



NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING
**2019 Pacific Conference on
Earthquake Engineering**
TURNING HAZARD AWARENESS INTO RISK MITIGATION
4 – 6 April | SkyCity, Auckland | New Zealand



Making bearings and expansion joints smart for seismic and other millennial challenges

P. Savioz & M. Imam

mageba (Shanghai)

V. Ghodke & S. Kazi

mageba (Australia)

ABSTRACT

Modern automated structural health monitoring (SHM) systems have much to offer the responsible engineers in the construction, inspection, maintenance and renovation of structures in general, and of key structural components such as bridge bearings, expansion joints and seismic protection devices in particular. In the past, monitoring of such components generally involved the use of separate, independent sensors, but improving technology is changing this, with “smart” components now available, with sensors pre-integrated in their design and fabrication before they leave the factory, and improved data analysis capabilities.

1 INTRODUCTION

Recent technological developments in the field of structural health monitoring (SHM), particularly in relation to sensors and data logging, have greatly increased the potential of such technology to play a valuable role in civil and structural engineering – especially as it relates to critical infrastructure such as road and railway bridges. Continually progressing research work, and the innovations of suppliers, have resulted in the development of systems and solutions that can greatly increase the effectiveness and efficiency of bridge construction, inspection, maintenance and renovation work (Moor et al, 2014).

One such area of innovation relates to the key components which, if present, are generally critically important to a bridge’s efficient design and proper functioning: its bearings, expansion joints and seismic protection devices such as dampers. This has led to the development of “smart” components, which feature pre-integrated SHM sensors already when fabricated, enabling bridge engineers to optimise the efficiency of their work as it relates to their structures’ key components.

Paper 327

2 TYPICAL USES AND BENEFITS OF SHM IN CONSTRUCTION AND MAINTENANCE

Modern SHM systems can be used to provide reliable, precise data on virtually any variable of interest – e.g. forces, movements or rotations of any part of a structure. The data can be automatically measured and recorded around the clock, all year round, and at high frequency if required (e.g. to analyse vibrations), making the SHM much more capable, and also more efficient and cost effective, than traditional manual methods in many cases. By presenting the recorded data on a graph, typically on a secure web interface, the effects of selected factors (e.g. temperature) on particular variables (e.g. structure movements, absolute or accumulated) can be easily analysed and understood. Where specific concerns exist about a structure’s safety or performance, an SHM system can be designed to provide notification, by email or SMS, to the responsible engineer of any exceeding of defined threshold values – for example, should movement of any part of the structure exceed expected values, or the width of a crack suddenly increase.

Modern SHM systems can also be programmed to statistically analyse the data they record for easier evaluation. For example, histograms can be generated to visually present the frequency of occurrence of values in any given variable during a selected period of time, enabling anomalies to be readily identified. Presentation of selected data on a single graph can also enable correlations to be established and significant deviations to be identified. It may also be helpful to be able to assess the static or dynamic behaviour of a structure due to certain influences but not others. By eliminating the influence of dominant, less relevant factors, small changes due to the factors of interest can be much more easily detected. For example, the effect of minor structural damage on a specific variable may remain unnoticed when clouded in data that includes the effects of temperature changes, but readily identifiable on a graph when the influence of temperature is excluded. Or the exclusion of temperature effects may enable the effect on deck displacements of other influences such as traffic to be more easily understood. Such analysis is made possible by the use of regression models as described by Islami & Modena (2013). The usefulness of this technique is illustrated by the graphs in Figure 1, which show how displacements at one point in a structure vary with time. The upper graph presents the measured data, unmodified, while the lower graph presents the data as modified to exclude the influences of environmental factors such as temperature but still showing the influence of traffic loading. As can be seen, the exclusion of particular data in this way makes analysis of the data far easier, with any irregular values being immediately recognizable, enabling the need for repair or preventative action to be assessed.

