TECHNOLOGY DIGEST
TD-16-038
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TIMELY TECHNOLOGY TRANSFER

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Bridge Condition Evaluation Using Vehicle Based Detection Systems

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Summary

Transportation Technology Center, Inc. (TTCI) is investigating the feasibility of using vehicle-based (onboard) systems to detect bridge impairments. A single onboard system offers the potential to assist with the inspection of numerous railroad bridges, as opposed to a structural health monitoring system that is captive to a single structure. This *Technology Digest* describes development work using various existing track inspection vehicles in an attempt to detect weak stringers and pier elevation changes in short-span trestle bridges. Initial exploratory testing was performed in revenue service. Developmental testing was performed at the Bridge Deflection Test Facility (BDTF) at the Transportation Technology Center, which was constructed to provide adjustable bridge strength and geometry conditions. The BDTF facilitates evaluation, development, and calibration of onboard systems for detection of bridge anomalies.

Pilot testing using the Association of American Railroads' (AAR) Track Loading Vehicle's (TLV) load system and track geometry system was performed in 2012, which demonstrated the feasibility of the concept.[1] In 2014, TTCI performed another set of tests with a track modulus measuring system (MRail) and track geometry on Federal Railroad Administration's (FRA) DOTX 218 (also called T-18) vehicle, track geometry on a passenger car, an accelerometer-equipped instrumented freight car, and a track modulus system (MRail) on a hopper car.[2,3,4,5] In 2015, track geometry systems on the T-18, DOTX 220 (also called the T-20) vehicle, and Class 1 railroad geometry car were examined.[6]

The results of the testing indicate the following preliminary conclusions:

- All three types of onboard systems (geometry, deflection, acceleration-based) are capable of detecting changes in pier elevations.
- Track geometry cars vary in their ability to detect weak spans, depending on weight and axle spacing.
- The track deflection systems distinguished weaker spans during the test.

For all systems, historical data from past runs is recommended for comparison and trending. For lines with many spans of the same construction, outliers might be flagged in lieu of historical comparison.

This work was performed as part of the AAR's Strategic Research Initiative on Bridge Life Extension.

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INTRODUCTION AND MOTIVATION

In an effort to provide better indications of bridges in need of maintenance or more detailed inspection, TTCI has been investigating the potential for using onboard technology to detect bridge impairment or changes in bridge behavior. The motivations for developing such a technology are twofold. First, bridges often show behavior under dynamic train loading that is difficult to observe otherwise. Second, an onboard system has the potential to provide observations for hundreds of bridges, as opposed to a structural health monitoring system that is fixed and capable of monitoring only a single bridge during a short period.

Vehicle-based detection has tremendous potential for the monitoring of many simple spans, of which there are many on North American railroads. Structural health monitoring systems may be useful for monitoring of individual long span or complex bridges with marginal calculated strength where vehicle-based detection might not be appropriate.

In recent years, several railroad industry bridge experts have noted that the location of bridges and/or bridge approaches can sometimes be observed in onboard data, such as track geometry measurements. Various onboard methods have been proposed to measure bridge response. This *Technology Digest* (TD) summarizes investigation on the potential use of existing onboard systems to detect bridge defects or significant changes in track support conditions provided by a bridge, focusing on the short span trestle bridges that are common in North America. The results indicated that some of the onboard systems tested can be used successfully for bridge impairment detection. A path forward for implementation is presented in this TD.

EARLY REVENUE SERVICE TESTING

Research into this topic began with TTCI working in conjunction with a Class 1 railroad. The railroad provided to TTCI a variety of information for selected lines including track geometry, locomotive vehicle-track interaction (VTI) exceptions, and global positioning system (GPS) coordinates of bridges. In addition, the TTCI instrumented freight car and the TLV were run over selected lines. The most promising data came from the TLV.

The TLV data showed vertical displacement signatures with wavelengths corresponding to the 14-foot span length of many short span trestles. However, without wayside measurements and a full characterization of each structure, it was difficult to determine exactly what the responses indicated. It became apparent that to continue this work further, an adjustable bridge structure was needed to provide calibration and evaluation capabilities for vehicles that might provide onboard detection for changes in bridge condition. This led to the design and construction of just such a bridge at the Transportation Technology Center (TTC) near Pueblo, Colorado.

