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# Vehicle/Bridge Interaction Modeling and Validation – Part 2

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## Summary

Railway bridges are critical in the transportation network and vital to the operations of the industry. Thousands of bridge spans more than 50 years of age are still in service. The current work under the Association of American Railroads' Strategic Research Initiatives Program on bridge life extension focuses on the effects of increased axle loads, extending the safe service life of existing steel bridge spans, and onboard inspection of bridge structural integrity. The program includes various tests on the Bridge Deflection Test Facility (BDTF) at the Transportation Technology Center, and it has developed the NUCARS®\* bridge and vehicle model. Part 1 of this study, TD-15-004, describes the modeling and validation of the bridge performance.<sup>1</sup> The results of the testing with revenue service production vehicles are presented in TD-15-006 and TD-15-007.<sup>2,3</sup>

This *Technology Digest* (TD) is the continuation of TD-15-004. Simulation and test results of an onboard system installed on the instrumented freight car that analyzed a railway bridge located at the BDTF indicated the instrumented freight car is a useful tool for identifying some bridge condition issues. The BDTF provides adjustable bridge strength and geometry conditions. The results of past field tests were utilized to validate the NUCARS three-layer track model of the BDTF. The experimental and analytical studies were evaluated to develop onboard systems for dynamic inspection of bridges under varying loads.

Instrumented freight car and instrumented locomotive vehicle-track interaction technologies are relatively inexpensive and rugged, with a high availability potential as compared to track geometry systems and track deflection/modulus systems. Therefore, there is a high motivation for improving instrumented freight car capabilities. Based on the findings from previous tests and NUCARS modeling, new transducers are proposed to be installed on the instrumented freight car. The additional accelerometers installed on the carbody and side frames of the instrumented freight car were investigated in the latest tests on BDTF performed at the end of August 2014. The new test results are presented in this study. With further refinement of processing algorithms, carbody and side frame displacements from an instrumented freight car has potential to be used for identifying changes in bridge conditions.

\*NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, Colorado



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**INTRODUCTION**

TTCI is investigating the feasibility of using vehicle-based onboard systems to detect bridge impairments. Research has focused on using existing onboard systems, rather than developing new ones. Three existing onboard detection systems studied to date include the following:

- Revenue service type vehicles (locomotives or freight cars) equipped with sensor packages – typically accelerometers and sometimes also spring displacements
- Track geometry measurement vehicles
- Vehicles designed to measure track deflection under vertical load

The findings indicate that each of these systems, with appropriate post-processing of the data, was able to identify the general location of the test bridge. Vehicles designed to measure track deflection under vertical load have shown the most promise for identifying changes in structural behavior of the test bridge. Work is ongoing to move this technology towards revenue service implementation. The most challenging technology at this point is the use of revenue service vehicles such as vehicle-track interaction equipped locomotives and freight cars. However, because many of these vehicles are already operating on several railroads in revenue service trains, it is highly desirable to continue investigation of using vehicle track interaction equipped vehicles to detect bridge impairment as well. In any case, it is not anticipated that these systems will replace manual inspection, but they should provide early notification of the need to have an inspector check a particular bridge. The systems should also provide an indication of the types and locations of defects to inspect. Trending of historical readings might be needed to track changes and predict when action might be required.

As a part of this effort, NUCARS® modeling is being used to predict performance of an onboard system installed on an instrumented freight car. The modeling is also being used to help determine the measurements best suited for detecting changes in bridge performance.

To determine the dynamic performance of bridges under a moving load, flexible bridge spans were added to the track model to predict the dynamic responses of the vehicle and bridge including wheel/rail interaction. The NUCARS multi-layer track model is described in TD-15-004.<sup>1</sup>

**Previous Testing on the BDTF**

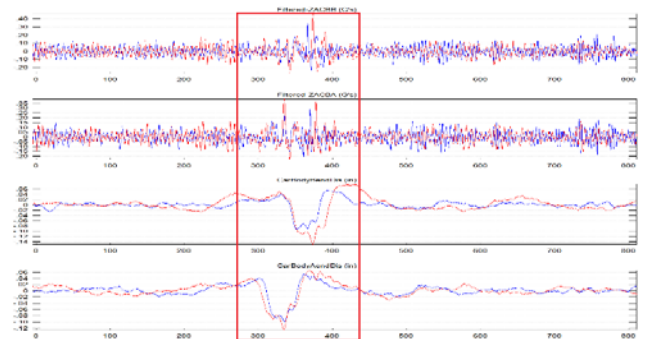
In 2012, TTCI performed tests with several onboard systems over the BDTF to determine their feasibility for use in onboard bridge condition assessment.<sup>4</sup>

