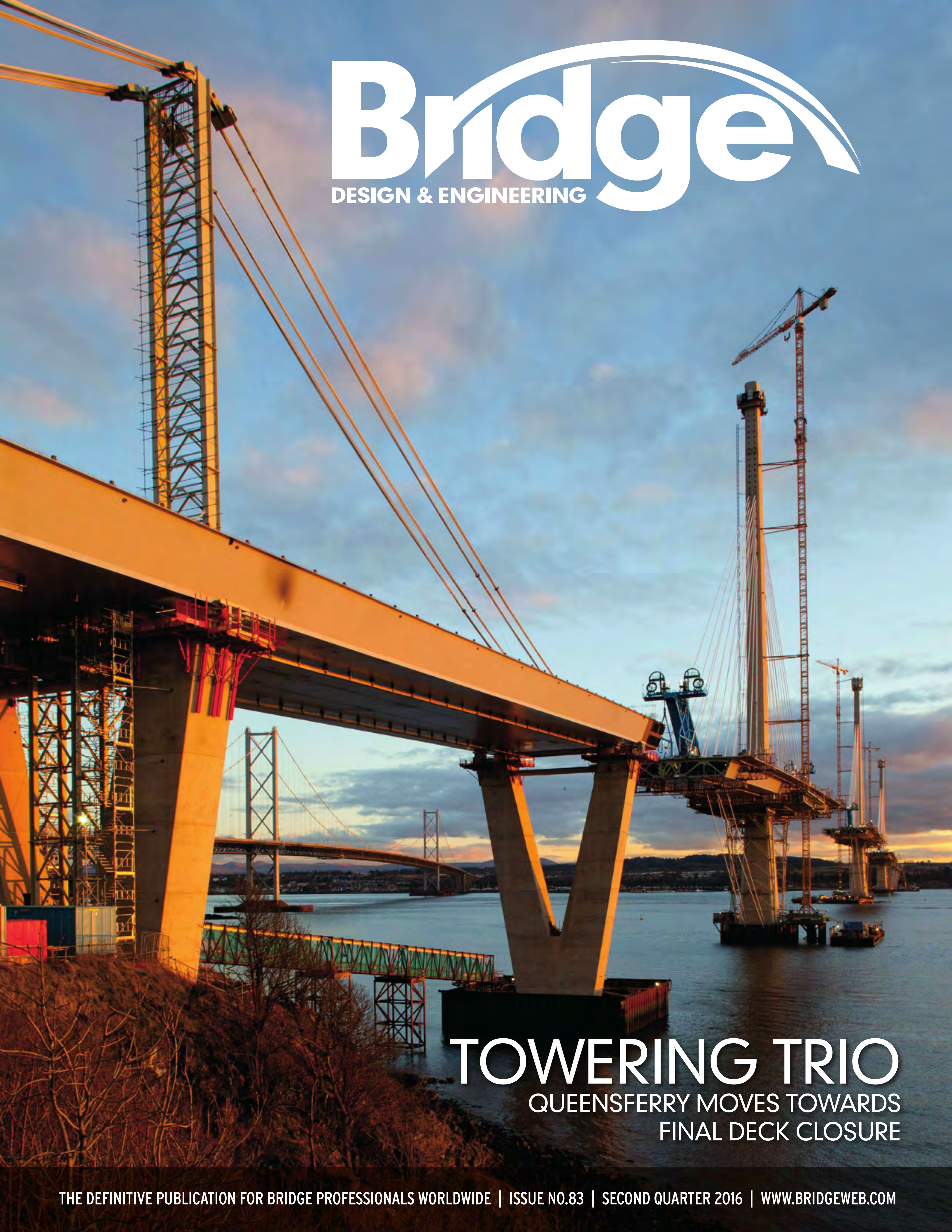
Bridge
DESIGN & ENGINEERING



TOWERING TRIO
QUEENSFERRY MOVES TOWARDS FINAL DECK CLOSURE

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The structural health monitoring system for the new Tappan Zee Bridge will be state of the art *(New York State Thruway Authority)*

ALL TOGETHER NOW

An effective structural health monitoring system is much more than just a network of instrumentation, explain **Thomas Weinmann** and **Fangzhou Dai**

Bridges are now being designed with expected service lives well beyond 100 years, and structural health monitoring systems in combination with bridge rating systems have been specified to provide rational basis for prioritisation of inspections and maintenance on primary and secondary structural components. For most signature bridge structures, bearing and expansion joint movements, cross-sectional stresses, pier movements and cable forces are just a few of the required measurement parameters that provide feedback which is used in finite element models of the structure to show real-time dynamic response. The components themselves - bearings, joints and cables for example – can be designed to provide this information, but by itself, this information does not provide a comprehensive evaluation of the structure for that specific component's performance or non-performance.