BDTF DESIGN AND CONSTRUCTION

The Bridge Deflection Test Facility (BDTF) is a 42-foot, 3-span, T-rail trestle with an open deck. It can be configured to provide variable pier geometries as well as variable stringer stiffness in all three spans. Adjustable geometry is provided by shims that support only selected rails at each pier cap (Figure 1). In its nominal condition, all six stringers of a chord are supported. To simulate a stringer in weakened condition, only three of the stringers are supported by 1-inch shims at each end. The remaining three stringers will only be engaged if the deflection exceeds 1 inch.

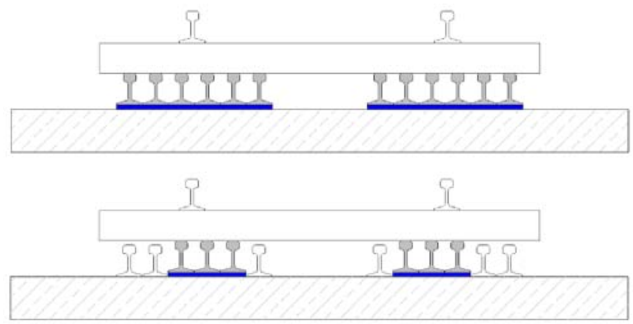

Figure 1. Illustrations of BDTF Normal Conditions (top) and Weakened Condition (bottom)

The BDTF is located on a lightly used section of track, so it is not subjected to high levels of degradation as might be experienced at the Facility for Accelerated Service Testing (FAST). By installing the BDTF on a lightly used section of track, the bridge conditions should remain nearly constant for years of use as a calibration and evaluation facility.

TEST RUNS

BDTF configurations during the test included various combinations of weak stringers and pier top elevation changes. Details about the configurations with appropriate drawings can be found in the previous research .[5,6] Test runs were made usually at speeds up to 45 mph to evaluate the effects of speed on the measurements.

ONBOARD SYSTEMS USED FOR TESTING

Since 2012, many different onboard systems were tested. This section presents an overview of each vehicle and system.

The TLV includes both the vertical load deflection measurement under 40-kip wheel loads and the track geometry system. The TLV uses an automatic location detector system in addition to GPS.

The instrumented locomotive (VTI) and the instrumented freight car measurements are primarily acceleration-based. The instrumented freight car is a loaded 110-ton hopper car, and the VTI locomotive is an EMD-SD70M six-axle locomotive. Instrumented freight car and instrumented locomotive VTI technologies are relatively inexpensive and rugged, with a high availability potential as compared to track geometry systems and track deflection/modulus systems.

The T-18 test vehicle is a self-propelled vehicle that weighs 175 kips and its average axle load is 43.8 kips. It is equipped with a track geometry measurement system. In addition, the car is equipped with an MRail system to measure vertical rail deflection. T-18 uses a differential GPS to provide high accuracy GPS coordinates.

A loaded conventional hopper car with an axle load of 65 kips is equipped with a track deflection measuring system to measure vertical rail deflection. The track deflection measuring systems on the T-18 and conventional hopper car make similar measurements despite the mounting differences and truck differences. The only significant differences are the weight and axle spacing of the two vehicles.

The T-20 test vehicle is equipped with a track geometry measurement system; a VTI system; and a differential GPS.

The Class 1 railroad vehicle is a converted railroad passenger car equipped to measure track geometry. The total car weight is 166 kips, and the average axle load is 41.5 kips.

TESTING ON THE BDTF

In 2012, TTCI performed the first tests with several onboard systems over the BDTF.[1] Three vehicles with onboard measurement systems were operated: an instrumented locomotive (VTI), an instrumented freight car, the TLV, and a track geometry system (mounted on TLV). The TLV deflection measurement clearly and correctly identified weak bridge stringers. The TLV track geometry system identified low bridge approaches and changes in track surface over the bridge. Deflection measurements under load, as well as some track geometry parameters, appeared to be valuable components of an onboard bridge impairment detection system.

In 2014,[4,5] several new systems were examined: track modulus measuring system (MRail) and track geometry on the T-18, track geometry on a lightweight passenger car, an accelerometer-equipped instrumented freight car, and a track modulus system (MRail) on a hopper car. Testing indicated that all three types of systems (geometry, deflection, acceleration-based) are capable of detecting changes in pier elevations. Track geometry data from the T-18 and track deflection data from both T-18 and the hopper car detected changes in bridge span condition. Track geometry data on the lightweight passenger car identified poor approach geometry at the ends of the bridge. The results were less useful to distinguish weak spans from the base bridge condition.

In August 2015, TTCI tested three onboard track geometry systems installed on T-18, T-20, and the Class 1 railroad car.[6] All three onboard track geometry systems detected changes in pier elevations. Track geometry data from T-18 and T-20 accurately detected changes in span condition. However, track geometry data from the Class 1 railroad car were good to identify weak approaches of the bridge, but were not quite as useful to distinguish weak spans from the base bridge condition.

