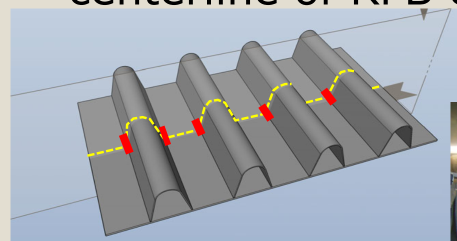
Images courtesy of Lehigh University

Fabrication of Test Specimens

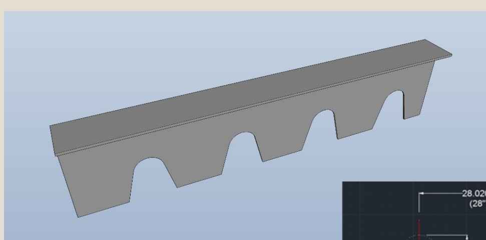
1. Position and make initial rib-to-deck plate weld according to design drawings

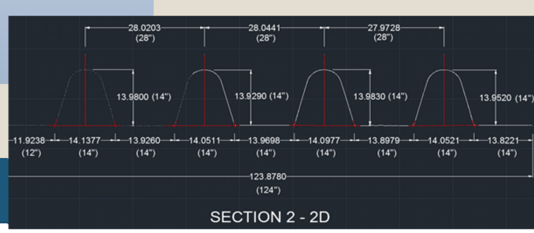


2. Take 2D measurements using laser tracker along centerline of RFB connection

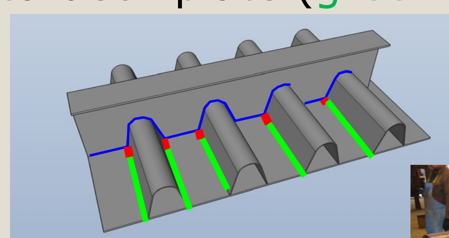


3. Cut floor beam web using plasma cutting table programmed with 2D measurements





4. Assemble panel and make deck-to- and rib-to-floor beam (blue), and rib-to-deck plate (green*) welds



Images courtesy of Lehigh University

Automated Measuring and Cutting


Fit up with as-designed rib geometry


Fit up with as-measured rib geometry

Images courtesy of Lehigh University

Maximum fit-up gap is the largest fit-up gap measured for each rib after tacking.

Largest maximum fit-up gap for each panel (for 4 ribs) given below

Panel	Max Fit-Up Gap
Fitted Panel 2	63 mils
Fitted Panel 3	45 mils
Slit Panel 5	55 mils
Slit Panel 6	94 mils

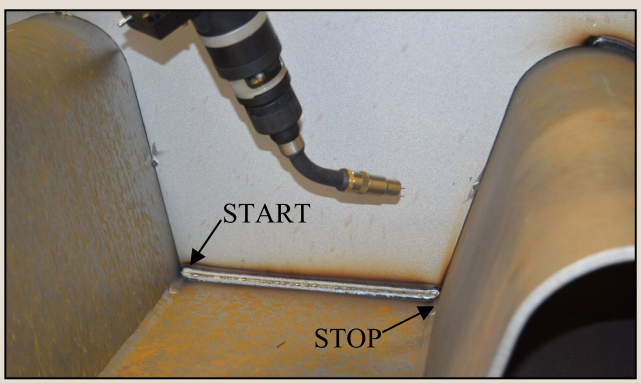
Robotic Welding

1. Test specimen in robotic welding bay, deck plate down

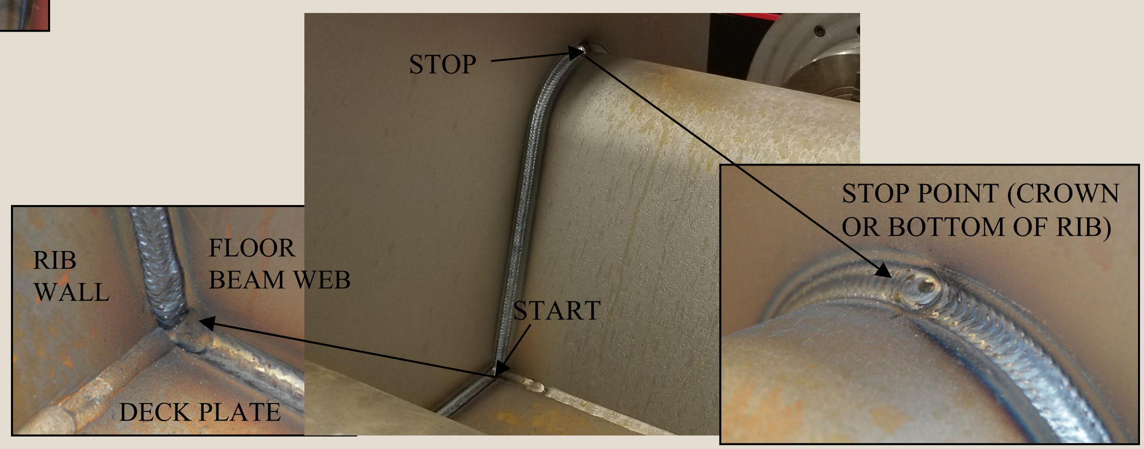
2. Program robot for deck-to-floor beam and rib-to-floor beam welds

- Deck-to-Floor Beam Weld
  - Lincoln RapidArc process
  - 0.052” dia. Wire
  - 2 Hz sine waveform weave
  - Without weld tracking
- Rib-to-Floor Beam Weld
  - Lincoln PrecisionPulse process
  - 0.052 dia. Wire
  - 1 Hz square waveform weave
  - With weld tracking

3. Make deck-to-floor beam welds



4. Make rib-to-floor beam welds



Images courtesy of Lehigh University

Robotic Welding Video

Conclusion

- OSD offers a durable and lightweight solution for bridge decks, but is getting limited use in the U.S. due to cost
- To improve economy of OSD, standard details amenable to automated fab are needed
- FHWA tests on rib-to-deck (RD) weld safely show AASHTO Category C performance
- RD weld penetration is less important to fatigue performance; weld area and leg size are more important

Conclusion

- RFB preferred detail is fitted (no cutout) for new and cutout for redecking
- Match cutting floorbeams with laser measurements and robotic welding are viable solution

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