Expert Knowledge

Expert Knowledge:
Self-evaluating bridge components

Special challenges of long-span bridges

Introduction

Multi-span and long-span bridges are essential links in transportation networks, and must be inspected and maintained accordingly. They are more likely to experience large deck movements than other bridge types, and **these movements must be accommodated** by deck expansion joints and bridge bearings.

The **performance and life expectancy** of such components are strongly dependent on the movements to which they are subjected, so the movement and vibration data that can be provided by modern structural health monitoring (SHM) systems can play a pivotal role in **improving their performance and extending their service lives.**

This is demonstrated in the following documentation with reference to the SHM systems of two major suspension bridges.

Preventative damage detection

The implications of the development of techniques of monitoring, of statistical modeling of the response of structures, and of gathering and processing data in real time, are important – especially in the context of particularly sensitive structures. It is desirable to verify whether the effects of various environmental variables measured in situ **influence the static or dynamic behaviour of the structure**.

Therefore, it is important to **eliminate** the influence of these factors, so that small changes due to damage can be **detected**. This is made possible by the use of regression models, which can **determine** the static variables starting from a predefined input.

All of these techniques have been used in the present study, and more importantly, have been applied to important suspension bridges that exhibit high movements.

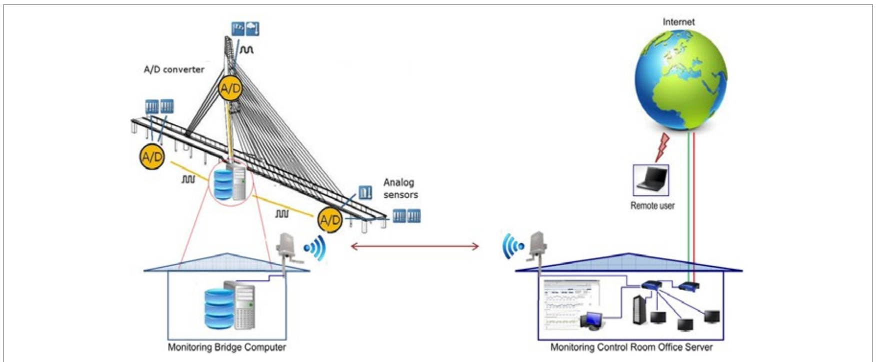
Basics of "smart" components including upgrades

The use of a "smart" system can:

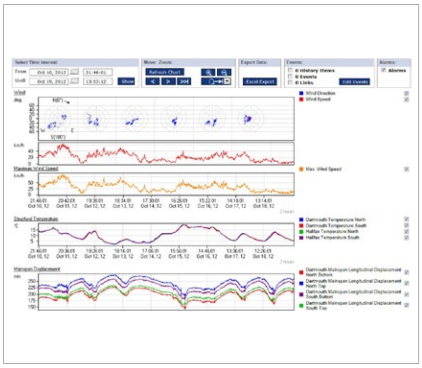
- enable **life-cycle cost optimisation** of an expansion joint by measuring accumulated movements leading to reduced maintenance intervals
- assess the structure's behaviour on the basis of **continuously measured** parameters, with real-time data accessible online **at any time** and receiving warnings in case of passing of certain thresholds
- optimise design of new expansion joints based on **actual required** rotational and movement capacities

To maximise the ability to monitor the condition and performance of a bridge's expansion joints, an **upgrade to the standard monitoring system can be realised.** The functioning of the new feature is based on the **measurement of structure-borne vibrations**. Hands-on details are presented in the following project examples.

