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Effects of Continuous Welded Rail on Open-Deck Steel Bridges

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Summary

Starting in 2003, as part of the Association of American Railroads' Strategic Research Initiatives Program to reduce the stress state of railroad bridges, Transportation Technology Center, Inc. (TTCI) conducted a series of bridge tests, developed an analytical model, and performed a parametric evaluation to investigate the interaction of continuous welded rail (CWR) with long open-deck steel bridges.

The results of this investigation indicate that there are conflicting considerations regarding thermal effects of CWR on long open-deck bridges. Expansion joints effectively accommodate rail thermal expansion and contraction; however, they generate high impact loads and accelerate bridge degradation,[1,2,3,4] are costly to install, and require high maintenance. Without expansion joints, longitudinal rail restraint must be incorporated to reduce gap width and derailment risk due to broken rails. Rail restraint may introduce high rail longitudinal forces into the bridge in case of a broken rail.

Also, longitudinal restraint causes longitudinal forces to develop in the rail during span expansion and contraction. These forces add to the rail force developed from heating and cooling of the CWR. Additional compressive forces in hot weather might increase the risk of track buckling at bridge approaches, particularly at abutments that support expansion bearings. Additional tensile forces in cold weather might accelerate rail defect and crack growth rates and increase the derailment risk in the case of a rail break.

Due to these fundamental conflicts, it is unlikely that all of the design goals will be completely addressed, but rather a balance is needed between a number of important considerations. Results emphasize the need to maintain good track lateral resistance and proper rail neutral temperature on bridge approaches to minimize track buckling potential. On approaches near expansion bearings, track lateral resistance is critical. Methods to provide additional lateral resistance should be considered; for example, additional ballast shoulders, full height wing walls, sheet piling, and ties with improved lateral restraint.

Unanchored CWR should generally be avoided on any spans where expansion joints are not used, because it might allow excessive rail gap widths should a rail break due to cold-induced rail tension. Fully anchored CWR should also generally be avoided on all spans, as it might cause hot weather induced buckling on bridge approaches and increase the risk of cold weather rail breaks. While expansion joints introduce increased cost and bridge degradation, their use can effectively control the risk of bridge approach track buckling, excessive rail gap widths from cold weather rail breaks, and high tension forces due to relative displacement between bridge and track.

TTCI recommends no change in the American Railway Engineering and Maintenance of Way Association (AREMA) recommendation that expansion joints be installed on spans of 300 feet or greater.[2] However, in order to reduce potential (predicted) cold weather broken rail gap widths, consideration should be given for using rail anchors on spans less than 300 feet following the current AREMA recommendations (near fixed bearings and only at ties fastened to the span) on any spans without expansion joints.

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INTRODUCTION AND CONCLUSIONS

Starting in 2003, as part of the Association of American Railroads' Strategic Research Initiatives (SRI) Program to reduce the stress state of railroad bridges, TTCI conducted a series of bridge tests, developed an analytical model, and performed a parametric evaluation to investigate the interaction of CWR with long open-deck steel bridges.

As a steel bridge expands and contracts due to thermal effects, relative displacement is introduced between the bridge and track. This may introduce undesirable forces into the bridge and/or track or, in the case of a rail break, result in a rail gap between broken rail ends or a sudden transfer of forces to the superstructure.

The results of this investigation indicate that there are a number of conflicting considerations:

- While expansion joints accommodate thermal expansion and contraction, they generate high impact loads, accelerate bridge degradation,[1,2,3,4] and are costly.
- If longitudinal restraint is incorporated to reduce rail break gap width and derailment risk, high longitudinal forces may be imparted into the bridge in the case of a broken rail.
- Longitudinal restraint also causes longitudinal forces to develop in the rail during span expansion and contraction. These forces might increase the risk of track buckling at bridge approaches.
- Additional tensile forces in cold weather may accelerate rail defect and crack growth rates and may increase the derailment risk in the case of a rail break.
- Excessive relative displacements between the track and bridge deck may damage ties and/or fasteners.

