Railroad Bridge Monitoring Case Study: Little Calumet River Bridge

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ABSTRACT: This case study summarizes campaign-type and continuous monitoring deployments of wireless smart sensors for the Structural Health Monitoring (SHM) of a railroad truss bridge near Chicago, Illinois. A top bridge research priority is to help railroad owners in their inventory management by measuring bridge responses under train loadings (Moreu and LaFave, 2012). More information about this project is available in a technical report (Spencer et al., 2015).

Test Structure and Measured Data

Canadian National Railway Company (CN) identified a two-track steel truss bridge for instrumentation and testing. The focus of this monitoring was the intermediate steel truss (tracks CN1 and CN2 – Figure 1), a 310'-4" span with both passenger and freight traffic in both directions: North Bound (NB) and South Bound (SB). The primary objective of this monitoring deployment was to SHM system for railroad bridges in North America using wireless smart sensors.

This project demonstrated that railroad bridge load response data can be efficiently collected using wireless smart sensors, and this data was used to predict structural responses of the bridge under trains running at different loads and at higher speeds. Figure 2 shows the general sensor deployment, including wireless accelerometers, wireless strain gages (both conventional and magnetic), and wired Linear Variable Differential Transformers (LVDT) for measuring transverse displacements. Both SHM-A (measures up to 2g) and SHM-H (measures up to 200 mg with 10 times higher sensitivity) accelerometers are used. To make strain measurement easier and simpler, a magnetic strain checker was used (see Figure 3). The magnetic strain checker (frictional strain gauge) model FGMH-2A from Tokyo Sokki Kenkyujo Co., Ltd was used. A permanent base station PC with a cellular internet connection was installed at the bridge to control the network and to collect data throughout the project. The base station collected the response of the bridge under regular traffic and made it available for autonomous remote monitoring.

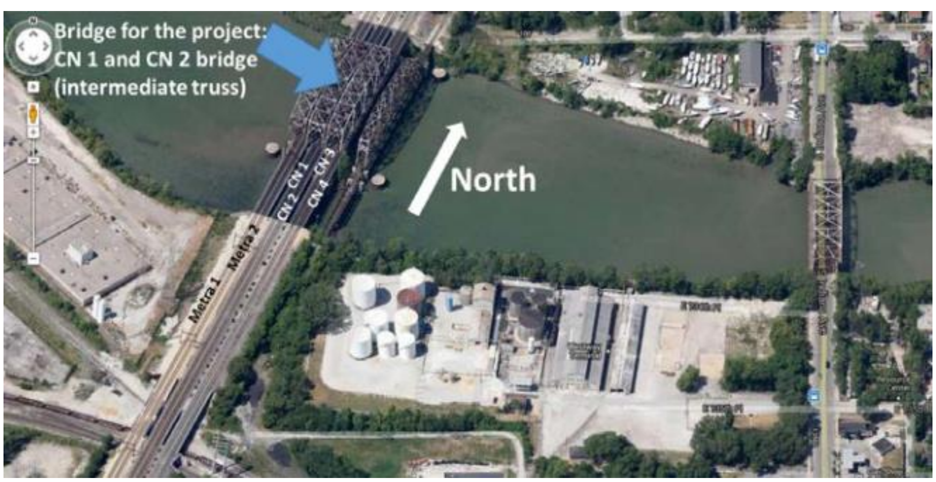


Figure 1: Bridge over the Little Calumet River (near Chicago, IL).