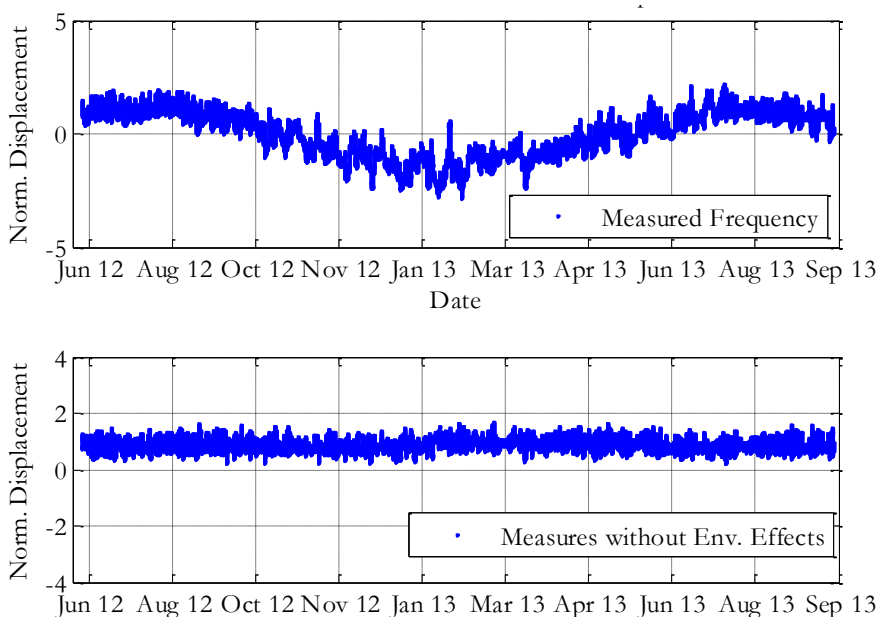


Figure 1: Example of regression analysis, showing displacement data, both before (above) and after (below) the elimination of environmental effects

3 MONITORING OF BEARINGS

A structure's bearings are critically important for its proper long-term performance, and any loss of functionality can quickly develop into a serious problem for the structure. For example, if a bearing no longer enables a bridge deck to expand/contract or move as required by its design, enormous constraint forces can build up, potentially causing severe damage to the structure. It is therefore essential that the proper condition and functioning of a structure's bearings be adequately monitored, to ensure that any such loss of proper functioning, through deterioration, accidental damage or otherwise, is recognised in good time and appropriate actions taken to protect the structure. Where the condition of a structure's bearings has been found to be questionable or where further confidence in the ongoing performance of the bearings is required, the use of an SHM system is an attractive alternative to traditional manual inspections. Not only are automated SHM systems far more accurate and precise than manual measurements, they can be designed to operate 24 hours a day, 365 days per year, thus ensuring that any sudden deterioration or damage is immediately recognised and reported to the responsible authority. And if frequent visits to a bridge are required to perform manual inspections, the investment in an SHM system can be quickly paid off and easily justified.

3.1 Case study: Spherical bearings of main junction of Qatar's new Orbital Highway

Qatar's new Orbital Highway is currently under construction around the country's capital, Doha, and is expected to significantly reduce traffic congestion in the city while improving connections to other cities. At one of the highway's main intersections (Fig. 2), a spaghetti junction where it crosses the Dukhan Road, it was decided to install an SHM system to monitor the condition of the various structures. The recently installed system is based on measurement of data from the bearings that support the various superstructures – spherical bearings of the TENSA-SPHERICAL type. In all, 28 of these bearings are connected to 14 control boxes, as shown in Figure 3. The SHM system is designed to continuously monitor, in particular, the load acting on each monitored bearing – all day, every day. This will enable it to immediately identify any change in loading conditions – for example, should the load on any bearing increase or decrease due to structural damage/deterioration or ground settlement, either rapid or gradual. With so-called alarm values defined (above or below which the responsible engineers should be notified), risks to structure users can be minimized, and any structural damage or deterioration arising can be addressed before it develops into a bigger problem.

The bearings in question were specially designed to precisely measure the loads they are carrying at any time, with load cells integrated in their design – inserted beneath the sliding material at one side of each bearing's concave sliding surface. A short cable connects this sensor to the side of the bearing, where an external cable connection point enables the sensor to be integrated into the SHM system.



Figure 2: Construction of the new Orbital Highway in Qatar



Figure 3: Testing of the load-measuring functionality and performance of a spherical bearing (left), and one of the SHM system's 14 control boxes and its connection to the spherical bearing above it (with dust skirt)

4 MONITORING OF EXPANSION JOINTS

Although a bridge's expansion joints may not be as central to the structure's strength and stability as its bearings or dampers, the condition and performance of its expansion joints are critically important to a bridge's proper functioning as a transportation link. And given that expansion joints, very often mechanical devices with sliding interfaces, are typically subjected to direct impact loading from traffic millions of times a year, they are generally far more prone to wear and damage, and management of life-cycle costs can benefit enormously from the availability of good information relating to condition and performance (Spuler et al, 2012). Therefore, of all a bridge's key components, it is probably the expansion joints that can benefit most from the sensible use of SHM.

