TECHNOLOGY DIGEST

TD-15-006

©MARCH 2015

TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Bridge Condition Evaluation Using Track Modulus Measuring Systems

Anna M. Rakoczy and Duane Otter

Summary

Transportation Technology Center, Inc. (TTCI) is investigating the feasibility of using vehicle-based systems to detect bridge impairments. A single vehicle-based system offers the potential to assist with the inspection of hundreds or thousands of railroad bridges, as opposed to a structural health monitoring system that is captive to a single structure. The focus of this series of tests is on detecting weak stringers and pier elevation changes in a trestle bridge. The 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. This research was conducted as part of the Association of American Railroads' Strategic Research Initiatives Program on Bridge Life Extension.

Pilot testing of onboard bridge condition evaluation using TTCI's Track Loading Vehicle's load system and track geometry system was performed in 2012.[1] In 2014, several new systems were tested: track modulus measuring system (MRail) and track geometry on Federal Railroad Administration's DOTX 218 (also called T-18) test vehicle, track geometry on a passenger car, an accelerometer-equipped instrumented freight car, and MRail on a hopper car (TUVX 001). This *Technology Digest* (TD) presents the results of testing with the track modulus systems. Testing indicates the following preliminary conclusions:

- All three types of systems (geometry, track modulus/deflection, and acceleration-based) are capable of detecting changes in pier elevations.
- MRail system on T-18 distinguished the weaker span during testing.
- MRail system on TUVX 001 clearly and correctly identified weak bridge stringers. The results were more accurate at lower speeds: 10 and 25 mph. For higher speeds, it detected weak stringers, but was less accurate.
- For all three types of systems, historical data from past runs is required for comparison. For lines with many spans of the same construction, outliers might be flagged in lieu of historical comparison.

Further results about TTCI testing of the other systems can be found in companion TDs.[2,3,4]

Please contact **Anna Rakoczy (719) 584-0782** with questions or concerns regarding this *Technology Digest.* E-mail: Anna_Rakoczy@ttci.aar.com.

INTRODUCTION AND MOTIVATION

In an effort to provide better indication 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.

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 study investigated 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 type bridge. Short span trestle bridges built with steel, concrete, or timber spans are common railway bridges in North America. The research focused on detecting weak bridge stringers and changes in pier elevations in short trestle bridges.

Previous Studies

In 2012, TTCI performed tests with several onboard systems at the Bridge Deflection Test Facility (BDTF) at the Transportation Technology Center (TTC). The BDTF was constructed to provide adjustable bridge strength and geometry conditions.[1] Three vehicles with onboard measurement systems were operated over the BDTF to determine their feasibility for use in onboard bridge condition assessment. The data was gathered using the following systems:

- Instrumented locomotive
- Instrumented freight car
- Track Loading Vehicle (TLV)
- Track geometry system (mounted on TLV)

The instrumented locomotive and instrumented freight car measurements were primarily acceleration-based measurements which have proven valuable in finding relatively short wavelength defects, especially related to rail surface conditions. These systems are relatively low cost, rugged, and have the potential to provide high availability and wide coverage. The TLV used vertical loading to provide measurements related to track deflection and stiffness under various loads. The TLV track geometry system provided the measurements of track surface, alignment, cross level, gage, and related parameters.

In summary, the track geometry data provides a good indication of low bridge approaches and a slight indication of a weakened stringer. The deflection measurement by the TLV under a center bogie load of 40 kips per wheel clearly and correctly identified weak bridge stringers. This demonstrates that it is indeed possible to detect some bridge deficiencies using vehicle-based detection systems. The rail surface measurement from the track geometry system is able to identify low bridge approaches and changes in track surface over a bridge. Both deflection measurements under load, as well as some track geometry parameters, appear to be valuable components of an onboard bridge impairment detection system.

New Testing on the Bridge Deflection Test Facility at TTC

The BDTF is a 42-foot, 3-span, T-rail trestle. It can be configured to provide variable pier geometries as well as variable stringer stiffness in all three spans. 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.

