Structural Monitoring Solutions: Concepts and Best Practices

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Summary
Structural monitoring systems have long been deemed technically impractical and too expensive by many bridge owners due to traditional, data-intensive, academic-driven applications. However, through the use of best practices developed over the past decade, this technology has become more practical for commercial uses, while providing owners a return on investment.

Keywords: structural monitoring, sensors, condition assessment, safely extending asset life℠, progressive diagnostics.

1. Introduction

While the benefits of structural monitoring solutions are now more widely accepted, the burdensome amount of data produced by its early application has perhaps prevented the technology from gaining the widespread acceptance it deserves. Owners understandably struggle with how these solutions should be most effectively configured for the best possible results at the lowest possible cost.

Many monitoring installations continue to capture massive amounts of sensor data, which has led to data storage issues, significant expense, and complex analytic approaches with limited practical value for bridge management. Commercial solution providers, however, can use fewer sensors to achieve their desired results while providing owners a return on investment. While there will likely never be an approach that works for every structure, over the past 10 years, best practices have been developed to provide bridge owners with more practical structural monitoring solutions.

2. Best Practices for the Practical Application of Structural Monitoring

Bridge owners should consider the following best practice recommendations:

Data intensity is overrated. Experience suggests that capturing and returning data six to ten times per day is sufficient for detailed analytics, including building calibrated finite element models (FEMs). Typically, data collection times should occur at peak and non-peak traffic times to capture best- and worst-case loading events.

Sensor accuracy is overrated. Bridge owners can specify and purchase structural monitoring solutions that can provide accuracy to one microstrain. The added investment needed to obtain such accuracy will not necessarily produce improved actionable data. Instead, it has been found that accuracies of 20–40 microstrain are more than adequate to conduct sophisticated analytics, including calibrating FEMs.

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Only use sensors that fit the need. A substantial variety of sensor types have been developed over the past 20 years, but if a particular sensor isn't essential for the bridge owner's purpose, adding such sensors only detract from the return on investment. In the authors' opinion, displacement (strain) and temperature sensors are essential for structural monitoring. Other sensors should pass the test of necessity before deployment.

Monitoring periods are underrated. Short-term monitoring has limited applicability, for example, when conducting static load tests to determine a bridge's ability to safely carry a known load. Experience suggests that structural monitoring is most effective if the owner captures data over a full thermal cycle, as opposed to a period of one or two months. Thermal cycles can account for more than 80% of the observed strain in a bridge member. Having strain and thermal data over a longer period also supports the development of calibrated FEMs.

Minimize sensors to start; allow for progressive diagnostics. The application of the minimum number of sensors required to capture essential information for subsequent analytics will maximize return on investment. The deployment of fewer sensors helps to avoid the unwieldy and expensive data overload common to academic systems. Also, fewer sensors generally result in a more reliable overall system. As more diagnostic information leads to a better understanding of structure hot spots, sensors can be moved to new locations for enhanced monitoring effectiveness.

Professional installation is essential. There are substantial safety risks involved in installing sensors on bridges, so the task should only be performed by committed professionals with adequate safety training and gear. Also, if the monitoring period exceeds three months, using conduit for cable runs is strongly recommended. Of course, conduit is more expensive, but this is clearly a scope item that supports overall system reliability and consistent data capture while minimizing the potentially greater cost of rework.

A professionally managed network operations center (NOC) is crucial. The NOC must be managed by professionals who can provide believable reliability statistics on the order of at least five nines (e.g., 99.999%), or the equivalent of 20 seconds of downtime per month. Any alternative would risk a bridge owner not being alerted when a bridge member experiences strain or crack propagation that is above an established threshold. A less reliable NOC could potentially render any structural health monitoring system worthless to the owner.

Confirm a return on investment. Solution providers should be able to support a return on investment. The use of hard-number financial analysis based on safely extending asset life is recommended as the primary metric. By simply accounting for deferrals of capital expenditures (costs of rehabilitation or replacement projects) at reasonable interest rates (3–7%), and factoring in the probability of successfully achieving that result (25–40%), owners should recognize significant financial returns.

Given these guidelines, it is also important to consider that individual bridges will require systems tailored to their specific needs. Generally speaking, for example, older bridges require a different approach than new bridges. Fortunately, with the variety of sensor types and applications, structural monitoring systems are inherently customizable.

3. Conclusion

Structural monitoring solutions, far from being relegated to academic research, have useful functions in commercial bridge management programs. Well-informed bridge owners will, no doubt, want to take advantage of the best practices developed in this arena to harness technology to produce actionable data, to enhance safety, to gain an objective understanding of structural health, and most of all, to produce a return on investment.