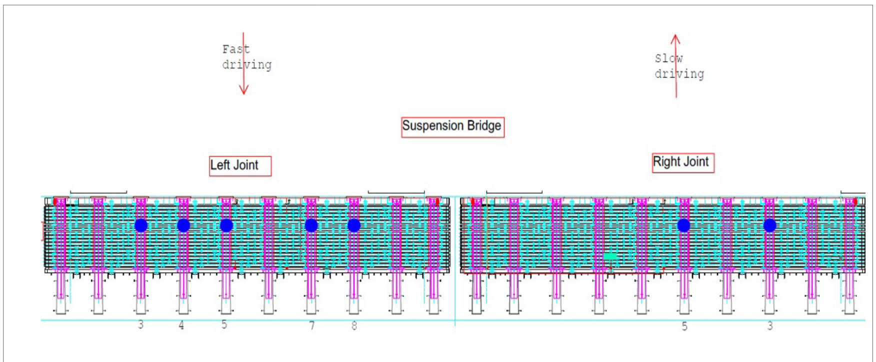
Data acquisition scheme



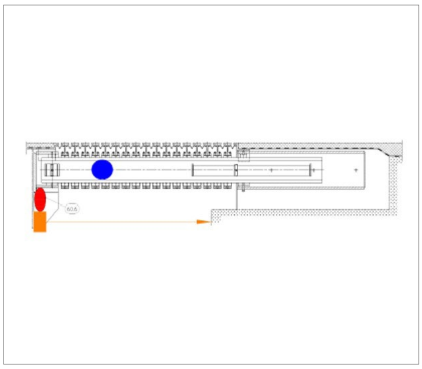
Online data presentation



Example of a final installation layout of acceleration sensors in the joint of a suspension bridge



Drawing of joint section



Bridge Monitoring

Project Example: Taizhou Bridge

The Taizhou Yangtze River Bridge, opened to traffic 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 expansion joints with 18 gaps each, capable of accommodating 1,440 mm of longitudinal movement, were installed at each end of the deck.

Smart solution for bridge monitoring

A SHM system was installed on the bridge to provide the type of data on the bridge's condition that is likely to be of interest to any owner whose structure is exceptional in some way.

The basic system:

- **Measures and records** movements and rotations of the deck
- Gives valuable impression of the structure's performance **at any time**
- Enables **quick identification** of need for maintenance or adaptation work
- Reports **accumulated sliding movements** over time

The upgrade:

- Brand new damage detection feature **incorporates** sensors and provides **clear information** about condition
- Based on measurement of structure-borne vibrations recorded at **sampling frequency of 25.6 Hz**
- Even **very tiny changes** in joint detectable and visually represented

The installed "smart" expansion joint measures high-frequency movements inclinations, temperature and vibrations enabling a **proper understanding** of the joint's and bridge's behavior.

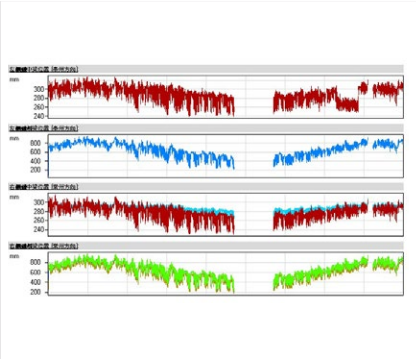
The main purpose of the project is not only to **monitor the condition and performance** of the expansion joints due to extensive movement or rotation (basic) but also to **detect damages at an early stage** by recording the level of accelerations and natural frequencies (advanced) caused by traffic.

How it works:

- Artificial failures were created in order to simulate damages
- Different setups of sensors mostly covered all of the joist beams of the expansion joint
- Good distinction between damaged and undamaged joint conditions during test enabeling the system to be fine-tuned before permanent installation
- Permanent monitoring sends data to remote server. If established limits exceeded, it appears on the system's web interface
- Site visit for damage verification and avoidance of further damage or deterioration