In addition to testing onboard systems, wayside measurements were collected on the bridge. Vertical deflections and bending strains were measured on the left and right sides of each span. TD-15-004 presented three BDTF test configurations and results from wayside measurements.<sup>1</sup>

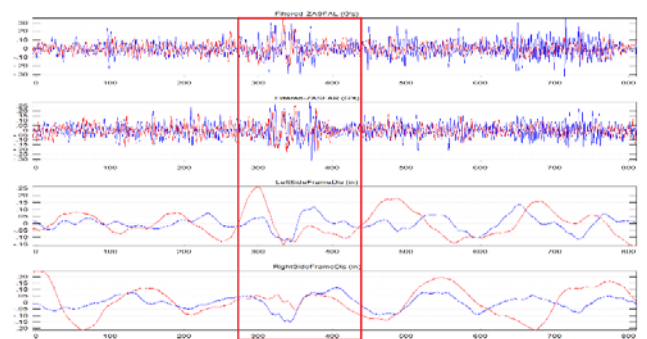
The instrumented locomotive and instrumented freight car measurements are primarily acceleration-based measurements, which have proven valuable in finding relatively short wavelength defects, especially related to rail surface

conditions. Data from the instrumented freight car was collected for the three test conditions on the BDTF. The results indicated that of the various instrumented freight car measurements available, carbody acceleration and side frame acceleration have the highest potential to detect changes in behavior of a bridge.

Due to high frequency ambient vibrations, it is not possible to detect even the location of the bridge, much less changes, from the raw acceleration data. It was necessary to develop a post-processing algorithm to obtain signals that might help to identify bridge conditions. Figures 1 and 2 show examples of vertical acceleration and displacement measurements for the instrumented freight car as it travelled over the BDTF at a typical revenue service operating speed of 40 mph. The results are presented for the normal condition of the bridge (blue line) and the weak stringer (red line). With the post-processing algorithm, the general location of the test bridge became evident. The BDTF is located between coordinates 300 and 400 on the x-axis. Changes in the acceleration signal with change in structural behavior were not very distinct, however.



**Figure 1. Vertical Carbody A-end Acceleration (2 top histories) and Displacement (2 bottom histories) at 40mph**



**Figure 2. Vertical Side Frame Acceleration (2 top histories) and Displacement (2 bottom histories) at 40mph**

Summarizing all the results, in some cases the deflections of the three individual spans could be distinguished. However, the distinction between different conditions of the bridge were not very evident.

The previous configuration of the carbody accelerometers in the instrumented freight car did not provide enough information to distinguish differences in displacements of the bridge from one side to the other, making it difficult to identify changes in behavior of only one side of the bridge. Although the results were not strong, the side frame accelerometers showed more promise since they were installed on the left and

right sides. Further work focused on changing the location of accelerometers and using noise-cancellation to improve the signal.

**Application of the NUCARS Model**

NUCARS was used to model typical freight train equipment as well as a track and bridge system. Part 1 of this study showed that the predicted dynamic responses of bridges from the NUCARS model closely matched test results.<sup>1</sup> The NUCARS simulations can also be used to predict the dynamic performance of the vehicle on the bridge.

Therefore, simulations were performed to predict results of additional accelerometers installed on the NUCARS model of the instrumented freight car. The simulated transducer outputs were analyzed to predict changes in bridge performance. The analysis provided information on how the additional onboard transducers might help detect changes in the bridge. More precisely, the analysis may provide potential locations of transducers on the vehicle that are likely to detect bridge conditions. Figures 3 and 4 present example acceleration and deflection histories for the lead side frame of the instrumented freight car simulated in NUCARS. The results showed noticeable differences between the normal condition of the bridge (blue line) and the weak stringer (red line). The acceleration data showed differences in both amplitude and frequency content while the displacement data showed only large differences in displacement. Note that with an actual onboard system, vehicle motions would probably be measured with accelerometers. Displacements would need to be derived from the acceleration data. Results of the modeling were analyzed to identify the most promising locations to install transducers on an onboard measurement system.

