Bearing Monitoring Case Study

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ABSTRACT: Bearing performance is closely tied to overall structural performance and serviceability issues and as a result demands considerable attention for condition assessment. It has been well documented that the lifecycle of bearing systems is far less than that of the bridge and will eventually breakdown causing undesirable forces / deformations. Currently the most common assessment method for bearings and other movement systems is through visual inspection. However, there is limited correlation between visual appearance and the functionality of movement systems. One solution is to perform temperature-based (TB) monitoring which can supplement visual inspection through the measured input-output temperature responses. A case study using this methodology is presented for a targeted bearing monitoring application along a steel tied-arch bridge.

Figure 1: Steel Tied-Arch Bridge

Test Structure and Measured Data

The TB structural health monitoring (SHM) system was installed along a 168m (550ft) steel tied-arch bridge, designed and constructed in 1929 (Figure 1). The monitoring system designed leveraged multiple input-output TB relationships. To measure local and global output responses it was decided to locally measure the member strains along the arch middle chord members framing into the bearings. Global longitudinal displacements were also measured at the bearings relative to the pier. Figure 2 illustrates the instrumentation setup locations. The temperature input was recorded at each of the sensors along with ambient temperature from a weather station. Redundancy was achieved in the experiment through installation of multiple strain gages along each middle chord. In addition, both the upstream and downstream sides were instrumented for strain and displacement measurement. All the sensors were recorded with a Campbell Scientific datalogger at a sampling rate of 3 minutes and remotely accessed in real-time through a cellular modem.

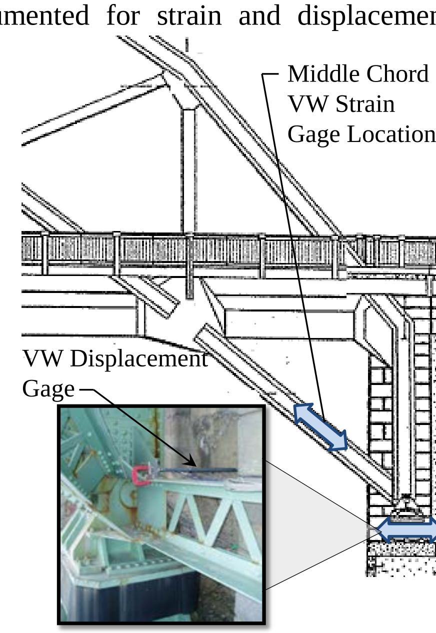


Figure 2: Measurement Locations

SHM Methodology and Results

A general framework was created for the bearing assessment which is broken down into six primary stages [1,2]. The primary objective of the study (Stage 1) was to assess / monitor the performance of the bridge bearings and resulting influence on the structural system. The west end expansion bearings were identified as critical mechanisms (Stage 2) since they allow for adequate thermal movement of the structure reducing any build-up of thermal forces. Performance metrics were then established (Stage 3) for quantitative assessment of the bearings (discussed further below). Next a monitoring system was designed (Stage 4) to evaluate these metrics (briefly discussed above). The system was installed (Stage 5) along the structure and data was recorded for roughly a year. This data was processed and the performance metrics were evaluated (Stage 6).

Metric 1: Percentage of Movement

The first metric was to calculate the percentage of measured to theoretical movement. If the movement was more or less than anticipated, then further evaluation would be justified to understand why. This was achieved through linear regression analysis of the measured displacement data for comparison with the theoretical movement. Linear regression was performed on roughly one year of data for each of the expansion bearings. Figure 3 illustrates the results from the upstream bearing. The slope of the best-fit line was used for the quantitative comparison of measured versus theoretical response. This technique was also utilized by Herman et al. [3]. Note that linear regression was considered adequate despite the nonlinear (short-term) behavior because the long-term slope of displacement versus temperature data can best be captured with a linear best-fit relationship. The nonlinear behavior was characterized in a separate study utilizing model-experiment correlation with a method termed Temperature-Based Structural Identification [4].

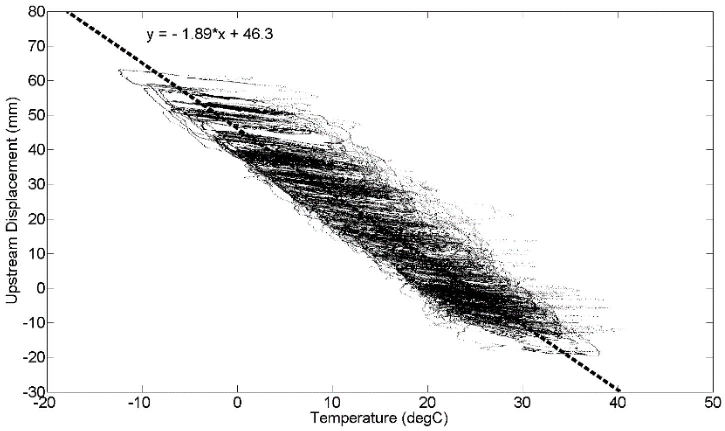
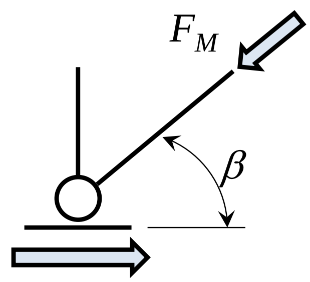


