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Considerations for Railroad Bridge Monitoring, Measurements & Structural Health Monitoring

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Summary

Transportation Technology Center, Inc. and the Association of American Railroads have a long history of railroad bridge measurement and monitoring, primarily for research purposes. In recent years, a number of vendors started offering structural health monitoring (SHM) systems, which take numerous measurements and promise bridge life extension. This digest offers an overview of the fundamentals of bridge monitoring and measurements, as well as examples and suggestions for appropriate use of each.

Key issues discussed include:

- Targeted applications are best for any monitoring, measurement, and SHM efforts.
- Several bridge monitoring or protection systems are already in regular use by railroads, although they do not fit the current marketing definition of SHM systems.
- One-time, short-term bridge measurements can be beneficial, particularly in conjunction with load capacity rating.
- Periodic monitoring can be beneficial and often is more appropriate than SHM.
- Railroads generally need actionable information as opposed to vast quantities of data potentially available from SHM systems.
- Any new systems should be highly reliable to keep false alerts, unplanned maintenance, and resulting service outages to a minimum.
- Best use for a full-time SHM system seems to be to get a few extra years out of an old bridge until a replacement is provided.
- SHM systems need to be as maintenance-free as possible or the cost of maintenance and the track time needed to perform maintenance will offset potential benefits.

The cost of a SHM system including ongoing operation, maintenance and repairs should be compared to the cost of bridge repairs.



INTRODUCTION

With increasing recognition of the nation's aging infrastructure, a number of products and services related to structural health monitoring (SHM) are coming to market. The challenge is to determine what sensors or technologies meet the needs and provide positive benefits for railroad bridge monitoring. Another challenge is to target the sensors and technologies to the bridges where they will provide a benefit. Railroads are already using a number of appropriate technologies to monitor the health and safety of their bridges.

A recent study investigated the causes of railroad service interruptions related to bridges.¹ It identified monitoring needs to reduce bridge service interruptions. Major causes of bridge service interruptions included strikes by highway vehicles, marine vessels, or railroad equipment; hydraulic issues such as flooding, scour, or washout; movable bridge signals or mechanisms; and fire. Railroads are already employing several systems targeted to address many leading causes of bridge service interruptions. In contrast, many of the new SHM devices being offered have limited potential to further reduce bridge-related railroad service outages. Most of these SHM systems focus on monitoring strains in bridge members. Yet failed structural members accounted for only 1 percent of railroad bridge service interruptions.

USES FOR BRIDGE MONITORING DEVICES OR SYSTEMS

Monitoring to Warn of or Protect Against Common Causes of Bridge-Related Service Outages

Railroads are already using several types of alerting systems, targeted to specific hazards or bridges:

- Weather notification networks and high water detectors provide warning of flooding and potential washout. The weather notification networks cover the entire railroad, and provide warnings for train operations and other hazards in addition to bridge related issues. High water detectors are targeted to specific bridges with a particular vulnerability or history of high water events.
- Earthquake notification networks provide warning of seismic events. These networks again are system-wide and provide warnings for train operations and other potential hazards in addition to bridge-related issues.
- High-wide / shifted-load detectors, dragging equipment detectors, and inner guardrails protect against bridge strikes from railroad equipment. These are commonly used to protect through truss spans which are the most vulnerable to damage from shifted loads or derailed equipment. Again, use is targeted to a specific hazard for a particular type of bridge.
- Some railroads have installed or experimented with bridge strike warning/notification systems, prevention systems, and/or protection systems for low-clearance highway underpasses. Again implementation is targeted to bridges with a particular history and vulnerability for strikes from over-height highway vehicles.

- Movable bridge signal systems are required to provide track integrity for movable bridge spans. These systems are also a significant source of train delays as noted in a previous study.¹ The large number of delays related to these systems points to potential pitfalls for additional monitoring systems – false alerts and maintenance requirements might offset potential benefits.
- Wheel Impact Load Detectors (WILD), Weigh-In-Motion (WIM), and other vehicle performance detectors provide notification of high impact wheel loads, and overweight or unbalanced vehicles. These systems protect the entire rail and track infrastructure, including bridges, from loads that can shorten service life. These devices are typically not located near bridges, but provide protection nonetheless.