Due to fundamental conflicts, it is unlikely that all design goals will be completely addressed. There are a number of important considerations that need to be balanced:

- Results emphasize the need to maintain good track lateral resistance and proper rail neutral temperature on bridge approaches subject to span expansion in order to minimize track buckling potential. Methods to provide additional lateral resistance should be considered; for example, additional ballast shoulders, full height wing walls, sheet piling, and ties with improved lateral restraint.
- Unanchored CWR should be avoided on all open deck spans where expansion joints are not used, as it might allow excessive rail gap widths should a rail break due to cold-induced rail tension, providing there are no overriding concerns.
- Fully anchored CWR should be avoided on all open deck spans, as it might cause hot weather induced buckling on bridge approaches and increase the risk of cold weather rail breaks. Instead, ties should be anchored near fixed bearings and only at ties fastened to the span per AREMA recommendations.[5]
- Expansion joints, in addition to being costly, induce high impact loads into the structure and significantly increase bridge degradation. However, the use of rail expansion joints can minimize the risks associated with CWR thermal effects.

As written, AREMA Chapter 15 guidelines for anchoring of rail and installation of expansion joints on open-deck steel bridges[2] provide a reasonable balance between the conflicting design goals. TTCI recommends no change in the requirement that expansion joints be installed on spans of 300 feet or greater. However, in order to reduce potential (predicted) cold weather broken rail gap widths, consideration should be given to using rail anchors or elastic fasteners on spans less than 300 feet following the current AREMA recommendations (near fixed bearings and only at ties fastened to the span) on any spans without expansion joints.

Canadian National Bridge Test – Reduction of Number of Expansion Joints

Figure 1 shows a CN 1,650-foot long open-deck steel bridge near Edmonton, Alberta, tested in 2003 and 2004.[6] The test was performed to quantify thermal performance before and after the number of bridge expansion joints was reduced.

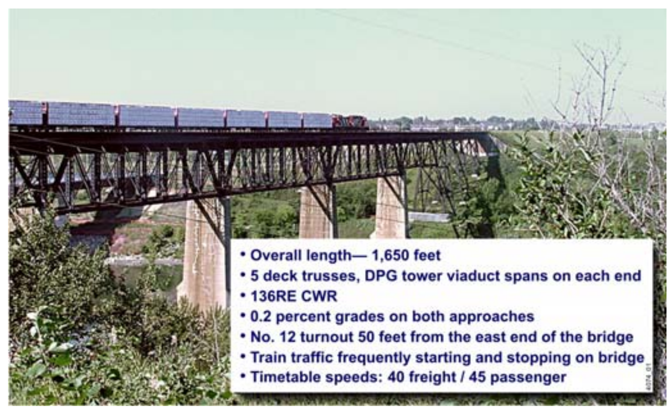

Figure 1. 1,650-foot Open-Deck Steel Bridge Tested in 2003-2004

Reducing the number of expansion joints, such that the length of unanchored rail increased from 950 to 1,450 feet, showed no negative effects in terms of rail longitudinal forces or displacement.

Steel Bridge at FAST – Simulated Cold Weather Rail Break

In January 2007, TTCI conducted a simulated cold weather rail break test on the steel bridge at the Federal Railroad Administration's Facility for Accelerated Service Testing (FAST).[7] The test was carried out on a cold morning when the rail was well below neutral temperature, resulting in rail tension. TTCI technicians cut the rail, and measured the changes in rail force as the tension was relieved.

Designers have traditionally relied on rail anchors or special fasteners to provide longitudinal restraint between CWR track and the bridge structure. This test has indicated that on bridges with a smooth interface between the bridge and deck, while the fasteners may provide a strong bond between the rail and deck ties, longitudinal restraint is weakest at the tie-to-girder interface.

Testing on the steel bridge at FAST has shown that high strain rate applications produce lower longitudinal restraint values than gradual strain rate applications. High strain rates would be caused by the instantaneous release of tension during a rail break under thermal tension. Low strain rates would be applied by thermal expansion and contraction of a bridge girder.

BNSF Railway Bridge Test – Performance of Long Bridge without Expansion Joints

Figure 2 shows a third test that was conducted in 2007 under the SRI program on a BNSF 400-foot steel bridge in Pueblo, Colorado. Track on the bridge was fully anchored with no expansion joints. The tie-to-bridge interface was smooth, with no protruding rivet or bolt heads.

Rail forces, rail and span temperatures, track-to-span displacements, and bridge bearing displacements were monitored for 6 months. Daily rail temperature reversals of nearly 70°F were recorded. Daily span temperature swings reached 45°F.