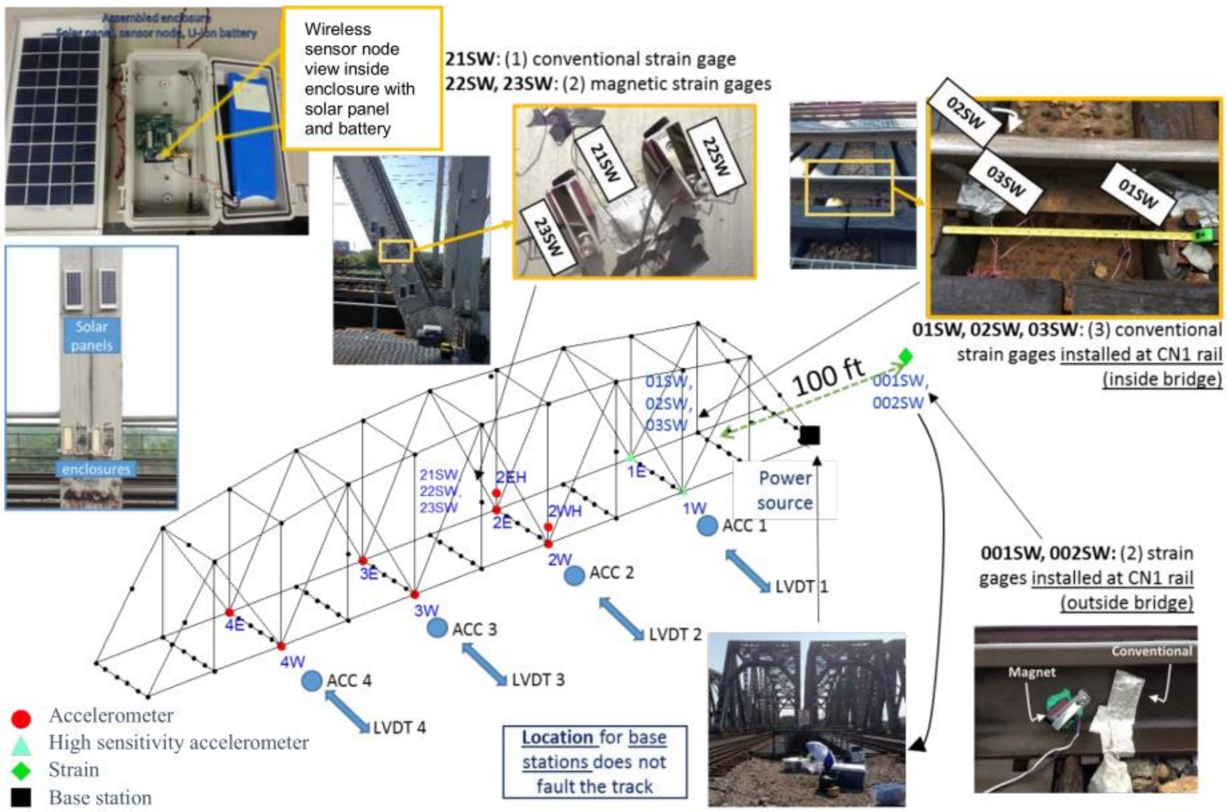


Figure 2: General layout of the sensors installed at the bridge.

Several sets of data under regular train traffic were collected during multiple campaign monitoring trips to the bridge and during remote monitoring of the bridge. The magnetic strain sensor was calibrated using multiple measurements of known loads and measuring the difference in magnitudes between the uniaxial magnetic strain and the conventional Tee-Rosette strain. Once the magnetic strain was calibrated, it was used independently for rapid strain monitoring of unknown loads. The vertical loads on the rail were estimated as the wheels passed over the strain gage. If a set of known loads crossed the bridge, re-calibration was performed on the strain measurements for higher accuracy.

Figure 3: Magnet strain checker.

The project team selected the L4-U5 element (diagonal truss member) for collecting structural strain under regular freight train traffic, because elements L4-U5 and L6-U5 are the only two elements in the truss undergoing significant levels of tension and compression due to trains crossing the bridge. Element L4-U5 was closer to the north end of the truss. Figure 4 shows a plot of the time history of the structural strain together with the rail strain measurements (at the L1 location) under the same train.

Displacement data was used for the dynamic assessment of the bridge responses. Examining the free-vibration response after the train crossed the bridge showed the damping in the first mode of the unloaded bridge to be 0.3% of critical damping. Additionally, the LVDTs captured the lower frequency response of the bridge, allowing confirmation of frequency components estimates from the high sensitivity accelerometers. The FE model of the bridge can be updated accordingly and used to obtain predict strain responses under loads in any member of the bridge.