These devices and systems provide important alerts that address a number of the most common causes of bridge-related service outages for railroads. These devices and systems, while operating 24/7/365 with high reliability, are often not considered to be SHM.

Monitoring for Purposes of Bridge Capacity Rating

Some railroads perform bridge measurements to help determine the load rating capacity for selected bridges. These measurements are normally performed on a one-time, short-term basis. Data is collected at the bridge site and analyzed in detail in the office. There is typically no need for dedicated on-site power or communications, no need to harden the system for long-term protection from the environment, no need for automatic triggering to turn on the system, and no need for compensation of long-term thermal or weather-related corrections.

Measurements collected for rating purposes are strains, deflections, and/or accelerations. Measurement transducers are selected and located based on analysis and inspection. Measurements are targeted to members and locations related to capacity or loads experienced by a member.

Bridge capacity rating measurements are performed on older bridges that might be performing well in service, but have calculated capacity near a desired limit. These measurements might also be performed on a bridge to assess performance before and after strengthening or other modifications. These types of measurements have proven valuable to extend the safe service life of bridges in many cases.²

Cost model for a typical installation of this type is a one-time cost of making the measurements. Benefit is typically a delay in bridge replacement. For major structures with large replacement values, the cost is typically easy to justify. For small common spans, measurement of a few representative samples can have a similar benefit.

The best uses of this type of bridge measurement are to provide a better bridge rating and better understanding of bridge behavior. Another potential use might be to determine behavior in a new bridge if there are questions regarding construction deviations from design plans.

Figure 1 shows an example of a bridge instrumented by TTCI to verify fatigue calculations. Measurements consisted of strain gages at quarter span and mid span locations. Data was recorded for unit trains of coal, grain, and tank cars. The measurements validated the effects of car length on the moment and stress ranges at those girder locations.³



Figure 1: Bridge instrumented by TTCI for one-time, short-term measurements to confirm calculations

Periodic Measurements of a Selected Bridge

Periodic measurements of a selected bridge are made to observe changes in performance over the long term. In many cases, periodic monitoring is more appropriate than full-time SHM, particularly if it is not necessary that the bridge be monitored at all times and for all traffic over the bridge.

Periodic measurements are targeted to particular members and locations of specific bridges. Data is collected at the bridge site and analyzed in detail in the office. There is no need for dedicated on-site power or communications, for automatic triggering to turn on the system, or for compensation of long-term thermal or weather-related corrections. If there are parts of the system (for example strain gages), that are left in place, it may be necessary to harden these parts of the system for long-term protection from the environment, wildlife, and vandals. There is no need for 24/7/365 reliability.

Measurements collected on a periodic basis are strains, temperatures, deflections, and/or accelerations. Measurement transducers are selected and located based on analysis and inspection. Periodic measurements are targeted to members and locations to monitor potential changes in the behavior or loads experienced by a member; e.g., for bridges where a change in traffic is anticipated, or for a bridge span of new design where no long-term performance data is yet available.

The cost model for periodic measurement systems includes the initial installation, plus the cost of repeat visits. The initial installation cost would be marginally higher than that for a one-time measurement; repeat visits would be less expensive assuming some components of the installation remain in place; better evaluation or further implementation of similar span designs or modifications may result from data collected that quantifies changes over time.

Figure 2 shows an example of a bridge instrumented to document baseline performance of the first revenue service installation of a hybrid composite beam span in railroad service. As no long-term performance data exists for these spans, the intent is to monitor this bridge annually for a number of years, observe any changes in performance, and compare to performance of a similar span at the Facility for Accelerated

Service Testing (FAST).⁴ Data was recorded for both mixed freight and unit commodity trains.



Figure 2: Bridge instrumented by TTCI for periodic measurements to observe long-term performance

Measurements consisted of strain gages at mid span at six transverse locations, as well as mid span deflections. Strain gages were applied with a long-term adhesive and protected from weather for use in subsequent annual measurements. Deflection measurements were taken using string potentiometers, which (for this bridge) can be quickly reinstalled on subsequent visits.

Full-Time SHM

SHM is generally considered to be a 24/7/365 operation, monitoring many aspects of the performance of a bridge. If there is a concern that a critical change needs to be detected and reported immediately, some form of SHM might be justified. Transducers installed include strain gages, accelerometers, thermal measurements, and displacement measurements.