Taizhou Bridge from top of pylon

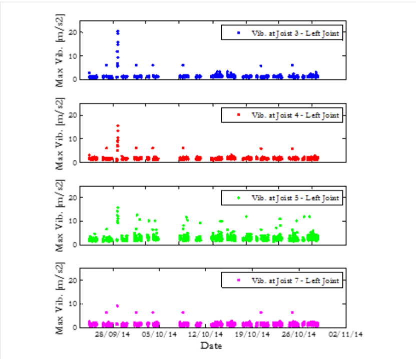
One year of displacement measurements



Wire sensors installed on the joint

Expansion joints with sensors installed

Vibration levels in the expansion joints



Ultrasonic sensors installed on the joint

Bridge rennovation works

Project Example: Angus L. Macdonald and A. Murray MacKay Bridges

The twin suspension bridges are critically important structures for the city of Halifax, Canada. The Angus L. Macdonald Bridge, in fact, is receiving an entire new deck, and computer modelling of the deck, verified by measured data, is playing a key role in the design process. The A. Murray MacKay Bridge, on the other hand, is retaining its existing deck, but is being subjected to significant renovation work.

Smart solution for bridge rennovation works

It was determined that an SHM system should be used to **measure** and **record** the movements and rotations of the deck of the Angus L. Macdonald Bridge at its expansion joints, providing the data needed by the **finite element modeling**. This particular data enables rotations and displacements (both longitudinal and transverse) to be **easily related to temperature**, and to **wind strength** and **direction**.

Targets of the SHM system:

- **Optimises** selection and design of replacement joints
- **Reduces** future maintenance and replacement effort
- **Precisely quantifys** the bridge's actual movements and rotations, which would be likely to differ from the theoretical values estimated at the time of the bridge's construction
- **Measures absolute** longitudinal and transverse movements, horizontal and vertical rotations, and accumulated longitudinal movements
- **Records** the structure temperatures needed to form a frame of reference for the movements and rotations, enabling these to be fully understood
- Movements due to traffic **can be decoupled** from temperature effects for better understanding

Angus L. Macdonald Bridge

Use of histograms

The principal movements were correlated to temperature during the monitored period. The plot shows a decreasing trend of displacement when temperature decreases. The same linear behavior must also be **evidenced by the finite element model** of the structure. To observe the distribution of movements, a very useful means is **offered by histograms**.

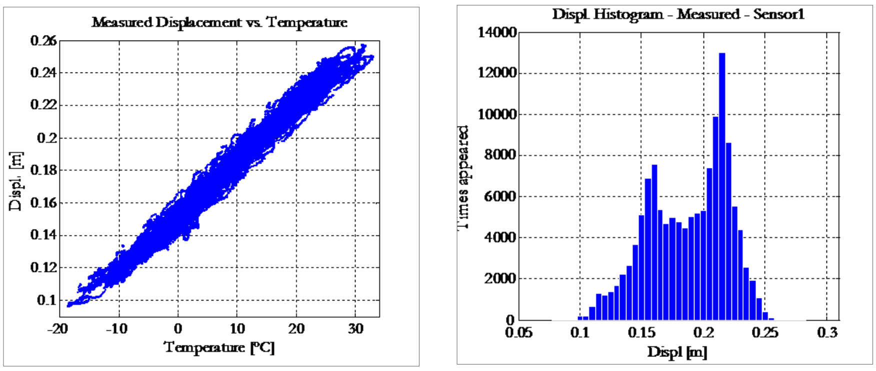
The histogram below shows the number of times a value of measurement arose during one year of monitoring at a single sensor.

Use of regression models

To **improve damage detection** at a bridge's expansion joints, **environmental effects** can be **eliminated** using a **regression model**, generated from the correlation between temperature or humidity and the movements of the bridge. The resulting movements recorded by the system **do not** then include movements **resulting from temperature or humidity**, enabling **abnormal influences** (due to damage or other unexpected events) to be easily recognized.

This is illustrated by the model below, which shows on the lower graph, with normalised values, the bridge movements that are due to traffic etc. and not due to temperature. Any abnormal shift on this graph would be **immediately recognisable**, enabling the need for repair or preventative action to be assessed.

Temperature effects on displacement measurements and histogram with distribution of measurements



Regression model showing measured and estimated displacement. Displacement, before and after the elimiation of environmental effects