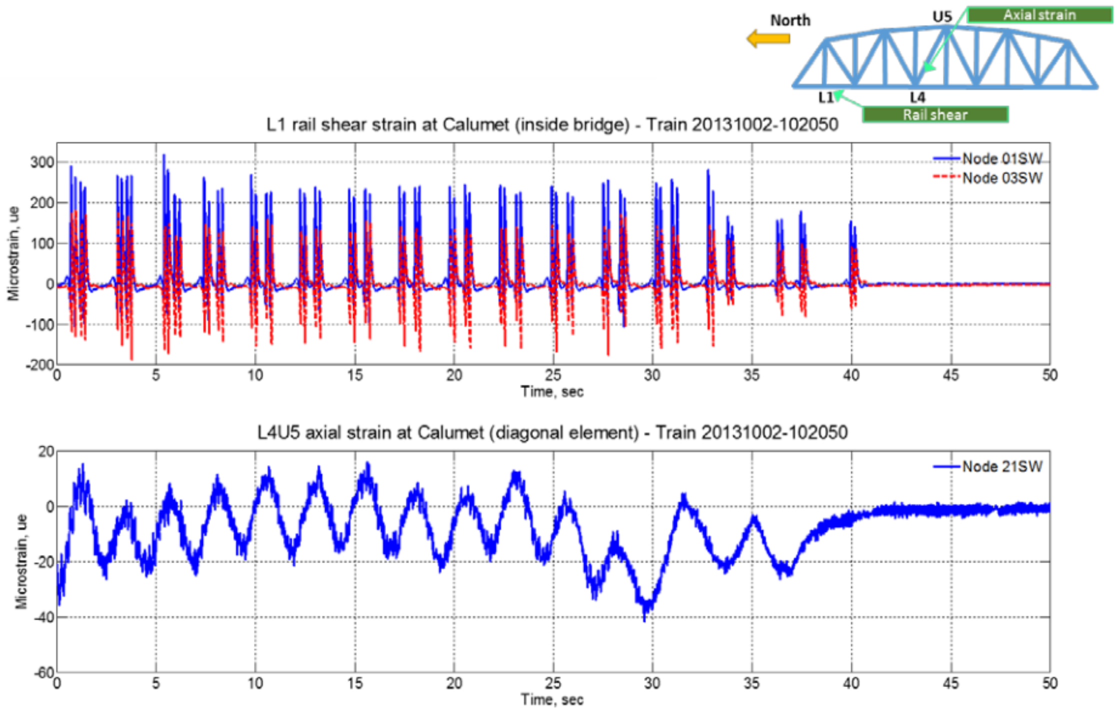


Figure 4: Rail shear strain at LW and structural strain at L4-U5.

SHM Methodology and Results

The estimation of the strain from the FE model was performed using static analysis, because the dynamic component is not significant in the member strain. The result exerts the predictive power of the FE model, providing a good tool for understanding the bridge behavior under given wheel loads. See Figure 5. Once the predictive power of the entire system is proved, the wheel loads determined from the instrumented rail in combination with the FE model of the bridge can provide an estimate of the strains and stresses experienced at arbitrary locations on the bridge.

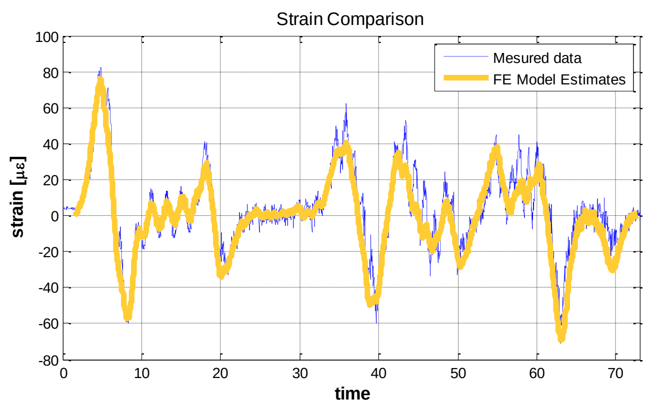
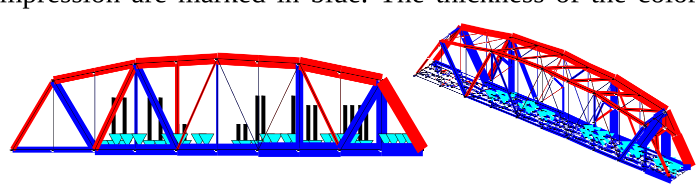


Figure 5: Strain comparisons.