To maximize the benefit that can be gained from such technology, a worldwide supplier of both expansion joints and SHM systems has developed and combined the technologies, so that expansion joints can now be delivered with pre-integrated sensors for connection to a tailored SHM system. Not only that, the data analysis capabilities of the combined system have been greatly developed, based on the high-frequency measurement of structure-borne vibrations. This enables damage or deterioration to be clearly identified based on general testing and teaching of the system. As a result, unexpected damage can be immediately recognized and automatically notified, enabling the timing of replacement of components to be optimised and disruption to service to be minimized.

4.1 Case study: Large-movement expansion joints of a new bridge

The Taizhou Yangtze River Bridge (Figure 4), constructed at a cost of USD 400 million and opened in 2012, is the world's longest-span bridge of its type: The three-tower suspension bridge, with two main spans of 1,080 m each and side spans of 390 m, crosses the Yangtze River where it has a width of 2.1 km. The ambitious construction project represented the first attempt to create a long-span multi-tower suspension bridge.

This extraordinary bridge required some extraordinary key components such as the expansion joints which accommodate deck movements while providing a driving surface for traffic. Modular joints with 18 gaps each (able to facilitate 1440mm of longitudinal movement) were installed at each end of the deck (Figure 4).

An SHM system was installed on the bridge to provide the type of data that is likely to be of interest to the owner of any exceptional structure. The basic system measures and records the movements and rotations of the deck at the expansion joints, and thus gives a valuable impression of the performance of the structure, enabling the need for maintenance or adaptation work to be quickly identified and planned.



Figure 4. The Taizhou Yangtze River Bridge (left), and one of its enormous 18-gap modular expansion joints, viewed from below.

To maximize in particular the system’s ability to monitor the condition and performance of the expansion joints, the above-mentioned newly developed technology was applied. By recording movements, inclinations, temperature and structure-borne vibrations at a frequency of 25.6 kHz, even very tiny changes in the joint or its performance can be detected and visually represented by changes in a curve on a graph. This will enable any sudden damage or deterioration to be immediately detected, based on testing and “teaching” of the system.

As a first step, many artificial failures were created simulating damages. This was done by temporarily removing stirrups which form sliding connections between the lamella beams at the joint’s surface and the support bars beneath (see Figure 5). High-accuracy accelerometers and ultrasonic displacement sensors (Figure 5) were then used to evaluate the effects of these “failures” on the movements of specific elements, giving the system the data it needed to “learn” what data might be significant in terms of damage detection.



Figure 5: An accelerometer at the location of a temporarily removed stirrup during fault simulation and measurement of resulting vibrations and modal analysis (left) and an ultrasonic displacement sensor (right)

In service, the system sends data to a remote server, including daily records of vibrations due to heavy traffic together with the associated modal frequencies. If established limits which might indicate the occurrence of damage are exceeded, an alarm notification is sent by email and also appears on the system’s web interface, prompting a site inspection. As a result of the system’s ability to automatically consider such information, therefore, planning of maintenance activities in general, and the timing of replacement of components in particular, can be optimized.

The graphs presented in Figure 6 show acceleration data recorded by the system, with data from each of three selected joist beams (also known as support bars, which span the bridge movement gap, supporting the joint’s steel surface beams). The graphs indicate a pre-defined limit of 20 m/s² (shown by red lines). Should a measured value exceed that limit, this could be a sign of a problem and so the SHM system is designed to send an alarm email to notify the responsible engineers. (The small number of data points above this limit were established to be no cause for concern, e.g. due to road works on the bridge.)