A full-time SHM system requires a more rugged, reliable, and extensive installation as compared to other systems. Dedicated on-site power and communications are required. There is a need for automatic triggering to activate the system as a train approaches and then cease data collection once all trains have cleared. There is a need for compensation of long-term thermal or weather-related conditions. The system and its various cabling and components need to be hardened for long-term protection from vandalism and the environment. All cabling should be run through conduit. The hardware needs to be rugged. Protection from lightning and power surges is necessary. The software needs to be robust and complete with error trapping, system diagnostics, and should be able to be reconfigured remotely. The software should provide in-the-field data reduction to minimize the amount of data that needs to be sent via the communications link. The transmitted data should consist primarily of actionable information, not a data dump.

Challenges for implementing full-time SHM on railroad bridges are cost, system reliability, and turning the data into actionable information. Installation cost alone is several times higher than for other systems. Reliability includes minimizing false alarms, minimizing the need for maintenance and system adjustment, and keeping the system functioning around the clock through all seasons of the year in the railroad environment.

A full-time SHM system should be capable of making integrity checks on the data, performing self-diagnostics,

automated data reduction and processing, and integration with car identification systems. To provide actionable information for the owner, the SHM system should incorporate trending analysis for long-term changes and provide robust detection algorithms for critical changes in behavior. At some point, it might be desirable to communicate data to passing trains.

Some new highway bridges have numerous sensors (that provide volumes of data) installed during construction, but the question is: Will the sensors and data acquisition system last until the bridge degrades to the point of needing a monitoring system? Also, are the transducers located in the places where needed when degradation begins to take place? Installing sensors on older spans rather than on new railroad bridges would seem to be a greater priority.

The best use for a full-time SHM system on a railroad bridge seems to be to reduce risk to get a few extra years of life out of a major bridge until a replacement is put in place. The cost of the system should be compared to the savings by delaying replacement. The cost model for a full-time SHM system includes initial installation (several times higher than previous systems), sometimes an ongoing operating contract, and periodic maintenance and repairs. Other costs may be train delays due to maintenance, false alarms, and unscheduled equipment repairs. The economics for SHM make it best suited for major structures, when a delay in bridge replacement might be worth the expense of the SHM system to reduce risk for continued service.

Figure 3 shows an example of a span with a full-time SHM system installed at FAST. A system of safety devices and measurements was in place during the testing at FAST of a welded steel girder span with a crack in the tension flange.⁵



Figure 3: Full-time SHM system installed on steel girder span

Devices included a deflection limit switch connected to an alarm beacon, strain and deflection measurements, and a manually operated maximum deflection monitoring device. In addition, safety cribbing was installed beneath the span to catch it if the crack rapidly propagated through the girder. The deflection measurements were analyzed in real time to produce a green-yellow-red light indication as part of the train and track performance monitoring display for the train operations manager. The system components were somewhat protected from the elements, but the system was not hardened to protect it from vandalism. Due to the safety critical nature of the testing,

the three deflection systems were all completely independent. The limit switch and the manually operated deflection device could be easily checked as needed before or during operation.

Conclusions

Several types of bridge monitoring, measurement, and SHM systems are available for use on railroad bridges. From one-time, short-term measurements to full-time, long-term installations, the type of measurement system selected should be appropriate for the intended purpose.

- Targeted applications are best for any monitoring, measurement, and SHM efforts.
- One-time, short-term bridge measurements can be beneficial, particularly in conjunction with load capacity rating.
- Periodic monitoring can be beneficial and are often more appropriate than SHM. Periodic monitoring is particularly useful to establish changes over longer time durations.
- Regarding SHM systems in particular, the following cautions are offered:
 - Railroads need actionable information as opposed to vast quantities of data from SHM systems.
 - Any new systems must be highly reliable to keep false alerts, unplanned maintenance, and resulting service outages to a minimum.
 - Best use for a full-time SHM system seems to be to get a few extra years out of an old bridge until replacement funding is in place.
 - SHM systems need to be as maintenance-free as possible so that maintenance and track time costs don't offset potential benefits.
 - Cost of a SHM system including ongoing operation, maintenance, and repairs should be compared to the cost of bridge repairs.

Note that railroads are already using several bridge monitoring or protection systems, although they do not fit the current marketing definition of SHM systems.

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