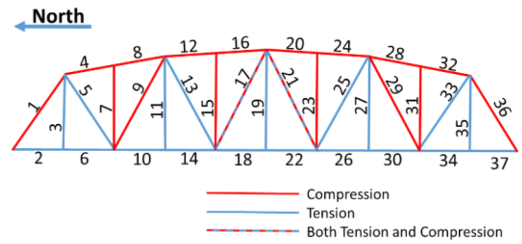
Figure 6 provides the evolution of the strain map as the work train crosses the bridge in 2D and 3D. The cyan triangle indicates the estimated locations of the wheels as the work train crosses the bridge. The length of the black lines above the cyan triangles indicates the magnitude of the wheel loads. Members in tension are marked in red, whereas members in compression are marked in blue. The thickness of the colored elements indicates the relative magnitude of the strain in each element. Then, Figure 7 shows the FE model estimates of maximum stresses for all the truss elements in the bridge under different



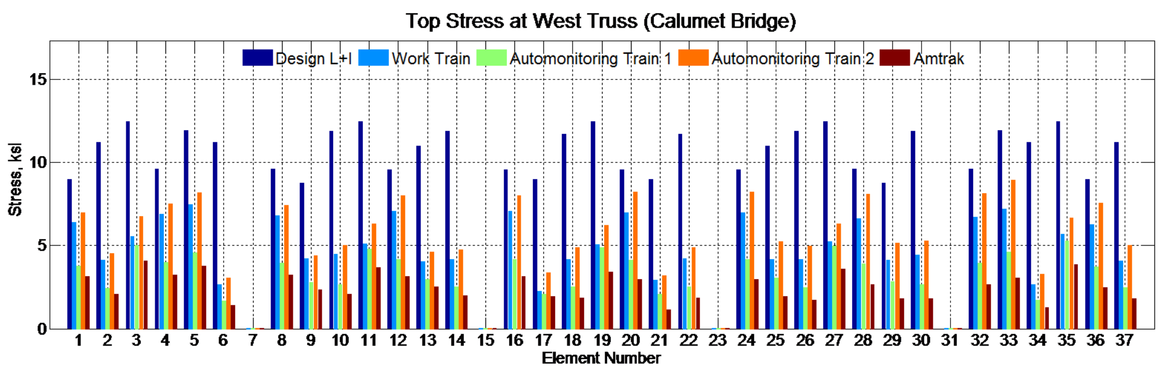
(a) 2D view (b) 3D air view

Figure 6: Strain map predicted by the FE model.

trains, as compared to the design stresses. As shown, the stress levels are lower than the design stresses. The endurance limit is the amplitude of cyclic stress that a member can undergo without experiencing fatigue, which is 30 ksi for structural steel. Based on a linear analysis, the stress levels measured in the bridge and those predicted by the FE model are well under the fatigue endurance limit. In the future, this predictive tool can estimate the remaining life of steel trusses where fatigue may be of concern.



(a)



(b)

Figure 7: Predicted stress under trains: (a) truss element labeling, (b) stress assessment.

Lessons Learned

This project successfully demonstrated a basis for developing a database of expected railroad bridge behavior based on measured bridge responses. Such a database would enable quickly measuring railroad bridge behavior under train loads. Railroads can use this information to prioritize railroad bridge repairs and make replacement policies.

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References

[1] Moreu, F., and LaFave, J.M. (2012). *Current Research Topics: Railroad Bridges and Structural Engineering*. Report No. NSEL-032, NSEL Report No. 032, Newmark Structural Engineering Laboratory Report Series. [http://hdl.handle.net/2142/34749].

[2] Spencer BF, Moreu F, and Kim RE (2015). *Campaign Monitoring of Railroad Bridges in High-Speed Rail Shared Corridors using Wireless Smart Sensors*. Report No. NSEL-040, Newmark Structural Engineering Laboratory Report Series. [https://www.ideals.illinois.edu/handle/2142/78095].