RESEARCH IMPLEMENTATION REPORT

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Report Date August 2007	Report No. SSRP 2007/13	Report Title Effects of Fabrication Procedures and Weld Melt-Through on Fatigue Resistance of Orthotropic Steel Deck Welds		
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Abstract

A common practice for the fabrication of orthotropic bridge decks in the US involves using 80% partial-joint-penetration groove welds (PJP) to join closed ribs to a deck plate. Avoiding weld melt-through with the thin rib plate may be difficult to achieve in practice because a tight fit may not always be achievable. When weld melt-through occurs, which is difficult to inspect inside the ribs, it is not clear how the geometric discontinuities affect the fatigue resistance. Furthermore, a distortion control plan, which involves heat straightening or pre-cambering, is also used for the fabricated orthotropic deck in order to satisfy the flatness tolerance. It is unclear how repeated heating along the weld line would affect fatigue resistance.

Six 2-span, full-scale orthotropic steel deck specimens (10 m long by 3 m wide) were fabricated and tested in order to study the effects of both weld melt-through and distortion control measures on the fatigue resistance of the deck-to-rib PJP welded joint. Three of the specimens were heat straightened, and the other three were pre-cambered to minimize the need for subsequent heat straightening. For the two distortion control schemes one of the three weld conditions [80% PJP weld, 100% PJP weld with evident continuous weld melt-through, and alternating the above two weld conditions every 1 m] was used for each specimen. Up to 8 million cycles of loading, which simulated the expected maximum stress range corresponding to axle loads of 3×HS15 with 15% impact, were applied at the mid-length of each span and were out of phase to simulate the effect of a moving truck. The load level and boundary conditions were modified slightly based on the observed cracks that occurred in the diaphragm cutouts in the first specimen. Based on the loading scheme applied and the test results of the remaining five specimens, it was observed that three specimens experienced cracking at the rib-to-deck PJP welds at seven loaded locations. It was thought initially that weld melt-through which creates geometric discontinuities at the weld root was the main concern. But only one of the seven cracks initiated from the weld root inside the closed rib, and all the other six cracks initiated from the weld toe outside the closed rib. Based on the loading pattern applied, therefore, it appears that these welds are more vulnerable to cracks initiating from the weld toe, not weld root. Of the only one crack that developed at the weld root, the crack initiated from a location transitioning from 80% PJP weld to 100% PJP weld. This type of geometric discontinuity may be representative of the effect of weld melt-through in actual production of orthotropic steel decks.

Achievement

- Two of the five specimens that were effectively pre-cambered did not experience PJP weld cracks.
- For the given loading pattern, welds are more vulnerable to cracks initiating from the weld toe, not the root.
- The only crack that developed at the weld root was initiated from a location transitioning from 80% PJP weld to 100% PJP weld, that may be representative of melt-through during fabrication of deck panels.

Conclusion & Recommendation

- Effective pre-cambering is beneficial to mitigate the crack potential in rib-to-deck PJP welds.

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Implementation Recommendations

- Report under review by Steel Committee (Lian Duan) and propose changes to AASHTO Specifications pertaining to design / fabrication of steel orthotropic decks, per Steel Committee Work Plan. See Attachment A.

Implementation Measures Taken

- Toll Program Construction Staff utilizing results to manage fabrication of steel orthotropic decks for SAS Structure

APPENDIX A

AASHTO Recommendations

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September 28, 2007

1. RIB-TO-DECK PLATE CONNECTION DETAIL

1.1 1998 and 2004 AASHTO LRFD Bridge Design Specifications (2nd and 3rd Editions)

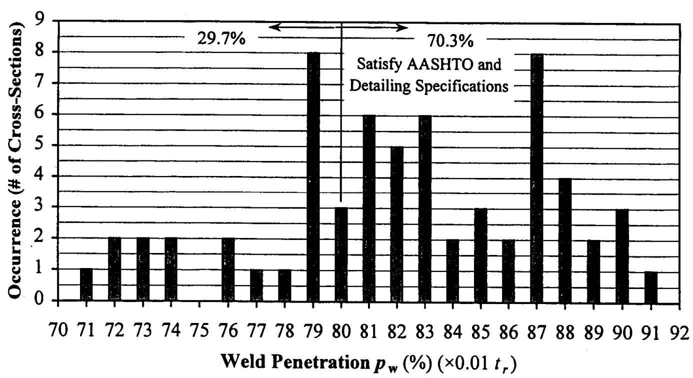
- The connection is categorized as a Distortion-Induced Fatigue detail; detailing requirements are provided in Article 9.8.3.7.
- Article 9.8.3.7.2 states "… 80% PJP welds should be permitted."
- C9.8.3.7.2 states, "… 80% PJP welds, generally used for this connection, are less susceptible to fatigue failure than full penetration groove welds requiring backup bars."
- No provisions are provided on the requirements of fabrication procedures (heat straightening or pre-cambering) and weld melt-through on the fatigue resistance of the PJP weld.