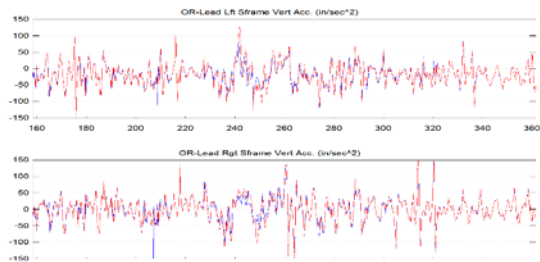


Figure 3. NUCARS Acceleration Histories for Lead Side Frame

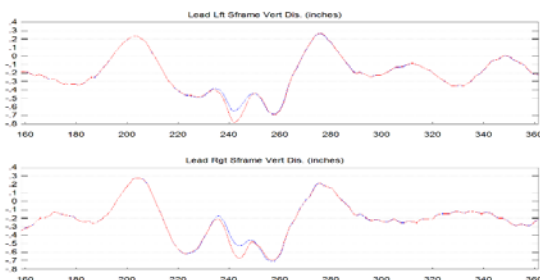


Figure 4. Displacement Histories for Lead Side Frame

Simulation results were compared to the field measurements. Figure 5 presents histories of displacement derived from measured acceleration and simulated displacement in NUCARS. The displacement signal from the measurements did not exactly overlay with NUCARS

simulated results; however, the overall amplitudes had similar magnitude at all the major features. Taking into account that a generic car was used in the simulation instead of an exact model of the instrumented freight car, the comparison of results are considered a good validation of the NUCARS modeling.

The best locations for the onboard system were chosen based on the location of accelerometers already installed on the instrumented freight car and potential improvement that could be easy to implement. The onboard technology to detect changes in the bridge behavior should distinguish changes in the left and right sides of the bridge. Previous tests with the instrumented freight car showed potential for using carbody accelerometers and side frame accelerometers.

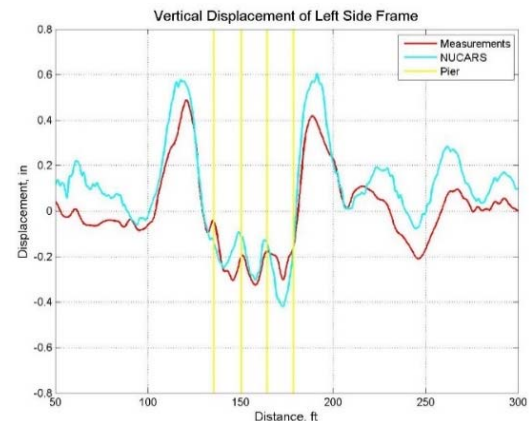


Figure 5. Comparison of Displacement Histories for Side Frame – Measurements vs. NUCARS Simulation

Many different locations of accelerometers were simulated and the results were examined. Then, new locations and methods of installation were proposed. Figure 6 shows the locations of the new accelerometers. On the side frames two accelerometers were installed with foam to reduce high frequency input and the other two are installed without foam.

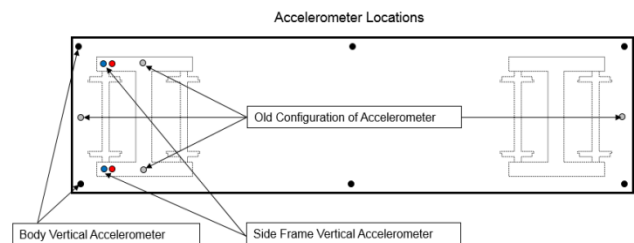
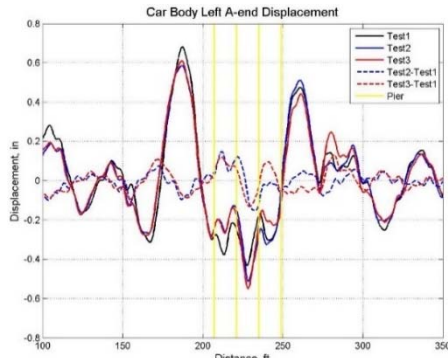


Figure 6. Locations of New and Old Accelerometers on the Instrumented Freight Car