Figure 2. BNSF 400-foot Steel Bridge

As with previous tests, the results increased the understanding of the longitudinal restraint characteristics between CWR and the bridge spans. In addition, rail force increases due to span expansion at the approach end of the 210-foot truss were measured at 45,000 to 50,000 pounds. These results emphasize the need to maintain good track lateral resistance and proper rail neutral temperature on bridge approaches subject to span expansion to minimize the risk of track buckling.

ANALYTICAL MODEL

TTCI researchers developed an analytical model for bridge longitudinal forces based on examples from the literature.[8,9] The model incorporates CWR longitudinal restraint values from full-scale bridge testing conducted under this and previous research programs and from a number of CWR tests conducted on open track.[10,11]

Parametric Evaluation

A series of simulations using the analytical model developed for this project serves as the basis for the recommendations presented in this *Technology Digest*. A number of issues were considered.

- Displacement between rail and bridge may induce high forces into the track and bridge superstructure.
- Joint removal possibly increases risks for track buckling or rail break.
- Broken rails may induce high rail thermal forces into the superstructure.
- Broken rails in cold weather may result in unacceptable rail gap widths.

Bridge expansion during hot weather can add compressive forces to the rail by transmitting forces through the track fastening system. This is of particular concern where longitudinal resistance is stiff and the expansion bearing of a long bridge abuts the bridge approach, where track is often weaker than typical open track.[12]

Figure 3 shows a distribution of track strengths that can be expected on the North American system. Track strength is expressed in terms of degrees above rail neutral temperature.[*] A differential (ΔT) of 60°F corresponds to single rail compression of approximately 150,000 pounds for 136-pound rail. A ΔT of 110°F corresponds to rail compression of about 275,000 pounds. Because bridge approaches are potential trouble spots, rail compression that exceeds 150,000 pounds can be considered at risk for rail buckling.

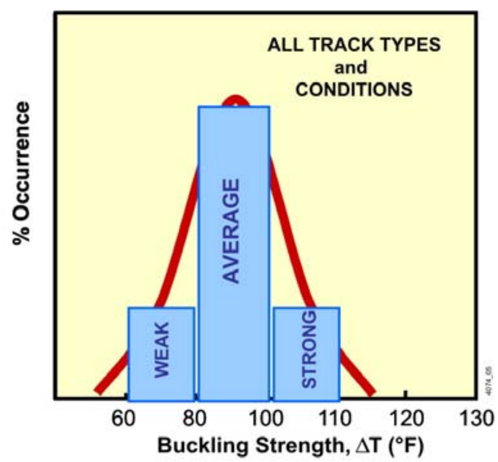

Figure 3. Track Strength Distribution (From presentation to Federal Railroad Administration Rail Safety Advisory Committee by Dr. Andy Kish, July 2007, reprinted with permission of author)

Conflicting effects of introducing longitudinal restraint are illustrated in Figures 4 and 5. Figure 4 shows predicted rail forces for a series of single-span steel bridges with the rail and span at 45°F above neutral temperature. Fully anchored rail and rail anchored per AREMA Chapter 15 are considered. Both smooth top (less restraint) and riveted top conditions (greater restraint) were simulated.

[*] Rail ΔT is the difference between the existing rail temperature and the rail neutral temperature, and span ΔT is the difference between the existing span temperature and the span temperature at time of installation.

While rail forces are predicted to approach buckling at 100-foot and greater span lengths for the fully anchored riveted top span, and at 300-foot span lengths for the fully anchored smooth-top span, the model indicates that both AREMA anchoring conditions effectively control buckling risk. In addition, fully anchored rail forces induced from span contraction during cold weather may increase the risk of a cold weather rail break.

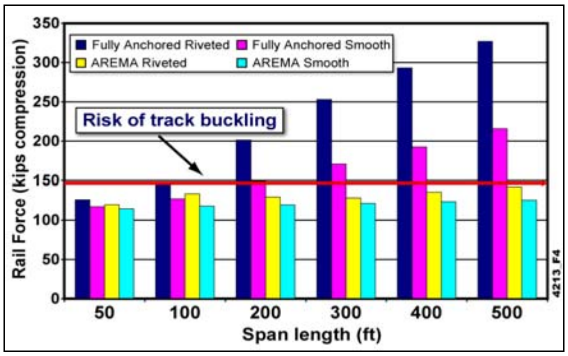

Figure 4. Long Single Spans – Maximum Predicted Rail Compression at Fixed End Approach Rail ΔT +45°F / Span ΔT +45°F

Current AREMA guidelines recommend spans up to 300 feet to be without rail anchors or expansion joints. While eliminating rail anchors would greatly reduce the risk of a track buckle, the rail gap resulting from a cold weather rail break may not be acceptable. As indicated in Figure 5, a 300-foot span without rail anchors or expansion joints would allow a potential (predicted) cold weather broken rail gap width of 7 inches for a rail ΔT of -100°F, which is considerably greater than would be expected on open track.