For all systems, historical data from past runs is required for comparison. For lines with many bridge spans of the same construction, outliers might be flagged in lieu of historical comparison.

SUMMARY

Several existing onboard systems were tested at the BDTF in 2012, 2014, and 2015. The results showed that some of the onboard systems can be used successfully for detecting changes in bridge condition. The findings from all the test results are as follows:

- Track geometry cars—some work better than the others, further investigation is recommended. The weight and axle spacing seem to be significant factors.
- Instrumented freight car—provides useful results for bridge condition evaluation; shows promise but is very sensitive to post-processing and requires further development.
- Track deflection measuring system—correctly identified weak stringers. This system has the best potential to be used in unmanned revenue service at this point.

- All three types of systems (two geometry systems, a track deflection measuring system, and an accelerometer-based vehicle response system) are capable of detecting changes in pier elevations in an open-deck trestle.
- Trending of historical readings are likely needed to track changes and predict when action might be required.
- Conventional hopper car equipped with a track deflection measuring system and the instrumented freight car can run unattended in revenue service trains.

CONSIDERATIONS FOR IMPLEMENTATION AND FUTURE WORK

Future work should focus on developing reliable procedures for processing the data. TTCI recommends that a revenue service demonstration be conducted using the track deflection measuring system on the track measurement vehicle and conventional hopper car to begin to explore implementation issues. For implementation, new data would be compared to historical data to look for changes in the track geometry to infer trends in bridge condition. Appropriate trending software should also be developed.[7]

Accurate location of bridge ends is essential, possibly including on-the-ground location indicators in addition to GPS.

Future work should include evaluation of additional track geometry cars and other track evaluation vehicles on the BDTF. Evaluation and further development of accelerometer-based measurement systems on typical locomotives and freight cars is also worth pursuing, particularly because of the potential for high availability and reliability in railroad service. There are already hundreds of locomotives equipped with VTI systems that might potentially be capable of providing bridge behavior information to a database for trending analysis.

Future challenges include ballast deck bridges, because changes in recorded signatures might be due to changes in ballast conditions rather than changes in the structural elements themselves. Additionally, longer spans will tend to have signatures that might be quite different, and may require modifications or different algorithms in trending software.

A further challenge will be finding defective conditions such as cracks in steel girders that do not manifest themselves in significant changes in deflection.

ACKNOWLEDGEMENTS

The authors acknowledge the following individuals for their contributions toward this effort: Gordon Davids and Ken Wammel (retired FRA), Luis Maal and Hugh Thompson of FRA, Gary T. Fry of Texas A&M University, Anne Gill of BNSF, Steve Millsap and Byron Burns (retired BNSF). The authors thank TUV Rheinland for donating the conventional hopper car, and specifically, Cory Hogan and Sheng Lu for monitoring the equipment during the test.

REFERENCES

1. Otter, Duane and Richard Joy. “Feasibility of Detecting Weak Bridge Stringers Using Onboard Systems.” *Technology Digest* TD-13-003, AAR/TTCI, Pueblo, CO. February 2013.
2. Rakoczy, Anna, Xinggao Shu, and Duane Otter. “Vehicle/Bridge Interaction Modeling and Validation – Part 1.” *Technology Digest* TD-15-004, AAR/TTCI, Pueblo, CO. February 2015.
3. Rakoczy, Anna, Xinggao Shu, and Duane Otter. “Vehicle/Bridge Interaction Modeling and Validation – Part 2.” *Technology Digest* TD-15-005, AAR/TTCI, Pueblo, CO. February 2015.
4. Rakoczy, Anna M. and Duane Otter. “Bridge Condition Evaluation Using Track Modulus Measuring Systems.” *Technology Digest* TD-15-006, AAR/TTCI, Pueblo, CO. March 2015.
5. Rakoczy, Anna and Duane Otter. “Bridge Condition Evaluation Using Track Geometry Systems.” *Technology Digest* TD-15-007 AAR/TTCI, Pueblo, CO. March 2015.
6. Rakoczy, Anna and Duane Otter. “Bridge Condition Evaluation Using Three Track Geometry Cars.” *Technology Digest* TD-16-027 AAR/TTCI, Pueblo, CO. June 2016.
7. Rakoczy, Anna M. and Duane Otter. “Vehicle-Based Detection of Changes in Bridge Condition.” In *Proc. AREMA Conference*, Minneapolis, MN. October 2015.