Conceptual work is currently being done to meet the requirements for the structural health monitoring system on the New Tappan Zee Bridge in the USA, and this is intended to address some of these issues.

Individual structural components on a bridge are often referred to as 'smart' when they are instrumented to provide a history of self-performance; something which is offered as a value-added service by the manufacturer or may be required in a performance specification. Information gathered from these components documents expected performance and can be used to identify maintenance requirements or focused inspections for specific components.

Bridge bearings are often instrumented during fabrication and calibrated during acceptance testing to document measured response for long-term cumulative measurements as well as response to event-driven conditions. These measurements can include bearing rotation, sliding displacement and/or bearing loads.

Cable force monitoring programmes are often performed on an 'as-required' basis which is established through vibration analysis surveys. However these surveys can only provide information for a single data point at any given time, and can potentially miss critical events of interest. For continuous monitoring, external accelerometers in conjunction with vibration analysis software can be used to determine average forces over a set time period; or through the use of fibre optic or standard strain gauges, anchorages can be instrumented to measure cable forces at any point in time and capture dynamic response.

Meanwhile expansion joints are often instrumented to measure joint movements in longitudinal directions and verify that joint expansion occurs uniformly across the joint. These movements are primarily attributed to temperature changes and usually include temperature sensors as well as displacement transducers.

All such 'smart' components provide valuable information to the engineer and owner with regard to the expected performance of the specific component and can help with long-term maintenance and focused inspection programmes

But, what happens to the rest of the structure or the adjacent structural components as a result of non-performance of the component or identified anomalies of component performance during event-driven conditions?

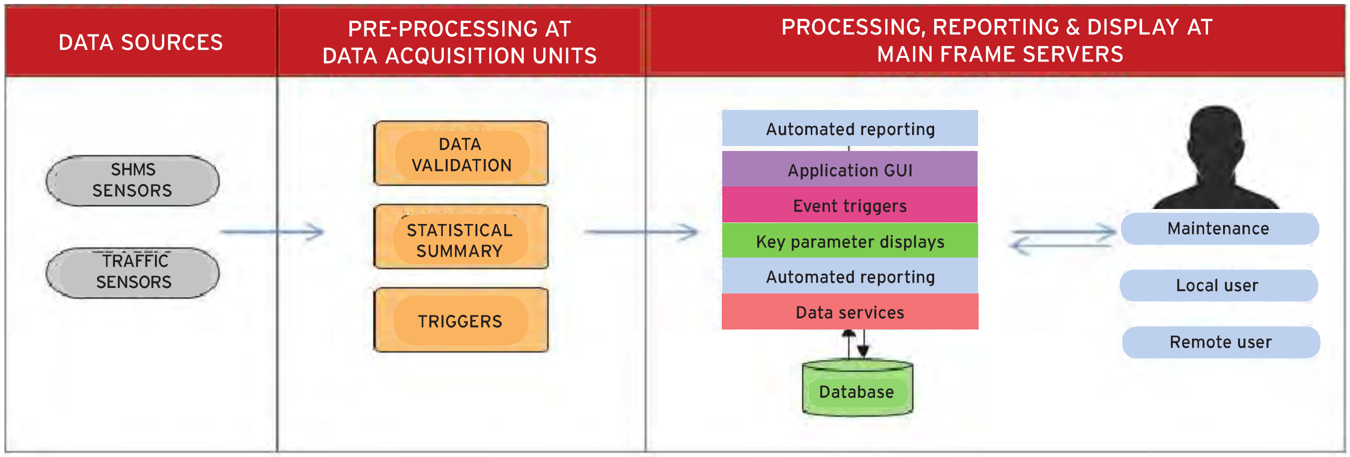
Bridge designers specify performance characteristics for nearly all components on the bridge structure and the degradation or unpredicted performance experienced by a single component can lead to larger than predicted stresses elsewhere.

The bottom figure on page 82 shows the potential interaction between a joint, cross-sectional deck strain and an adjacent pier. This could also apply to other components such as cable force, deck displacement and main-span bearings. While the information obtained from an individual component is valuable, the effects of this anomaly are seen on other parts of the structure.

A structural health monitoring system is used to detect changes that could potentially damage the structure through changes of the boundary conditions which may adversely affect a structure's performance. This includes the periodic sampling of dynamic response measurements, analysed through statistical methods to evaluate the current state of health of the structure. To identify the structure's response, key elements of the structure need to be instrumented in a methodology that allows for redundancy through measurements of component interaction.