The three test vehicles ran each of the BDTF test configurations at 10, 25, 40, and 45 mph (a total of 24 runs) to evaluate the effects of speed on the measurements. The six BDTF test configurations included the following:

1. Base case – all spans and piers in normal full strength condition
2. Weak stringer in one side of center span
3. Weak stringers in both sides of center span
4. Weak stringers in one side of two spans (exterior and center) and abutment elevation raised
5. Weak stringer in one side of center span and on opposite side of exterior span and abutment elevation raised
6. Base case – all spans and piers in normal full strength condition

Figure 1 shows the BDTF test configurations; weak stringers are red and elevated abutments are orange.

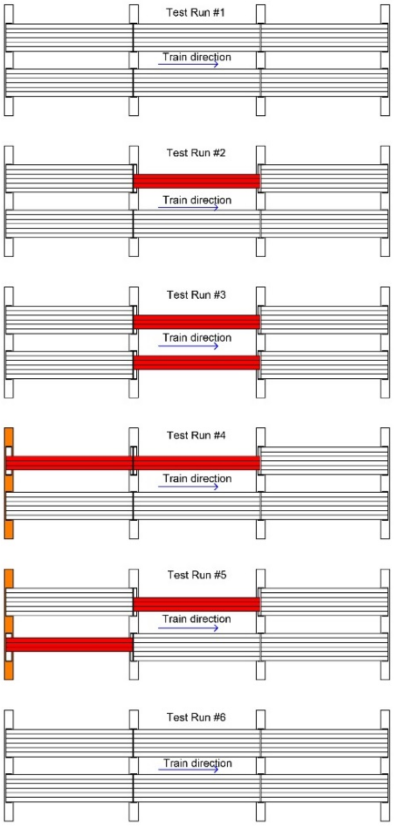

Figure 1. Illustrations of BDTF Test Conditions

Testing on BDTF with T-18

Federal Railroad Administration's (FRA) T-18 test vehicle is a self-propelled state-of-the-art vehicle that conducts performance-based testing of railroad track strength. The total car weight is 175 kips and the average axle load is 43.8 kips. It is equipped with a track geometry measurement system to measure gage, alignment, and track surface. In addition, the car is equipped with an MRail system to measure vertical rail deflection. T-18 utilizes a differential Global Positioning System (GPS) to provide high accuracy GPS coordinates for each foot surveyed.

The MRail system includes two rigid beams attached to the truck frames of the track geometry car, two sensor heads holding cameras and lasers at the ends of the rigid beams, a solar panel array, a GPS antenna on the top of the car, a GPS receiver, and an enclosed box containing data acquisition boards and two computers for onboard image processing and data computation.[5]

The MRail system measures the displacements of the two rail surfaces with respect to the wheel/rail contact plane, Yrel (Figure 2). The measurements are dependent on the four wheel loads. On T-18, correction factors based on measurements of primary suspension deflections are used to permit an assumption that the instrument beam, truck, and wheels are rigid.

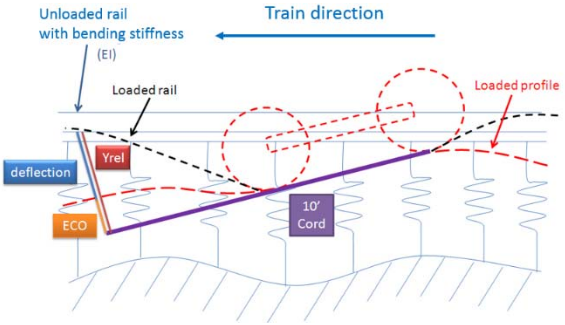

Figure 2. Scheme of MRail Measurements

MRail measurements are presented in Figure 3 for the left side of the bridge and on Figure 4 for the right side of the bridge. The comparison of peak displacements for each bridge condition and various speeds are summarized in Table 1.

Note that for the right rail, increased deflection is shown only for the case of both stringers weak (Test 3), not for the case of only the left stringer weak (Test 2). The fact that the right rail deflection measurement is not influenced by the weak stringer under the left rail is encouraging, as it indicates that such a system is capable of isolating and locating a defective member with greater accuracy.

Based on the results presented in Figures 3 and 4 and in Table 1, the MRail system on the T-18 car accurately detected weak spans. The variation of Yrel peaks for various speeds was from 1 to 5 percent, which indicates measurements were not sensitive to speed.