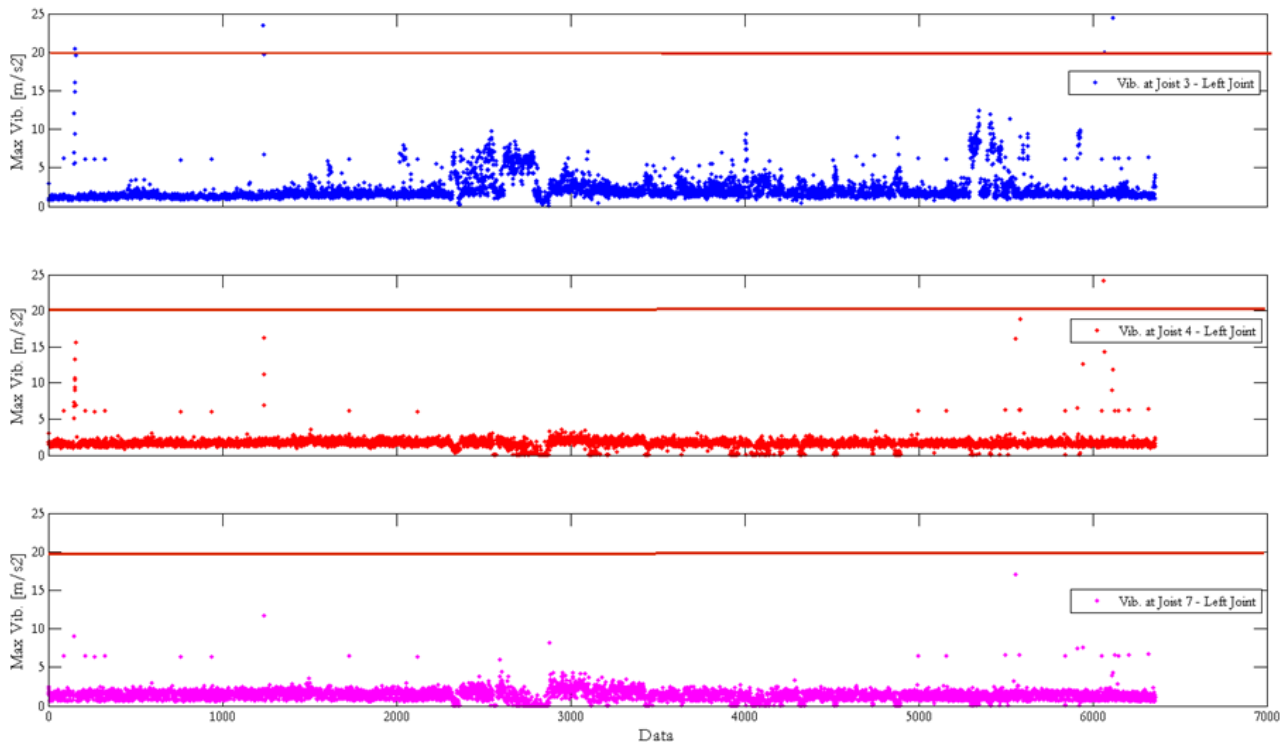


Figure 6: Acceleration data recorded by the system, with data from three of the expansion joint's joist beams; the graphs indicate a pre-defined limit of 20 m/s² (shown by red lines), above which alarm messages are sent to the responsible engineers

5 CONCLUSIONS

The integration of SHM systems in key components (bearings, expansion joints and seismic protection devices) of bridges and other structures can offer great benefits to their asset management programs. Such systems can efficiently provide data required for almost any purpose, at any stage of a structure's life cycle.

In the case of expansion joints, in fact, the technology has already been brought another step forward, with the SHM system designed to clearly identify component damage based on general testing and teaching of the system. This enables any unexpected behaviour of the component (or the bridge) to be immediately recognised and notified, thus enabling the timing of component replacement, or other maintenance/repair work, to be optimised. With similar developments being planned for bearings and dampers, making them yet smarter and more efficient and useful in the construction, inspection, maintenance and renovation of structures, the potential benefits of the use of SHM technology in bridge asset management programmes continue to grow.

REFERENCES

- Islami, K. & Modena, C. 2013. Life-cycle assessment by dynamic diagnosis and long term monitoring of old bridges in northeastern Italy, *Proc. 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII)*. Hong Kong.
- Moor, G., Islami, K. & Meng, N. 2014. Construction and maintenance of bridges – the contribution of automated monitoring, *Proc. 9th International Conference on Short and Medium Span Bridges*, Calgary, Canada.
- Spuler, T., Loehrer, R. & O'Suilleabhain, C. 2012. Life-cycle considerations in the selection and use of bridge expansion joints, *Proc. 18th IABSE Congress*, Seoul, South Korea.