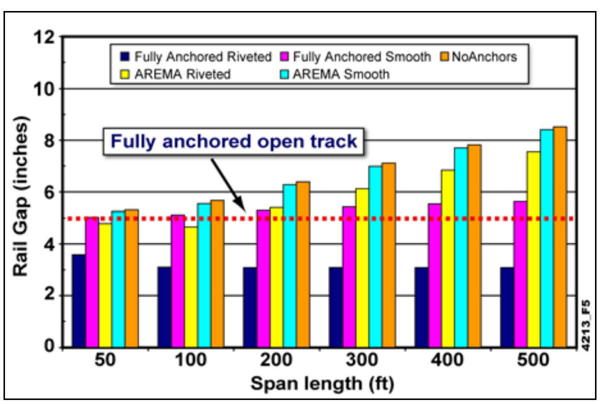

Figure 5. Long Single Span – Predicted Cold Weather Broken Rail Gap Width – Expansion Bearing End, Rail ΔT -100°F, Span ΔT -70°F

Anchoring a 300-foot span only at hook bolt locations for the first 100 feet from the fixed end as recommended in AREMA 15 would reduce the predicted cold weather broken rail gap width to about 6 inches for a riveted-top girder. There would not be a significant reduction for a smooth-top girder. No significant risk of track buckling or rail break would be introduced.

Addition of expansion joints would effectively eliminate cold weather broken rail gap conditions without introducing risk of track buckling or broken rails. However, costs of installation and maintenance for expansion joints are high, and significant bridge degradation is likely to occur due to increased impact loading.

REFERENCES

1. Gonzales, K., B. Doe, D. Otter, and D. Davis. May 2007. "Evaluation of the Effects of Heavy Axle Loads on Rail Joints for Moveable Span Bridges" Research Summary RS-07-001, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
2. Akhtar, M., D. Otter, and B. Doe. November 2007. "The Effects of Moveable Bridge Joint on the Fatigue Life of Welded Braces of Open Deck Steel Bridge at FAST." *Technology Digest* TD-07-037, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
3. Akhtar, M., D. Otter, and B. Doe. May 2005. "Preliminary Impact Load Assessment of Ballast Deck Prestressed Concrete Bridges." *Technology Digest* TD-05-013, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
4. Akhtar, M., D. Otter, and B. Doe. October 2004. "Update: Cracks in the Welded Girders of the Steel Bridge at FAST." *Technology Digest* TD-04-014, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
5. American Railway Engineering and Maintenance of Way Association, 2007. *AREMA Manual for Railway Engineering*, Chapter 15, Section 8.3.
6. Read, D., D. Otter, and B. Doe. August 2006. "Reduction of CWR Expansion Joints on a Long Open Deck Bridge." *Technology Digest* TD-06-020, Association of American Railroads, Transportation Technology Center, Inc, Pueblo Colorado.
7. Joy, R., D. Read, and D. Otter. September 2007. "Continuous Welded Rail Restraint on an Open-Deck Girder Bridge." *Technology Digest* TD-07-026, Association of American Railroads, Transportation Technology Center, Inc, Pueblo Colorado.
8. Fryba, L. 1996. Dynamics of Railway Bridges. Chapter 8, pp. 139-141, Thomas Telford Services Ltd, London.
9. Esveld, C. 1989. Modern Railway Track. Chapter 5, MRT-Productions, Duisburg, West Germany.
10. Joy, R.B. et al. July 2001. "FAST Bridge Tests 1997-1999." Research Report R-948, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
11. Read, D., A. Kish, and J. LoPresti. June 2005. "Management of Rail Longitudinal Forces under Heavy Axle Loads." *Proceedings 8th International Heavy Haul Association Conference*, Rio de Janeiro, Brazil, pp. 659-665.
12. Li, D., C. Duran, and R. McDaniel. August 2006. "Investigation of Open Deck Bridge Transition Issues at the Eastern Mega Site." *Technology Digest* TD-06-022, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.