While the value of individual component performance is recognised, the true value of a structural health monitoring system offers the ability to highlight more focused inspections, carry out timely maintenance and provide a more cost-effective asset management programme.

For a signature structure such as the New Tappan Zee Bridge, more than 780 measurements will be obtained from more than 480 sensors to provide automatic



Measurement processing - data are forwarded to the mainframe server and further analysed for event triggers, data archival and display

assessment of this statistically-analysed data. These measurements, providing mostly dynamic response data, generate an overwhelming amount of data, which initially has to be processed in the data acquisition units for data quality and statistical summaries, including rainflow fatigue analysis, over defined time periods. Greatly reduced quantities of data are then forwarded to the mainframe server to be further analysed for event triggers, data archive and display as shown in the schematic.

Event triggers are based on user-defined limits set for sensors related to long-term cumulative performance or short-term event-driven conditions that can initiate maintenance or inspection programmes that may otherwise go unnoticed until scheduled inspections. These event driven conditions can include seismic events, hurricane winds or barge/ship impact that can potentially change the distribution of forces in the bridge structure.

Key parameter displays are used to view predetermined processing of data algorithms such as cumulative displacements of joints or bearings, fatigue stress range histograms, modal frequencies and mode shapes from accelerometers to compare with design/theoretical values. All of this is established by the owner early on in the process to allow immediate evaluation of data and better asset management decisions.

The graphical user interface allows the user to interact with the structural health monitoring system and focus in on bridge sections or specific sensors for immediate review of real-time data and defined trend periods. This interface uses colour-coded sensor icons that immediately identify if the sensor response is acceptable or needs attention.

Automated reporting is set up by the user for a series of defined reports on a weekly, monthly or annual reporting schedule. This can include statistical summary reports that help focus inspection or maintenance activities. While this automated reporting can identify performance of individual components, it can also be set up to incorporate adjacent or selected components to provide data similar to that shown in the graph above.

Technological advances allow bridge designers and owners to better manage data and as a result they have the tools to better maintain bridge structures for long-term asset management purposes. In the same way as we go to a doctor and provide them with the information needed to better assess our health, a structure with smart components integrated into a structural health monitoring system provides this same level of information which the owner can use to better understand the health of the whole structure, not just the components

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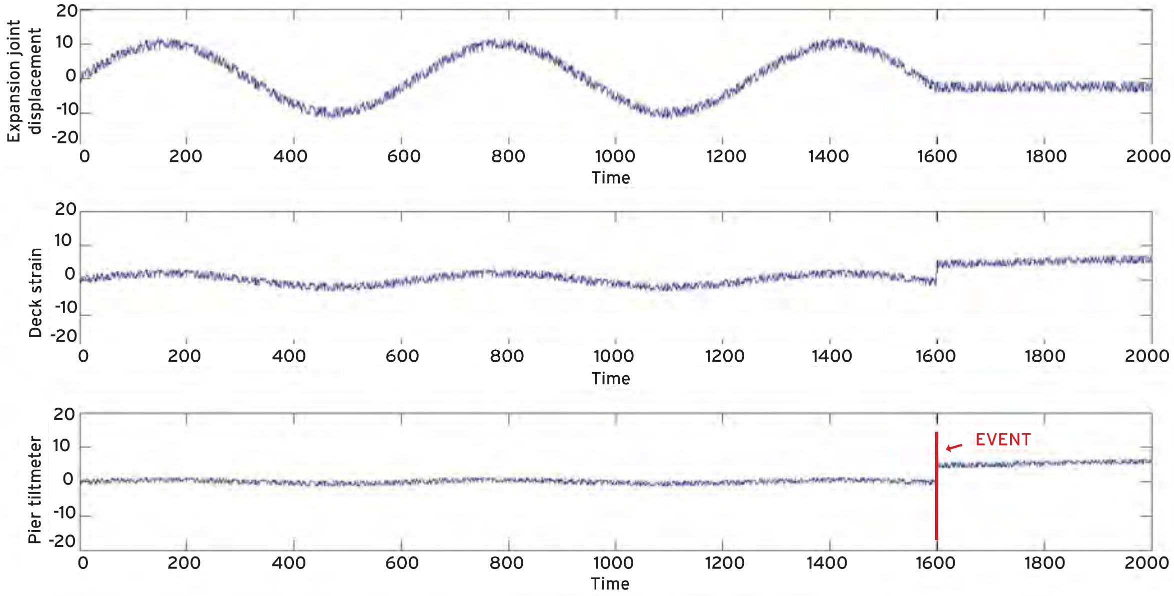

An example of the potential interation between a joint, cross-sectional deck strain and an adjacent pier