1.2 ASCE Seminar on Orthotropic Deck Bridges (Wolchuk, 2004)

- "Heat-straightening after fabrication to satisfy prescribed plate flatness tolerance may also increase residual stresses at the welds and contribute to cracking."

1.3 Fatigue Testing at Lehigh University (Lehigh Report, 1997, 1998,1999)

- 80% PJP welds were specified for specimen fabrication.
- The study, conducted in the late 1990s, did not specifically address the fabrication issues. But the statistical distribution of rib-to-deck PJP weld penetration of 64 cross sections was reported. The figure below shows that no weld melt-through was reported in their tested specimens.



- Test results showed that the rib-to-deck PJP welded connection was adequate; no fatigue cracking was observed.

1.4 Fatigue Testing at UCSD (Sim and Uang 2007)

- Six full-scale orthotropic deck specimens were commercially fabricated. Fatigue test results showed that two of the six specimens that did not show cracks were the ones that were properly pre-cambered. Therefore, the beneficial effect of pre-cambering may be considered for inclusion in Article 9.8.3.7 or its Commentary.
- The majority of the cracks that propagated into the deck plate initiated from the weld toe. One crack that initiated from the weld root occurred at the location transitioning from the 80% PJP weld (without melt-through) to 100% PJP weld (with melt-through). Therefore, intermittent weld melt-through which produces abrupt changes in weld profile appears not desirable, and this issue may be addressed in Article 9.8.3.7 or its Commentary.

2. RIB-TO-DIAPHRAGM PLATE CONNECTION DETAIL

2.1 1998 AASHTO LRFD Specifications (2nd Edition)

- Article 6.6.1.2.3 classified this type of *fillet* weld as Detail Category *D*.
- Article 9.8.3.7.4 stated that this fillet weld should *not* wrap around the diaphragm cutout (i.e., the weld can be terminated short of the cutout edge).

2.2 Fatigue Testing at Lehigh University

- The fillet weld connection was found from testing to be as low as Category *E*.
- An alternative weld detail that combined the CJP groove weld and fillet weld was developed and verified by testing at Lehigh University.
- Testing showed that the alternate weld detail performed better and could be classified as Category *C* detail.

2.3 2004 AASHTO LRFD Specifications (3rd Edition)

- Based on the Lehigh research findings, Table 6.6.1.2.3-2 specifies a Detail Category lesser of *C* or Eq. 6.6.1.2.5-3 for fillet welds, and *C* for fillet-groove combination welds.
- Article 9.8.3.7.4: (a) fillet welds are to be wrapped around; (b) combination fillet-groove welds may have to be used in cases where size of fillet welds needed to satisfy the resistance requirements would be excessive.

2.4 Fatigue Testing at UCSD

- The combination fillet-groove weld detail was specified.
- No cracks were observed in this weld detail.

3. RIB-TO-BULKHEAD PLATE CONNECTION DETAIL

3.1 1998 AASHTO LRFD Specifications (2nd Edition)

- No provisions on bulkhead plates and its welding detail was provided.

3.2 Fatigue Testing at Lehigh University (reference)

- Bulkhead plates were used inside the closed ribs.
- Fillet welds, not wrap around, were used.
- Although the bulkheads were effective in providing continuity through each closed rib, cracks developed in these welds.
- The study recommended using: (a) either PJP or CJP groove welds, but not terminating short of the bulkhead plate, (b) or fillet welds that wrap around the bulkhead plate.

3.3 2004 AASHTO LRFD Specifications (3rd Edition)

- Table 6.6.1.2.3-2 specifies a Detail Category Lesser of *C* or Eq. 6.6.1.2.5-3 for fillet welds, and *C* for combination fillet-groove welds.
- In case the bulkhead terminates below the top of the free cutout, Article 9.8.3.7.4 requires that the bulkhead extend at least 25 mm below the top of the free cutout and must have a fatigue resistant welded connection to the rib wall. The "fatigue resistant welded connection", however, is not clearly defined in the Specifications.

3.4 Fatigue Testing at UCSD (2006)

- Wrap-around fillet welds were used.
- The specified 25 mm distance was not achieved during fabrication; the actual distance was about 20 mm.
- Cracks on the rib walls initiating at the weld toe below the bulkhead indicated inadequate fatigue resistance even though fillet welds were wrapped around at the bottom end of the bulkhead plate.

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