T-18 is also equipped with a track geometry measurement system. The results from tests using the track geometry system can be found in TD-15-007.[5]

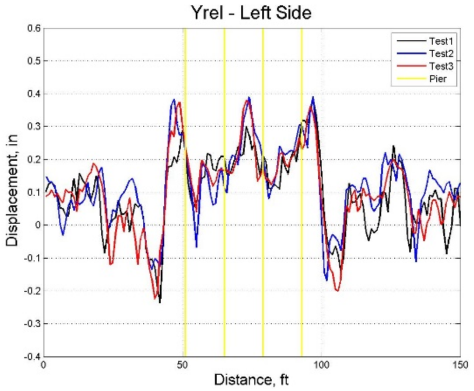

Figure 3. Comparison of Yrel Measurements on Left Side for Different Bridge Conditions

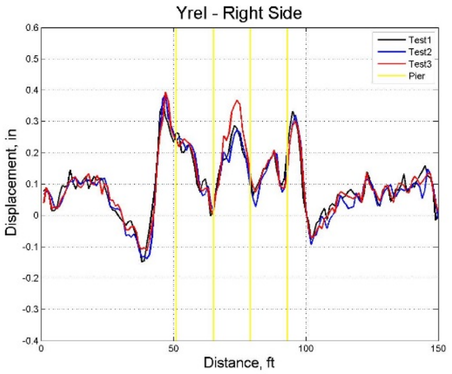

Figure 4. Comparison of Yrel Measurements on Right Side for Different Bridge Conditions

Table 1. Mid-span Peaks for Different Test Configurations

Test	Speed (mph)	Left Yrel (inch)	Right Yrel (inch)
1	11	0.302	0.309
	23	0.300	0.287
	37	0.290	0.284
2	11	0.403	0.276
	24	0.390	0.272
	38	0.407	0.257
3	11	0.376	0.364
	24	0.380	0.368
	38	0.348	0.372

Testing on the BDTF with TUVX 001

TUVX 001 is a loaded hopper car with an axle load of 65 kips. It is equipped with an MRail system to measure vertical rail deflection. The MRail system on the T-18 car and on the TUVX 001 car are the same. Measurement differences are related to the axle spacing and weight of the railcar on which the system is installed. The T-18 and TUVX 001 MRail systems make similar measurements despite the mounting differences and truck differences.

Figure 5 shows vertical rail deflection Yrel measurements from the left side of the system and Figure 6 shows measurements from the right side of the system. The only significant difference is the weight of the two vehicles. This has been fully demonstrated in tests and analyses by the Volpe National Transportation Systems Center for FRA.

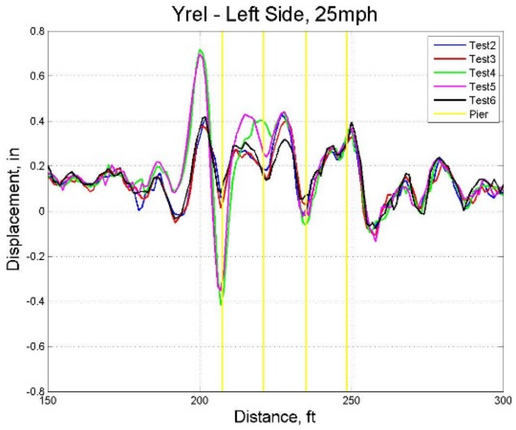

Figure 5. Yrel Measurements on Left Side for Different Bridge Conditions

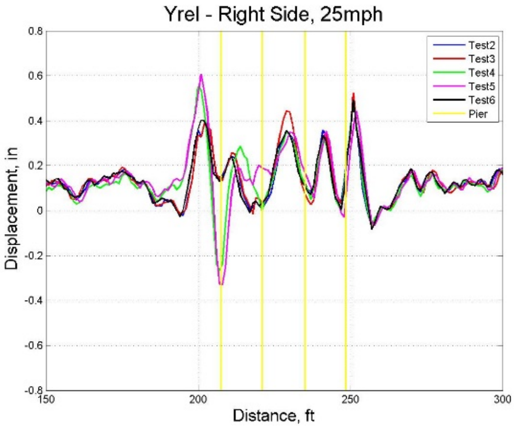

Figure 6. Yrel Measurements on Right Side for Different Bridge Conditions

Both figures show variation between different test conditions. During Tests 4 and 5 the approaches of the bridge and the support conditions are different than the base case (Test 6). Also, for the right middle span, the increased deflection is shown only for the case of both stringers weak (Test 3), but on the left middle span all cases have increased deflection except the base condition (Test 6).

