Manufacturable Orthotropic Steel Deck Bridges

TRANSPORTATION ASSET AND INFRASTRUCTURE MANAGEMENT CONFERENCE
PENNSYLVANIA STATE UNIVERSITY
OCTOBER 25, 2019

BRIAN M. KOZY, PH.D., P.E.
PRINCIPAL BRIDGE ENGINEER
U.S. FEDERAL HIGHWAY ADMINISTRATION

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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.
What is “orthotropic steel deck?”

- Steel deck plate with stiffening ribs and floorbeams to provide load distribution in 2 orthogonal directions.
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

  - Commentary, discussion, design examples

- **AASHTO LRFD Bridge Design Specs**
  - Expanded OSD specs in 2012
  - Strength, Service, Fatigue limit states
  - Detailing provisions

Typical Bridge Sections

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

Trapezoidal

U-Shape

V-Shape

Types of Closed Ribs

Flat

Angle

Bulb

Types of Open Ribs
Fabrication

- Requires specialized techniques
- Tolerances often difficult to control
• Rib to deck welding (closed rib)
  ○ One sided partial penetration
  ○ 60% min. penetration with 0.02” tight fit prior to welding

≤0.020”
Details

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

Free Cutout, See Commentary
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)
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 Diagram]
RD Weld Fatigue Test Results
Correlation to resistance determined through regression
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:

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

- Leg Length on Deck Plate
- Penetration
Regression Results
The results of testing and recommendations are published in FHWA report.

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:
- $30\% < \text{Penetration} < 90\%$
- $0.222(d_1/d_4)^{-1.5} < \text{Penetration}$ 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
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

<table>
<thead>
<tr>
<th>Panel</th>
<th>Max Fit-Up Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitted Panel 2</td>
<td>63 mils</td>
</tr>
<tr>
<td>Fitted Panel 3</td>
<td>45 mils</td>
</tr>
<tr>
<td>Slit Panel 5</td>
<td>55 mils</td>
</tr>
<tr>
<td>Slit Panel 6</td>
<td>94 mils</td>
</tr>
</tbody>
</table>

Images courtesy of Lehigh University
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

3. Make deck-to-floor beam welds

4. Make 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

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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