

concrete

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Incorporating **CONCRETE**  
**ENGINEERING**  
*International*

**Fistful of steel**  
Concrete reinforcement

**Hoover Dam Bypass Bridge**  
Precast block system is 'child's play'



*In developed nations, many civil structures are in urgent need of strengthening, rehabilitation, or replacement.*

## Rethinking approaches to sustainable transport infrastructure

**Making sense of structural health monitoring data is crucial to the safety and sustainability of civil structures supporting strategic transport links.**

*Jeff Matros, STRAAM, New York, USA*

Engineers and public authorities face a mounting challenge to shore-up the civil structures supporting transport infrastructure. Bridges in particular play a crucial role in the transport network and their removal from service can result in severe disruption or worse. Perhaps the most recent example of the risk posed to public safety by depreciating civil structures is the tragedy that unfolded in the USA, when the I-35W Bridge in Minneapolis collapsed into the Mississippi River on 1 August 2007, killing 13 people and injuring more than a hundred.

The subsequent investigation by the National Transportation Safety Board concluded that a metal 'gusset' plate had been too thin to serve as a junction of several girders. Designed and constructed in the 1960s to accepted codes of practice at that time, I-35W had gradually gained weight as concrete structures were added to separate

lanes, while further changes had served to create additional strain. At the time of the collapse, maintenance crews had brought tonnes of equipment and material onto the deck to make repairs.

### Consequences

In August 2010, URS Corporation, the engineering and construction company hired by the state of Minnesota to assess the safety of its bridges, agreed to pay US\$52.4 million to settle claims that it failed to spot problems with I-35W. Meanwhile, the State of Minnesota and URS still have claims pending against Jacobs Engineering Group, which took over the firm that designed the bridge. This is one instance of the far-reaching consequences of failing to protect the public, faced by asset owners and public authorities in constructing and maintaining civil structures supporting critical transport links.

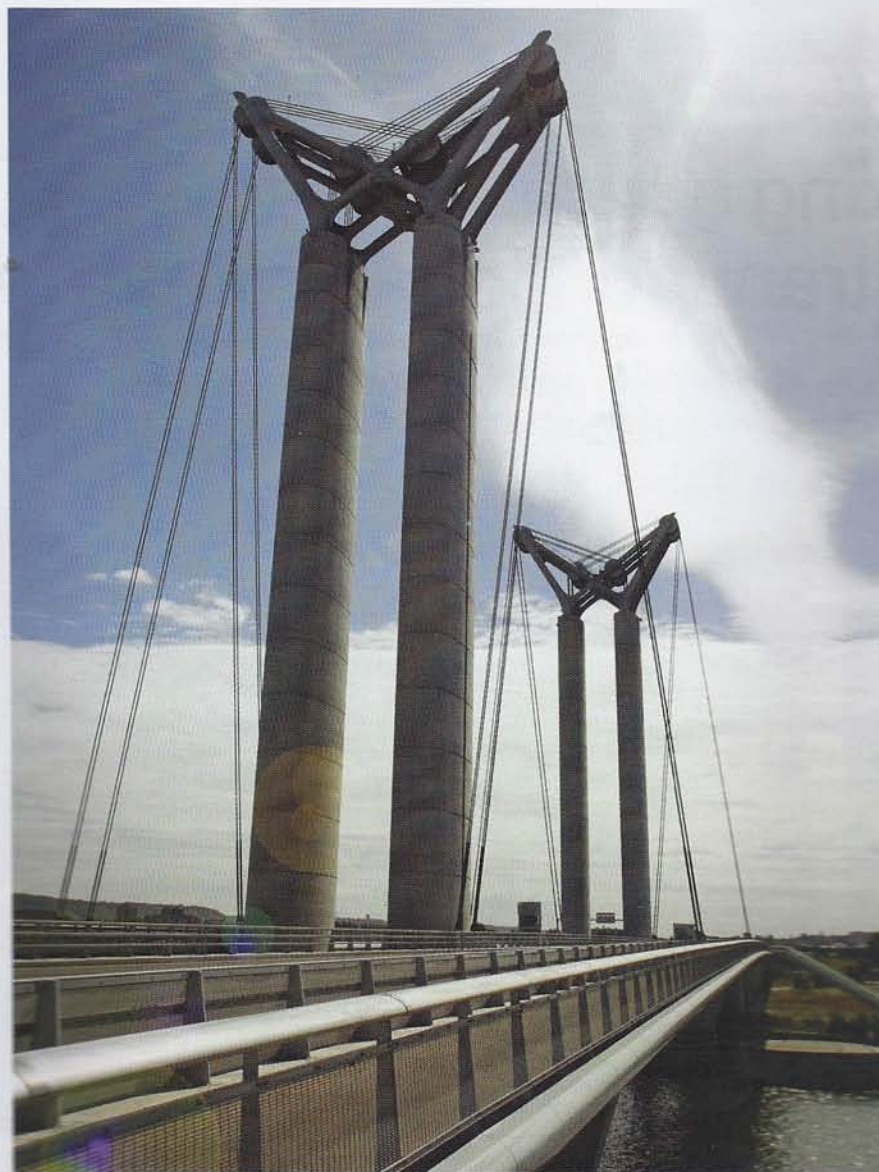
In developed nations, many civil struc-

tures are in urgent need of strengthening, rehabilitation, or replacement. This is due to multiple factors, including the corrosion of steel reinforcement and consequent breakdown of the concrete, or the fact that some structures may be sound, but have become functionally obsolete, eg, a bridge that is no longer able to support growing traffic volumes, vehicle sizes and weights.