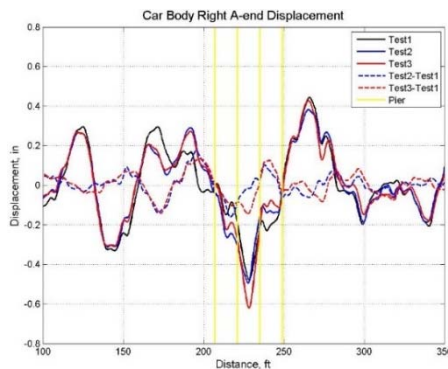
**Test Results from New Accelerometers**

Tests conducted in August 2014 showed the new configuration of accelerometers at A-end and B-end have the biggest potential to collect useful data. Also, the old configuration of accelerometers was not as good as the new locations, because it did not collect data from the left and right sides – only from the centerline of the carbody. Figures 7 and 8 show results of carbody displacements from the new transducers. The displacements show definitely that the left side of the bridge was weaker during Tests 2 and 3.

Although the differences were not as clear as for the left side, the right side results showed that during Test 3 the center span was weaker. This can be seen by looking at the relative displacement (dashed red line) between Piers 2 and 3.

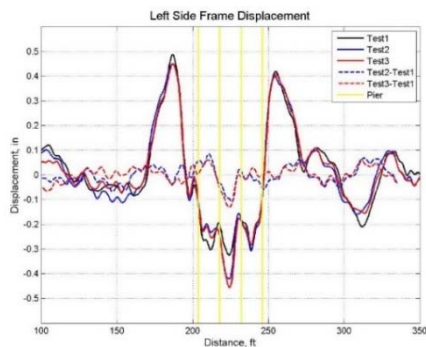


**Figure 7. Comparison of Carbody, Left side, A-end Displacement for Different Bridge Conditions**

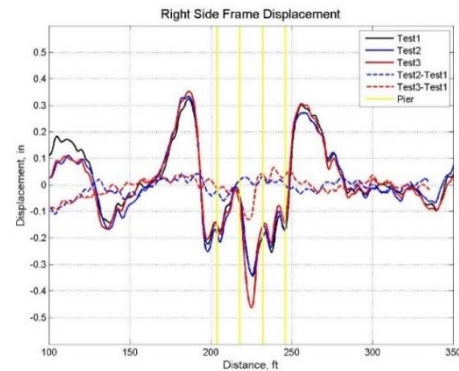


**Figure 8. Comparison of Carbody, Right Side, A-end Displacement for Different Bridge Conditions**

A significant improvement was noticed between results from the old configuration and the new locations of accelerometers placed on the side frame. Almost no difference was found between new configurations of accelerometers with and without the foam mounting. Therefore, only results from the new locations are presented in Figure 9 for the left side frame and in Figure 10 for the right side frame. The relative displacement (dashed lines) between Pier 2 and Pier 3 shows definitely that Test 2 and Test 3 have a weak span on the left side (Figure 9). Test 3 also shows a weak span on the right side (Figure 10).



**Figure 9. Comparison of Left Side Frame Displacement for Different Bridge Conditions**



**Figure 10. Comparison of Right Side Frame Displacement for Different Bridge Conditions**

## CONCLUSIONS and FUTURE RESEARCH

NUCARS was used successfully to evaluate vehicle-bridge interaction presented in this TD (Part 2) and in TD-15-004 (Part 1).<sup>1</sup> Part 1 described in detail the modeling and validation of the bridge performance. Part 2 presents additional NUCARS simulations and tests on the BDTF that were conducted in August 2014 using an onboard measurement system with transducers and locations derived from the NUCARS simulation results.

This TD compared test results to the NUCARS simulations to validate NUCARS capability to simulate bridge performance and the responses of an onboard data system. Test and simulation results were used to improve the onboard measurement capability.

The new configuration of accelerometers provided useful results for bridge condition evaluations. First, all data from accelerometers was post-processed to develop displacements from the instrumented freight car accelerations. Then, the results from different bridge conditions were compared and relative deflections were calculated. Side frame displacements clearly identified a change in bridge condition. Carbody displacements also showed good correlations with bridge conditions, but they were less definitive than side frame displacements.

The results of the testing with revenue service production vehicles are presented in TD-15-006 and TD-15-007.<sup>2,3</sup>

## REFERENCES

1. Rakoczy, A., X. Shu, and D. Otter. February 2015. "Vehicle/Bridge Interaction Modeling and Validation – Part 1." *Technology Digest* TD-15-004, AAR/TTCI, Pueblo, Colorado.
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