Figure 3: Upstream Temperature vs. Displacement Relationship

Stage 2: Coefficient of Friction

A second quantitative assessment metric was performed utilizing the middle chord member forces (F_M) (converted from the measured mechanical strains) to identify the current bearing plate coefficient of friction. Equilibrium was then used by summing the forces in the horizontal direction to find the bearing frictional forces. Negligible shear force was assumed in the vertical member above the bearing. Therefore, the bearing friction force (F_{FR}) was set equal to the horizontal component of the middle chord member. Figure 4 illustrates a free body diagram at the expansion bearing. The coefficient of friction of the bearings was then obtained using the dead load reactions. This value can be either calculated or pulled from the existing construction drawings.



$$F_{FR} = F_M \cos(\beta)$$

Figure 4: Free Body Diagram at the Expansion Bearing

Stage 3: Recovery

A global evaluation was also performed using the overall recovery of the arch to thermal movements and mechanical strains. If the structure continually returns to a common state of equilibrium, this is a good indicator the structure is performing properly. Conversely, if the data continually drifts (when utilizing a zero drift sensor such as VW technology) it may be a sign of a potential problem with the bridge related to changes in the global load path, and could be potentially worsening over time. If this were the case, an in-depth evaluation must be performed to fully understand the situation. The approach utilized to quantitatively assess recovery was to use the temperature and displacement time history data. For each of the time histories a high order polynomial was fit to the data to establish a general trend over the long-term. Figure 5 illustrates the temperature and displacement time histories showing the raw data along with the polynomial fit curves. The next step was to select a discrete temperature within the first few months of recording (5°C was selected). The corresponding record for that temperature was pulled from the curve. Then the displacement reading for the same time record was obtained. While this analysis is analogous to plotting temperature versus strain, given the complex strain and displacement relationship for this structure, the presented analysis was carried out for further verification. Note that the seasonal middle chord mechanical strain data was also investigated. However, long-term drift was clearly not present.

Summary of Results

The assessment concluded the bearings were performing adequately in their present condition (10 years after installation). This was a result of the regression analysis closely matching theoretically calculated expansion and contraction of the arch (97% to 98% of the expected values). The coefficient of friction was determined experimentally as 0.07 which was within the bounds specified by the bearing manufacturer (ranging from 0.045 to 0.10 based on the temperature). In addition, 95% recovery of the longitudinal displacement measurements was calculated indicating sufficient recovery.

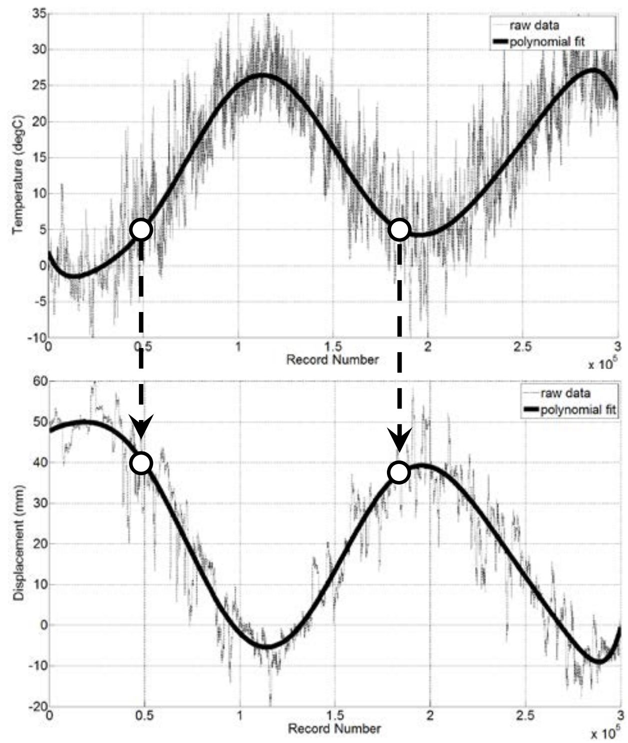


Figure 5: Global Recovery Illustration

Lessons Learned

As a result of the SHM case study performed along a steel tied-arch structure several overarching conclusions and recommendations were drawn specifically as they relate to bearing assessment:

- Functionality of movement mechanisms (e.g. expansion bearings) cannot be adequately assessed solely from visual appearance, due to the lack of correlation between visual appearance and performance. Targeted sensing technology, if applied with sound engineering knowledge and experience, can be used to sufficiently evaluate these systems.
- To perform TB monitoring on an existing structure a logical framework should be followed. This should include the identification of clear performance metrics beforehand that quantitatively assess the performance of the system and allows for an objective measure of bearing performance.
- TB monitoring should (1) include measurement at both the local and global levels, (2) consist of redundant sensors, (3) characterize in-situ coefficient of thermal expansions and incorporate with instrumentation where applicable, (4) select the appropriate sensing technology for the mechanism timescale, and (5) utilize reliable sensing hardware designed for harsh environments.
- The arch bridge owner now has a reliable means to evaluate in real-time the performance of the bearings in comparison to the performance metrics identified through the monitoring to-date. In the event of a bearing failure, the temperature-displacement relationship would be altered in a detectable way allowing for the deployment of maintenance action items in a timely fashion.

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