According to the American Society of Civil Engineers, one in four bridges in the US is either structurally deficient or functionally obsolete, while more than 40% of the operational bridges in Canada were built over 30 years ago and have been impacted by the adverse climate and extensive use of de-icing salts. In the UK, an increasing number of bridges and other structures need to be strengthened to comply with legal minimum requirements set-out by European Community legislation. The UK's Cabinet Office is also leading an initiative to



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reinforce the resilience of key infrastructure to extreme weather events, following recent flooding that resulted in the collapse of a bridge and the death of a policeman.

Moreover, many developed nations are unable to expand their current transport infrastructure, resulting in increasing pressure to optimise and extend the life of supporting civil structures in place today. Thus the construction and engineering industry finds itself at an evolutionary crossroads: on the one hand being tasked with pushing existing infrastructure to its structural limits; and on the other, having to adopt new approaches to the accurate monitoring of the integrity of key structures supporting rail and road networks.

A structure is said to have integrity if localised damage does not lead to widespread collapse. Conventional methods of assessment have centred on visual inspections, evaluations using conservative codes of practice and the use of large machines to 'excite' a structure so that various parameters can be measured and analysed. Such techniques have limitations in that, while they enable engineers to identify and assess the physical manifestation of an issue, identifying the actual cause of the issue is more complex by an order of magnitude.

### Monitoring

Structural health monitoring (SHM) is a system that provides information on demand about any significant change or damage occurring in a structure. Although SHM instruments have been used for many years, difficulties in managing the huge volumes of data they generate have made efficient monitoring in civil engineering applications a challenge. However, major advances in communications, data transmission and computer processing have enabled SHM solutions that provide the ability to acquire vast volumes of data in relatively short periods of time and transfer them via high-speed fibre-optic or wireless connections to a central database. Most importantly, advanced SHM solutions are now able to provide analysts with the means to interpret these data and diagnose potential problems early, and to a high degree of accuracy.

A field-proven technology lies at the heart of SHM innovation. In the past few decades, sensors based on MEMS (micro-electro-mechanical systems) technology have become smaller, more cost-effective and so sensitive that there is no longer a need to excite a structure in order to gain vital information about its integrity. Simply placing a sensor on a bridge will provide analysts with all the data required via ambient sources such as gusts of wind, foot falls and traffic flows. Moreover, advanced algorithms have been developed that allow analysts to evaluate this simple, specific data set, to make both short- and long-term structural

integrity assessments that provide essential information for asset owners and managing authorities in taking decisions regarding repairs and upgrades, strengthening projects, financing, insurance and dispute resolution.

### Use of technology

Meaningful interpretation of the SHM data acquired is where the rubber hits the road in civil engineering and infrastructure management applications are the key to unlocking the vital data that analysts use to compare the dissipation of vibrations, with either the predicted behaviour of the structure given its design and materials, or with baseline measurements captured earlier.

Key to capturing these baseline measurements are customised servo-accelerometers developed by Sherborne Sensors. Simply placed on a single position on most bridges for a few hours, these devices record a structure's three-dimensional movement in extreme detail.

However, the use of this technology does not stop here but encompasses road deck frequency and mode shape determination; seismic structural monitoring; vertical, lateral and rotational acceleration measurements of decks, cables and bridge towers; and integration with GPS systems to improve

deflection frequency response. A long-span suspension bridge currently under construction in Asia, for example, employs a sensor that enables the identification of structural problems at an early stage, prolonging the life of the structure, identifying areas of concern and improving public safety.

### Diagnosis

SHM's benefits were clearly demonstrated recently at a remote steel bridge in the heart of Brazil's Amazon basin. Supporting freight trains carrying 10% of the world's iron ore each year, the bridge had been rolling back and forth whenever a heavy-laden train was crossing.

A horizontal crack had also appeared in one of the supporting concrete girders, with train drivers returning to the mines reporting increasingly violent vibrations as they crossed – despite their cars being empty. However, after monitoring the bridge over a period of time and using data collector devices and advanced analysis techniques, it was discovered that the crack in the concrete was not the cause. Rather, it was the frequency of the movement of the returning trains coupled with that of the bridge.

The solution was simply to reduce the speed of the trains by 20km per hour when they crossed the bridge unladen and the

vibration was eliminated, without the need for costly engineering works to the bridge.

Using conventional methods, a meter would have been placed over the crack to measure how it responded to ambient vibration over time. But such a device would not have told the bridge owner why the crack had come about and whether it had anything to do with the movement in the structure.

An SHM solution has been created that takes raw vibration data and turns them into valuable information enabling analysts to provide a holistic diagnosis of a structure. This ensures asset owners and management authorities are fully equipped with the knowledge to establish the most appropriate strategy for modifying a structural system to repair current weaknesses, minimise further issues and thus prolong the life of the asset.

In an economy where budgets remain under severe constraint, the refurbishment of critical transport infrastructure takes on renewed emphasis. Although implementing change in the civil engineering and construction industry takes time, new approaches to SHM can deliver immediate benefits to asset owners, financiers and public authorities in reducing the risk of litigation, improving public safety and the sustainability of critical transport infrastructure. ■