The variations of maximum deflection are presented in Figure 7 for the left spans and Figure 8 for the right spans. For both figures, the peaks on span 3 are constant over all test cases. Span 2 on the left side has larger peaks for all cases besides the base condition, whereas on the right side only Test 3 has a larger deflection. Span 1 on the left side has larger peaks for Tests 4 and 5, whereas on the right side the difference is not very clear. The influence of bad approach and support conditions on the abutment definitely influence the deflection of the first span.

At higher speeds the MRail system can still detect weak stringers, but the conditions are less distinguishable. The accuracy may be related to the sample rates or to the dynamic interaction between the car and the bridge. Therefore, lower speeds are recommended for detecting bridge condition with the MRail system.

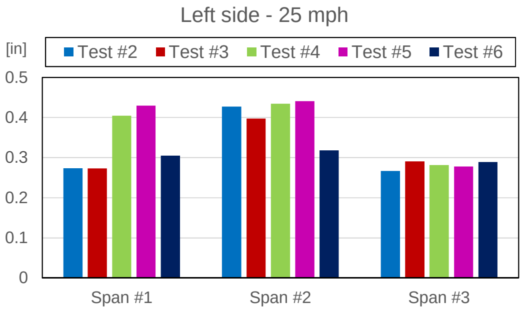

Figure 7. Comparison of Span-Peaks Based on the Yrel Measurements on Left Side for Different Bridge Conditions

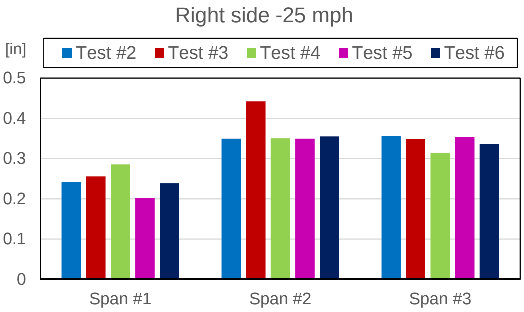

Figure 8. Comparison of Span-Peaks Based on the Yrel Measurements on Right Side for Different Bridge Conditions

Summary

The results show that the MRail systems can be used successfully for bridge condition assessment. The MRail systems mounted on T-18 and TUVX 001 correctly identified weak stringers. This system has potential to be used in unmanned revenue service. It is recommended to use the MRail systems on T-18 and TUVX 001 for a Beta test.

Acknowledgements

The authors thank TUV Rheinland for donating TUVX 001 and for processing the data. Special thanks are due to Cory Hogan and Sheng Lu who monitored the equipment during the test and delivered the data. Thanks to Luis Maal and Hugh Thompson of the FRA for making the T-18 car available for this testing.

References

1. Otter, D. and R. Joy. February 2013. “Feasibility of Detecting Weak Bridge Stringers Using Onboard Systems.” *Technology Digest* TD-13-003, AAR/TTCI, Pueblo, CO.
2. Rakoczy, A., S. Shu, and D. Otter. February 2015. “Vehicle/Bridge Interaction Modeling and Validation – Part 1.” *Technology Digest* TD-15-004, AAR/TTCI, Pueblo, CO.
3. Rakoczy, A., X. Shu, and D. Otter. February 2015. “Vehicle/Bridge Interaction Modeling and Validation – Part 2.” *Technology Digest* TD-15-005, AAR/TTCI, Pueblo, CO.
4. Rakoczy, A. and D. Otter. February 2015. “Bridge Condition Evaluation Using Track Geometry Systems.” *Technology Digest* TD-15-007, AAR/TTCI, Pueblo, CO.
5. Lu, Sheng. December 2008. “Real-Time Vertical Track Deflection Measurement System.” Dissertation, University of Nebraska – Lincoln.