Tomorrow's world – developing data-centric engineering

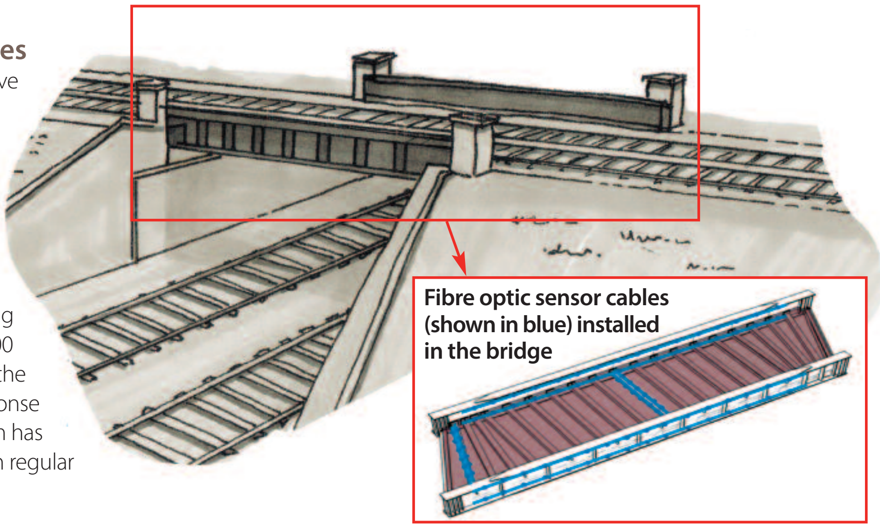
Introduction

Smart infrastructure delivers an abundance of data that offers new engineering insights, but how does an organisation identify valuable information from this data? In collaboration with the Lloyds Register Foundation, CSIC engineers, the Alan Turing Institute (ATI) data scientists and researchers from the Department of Mathematics at Imperial College London are working together to design and deploy long-term mixed-sensor monitoring systems to live stream data for high-level statistical analysis in real time.

This collaboration between structural engineers and big data analysts is being tested and developed on bridges at opposite ends of their service life: two new-build self-sensing bridges built as part of the award-winning £250m Stafford Area Improvements Programme on the West Coast Main Line near Crewe; and a Victorian masonry viaduct in Leeds. Both are owned and operated by Network Rail. These two data sets provide a rich resource of information, enabling engineers and statisticians to transform the current approach to structural health monitoring and optimise future design and asset management.

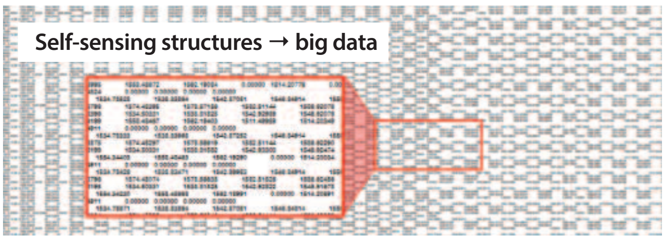
Sensing the Staffordshire Alliance Bridges

Two types of fibre optic sensor monitoring systems have been installed at the Staffordshire Alliance Bridges: a distributed system based on Brillouin Optical Time Domain Reflectometry (BOTDR); and a point-based system using fibre Bragg gratings (FBG) capable of measuring changes in strain in real time. Fibre optic sensor cables were installed into the main prestressed beams, steel girders and concrete sleepers off-site to allow faster installation of monitoring systems. More than 400 FBG sensors and more than 600 metres of BOTDR sensor cables have been installed in the two bridges to determine the static and dynamic response during whole-life performance. This monitoring system has already been generating vast amounts of data through regular data collection visits by CSIC researchers.



Integrating analytics to make sense of data

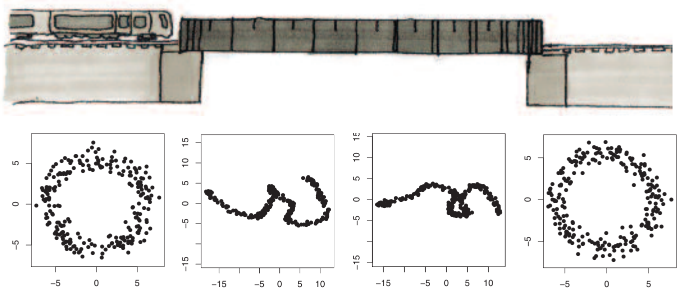
Provisions are currently being made in collaboration with Network Rail to enable real-time and live-streaming of data from the Staffordshire bridges. In collaboration with researchers from the Data-Centric Engineering programme, led by Prof Mark Girolami at the Alan Turing Institute, high-level integrated data analytics will be performed on the continuously collected data. Data will no longer be collected and then analysed separately, but will be streamlined to deliver analytics in real time using advanced statistical methods. These methods will be used to identify anomalies in the data patterns in order to alert asset managers to a change or an event in the structure which can then be investigated and addressed in real time. This system will allow for the identification of both time-sensitive data and long-term trends.



0.1 seconds of data from Staffordshire Alliance bridges

Doughnuts from data

Initial statistical analyses of data (based on principal component analysis) from the Staffordshire bridges have produced a doughnut-shaped plot which provides insight into how the sensor network data covaries over space and time. When a train passes over the structure, we see the shape of the plot change and then return to its original form after the train has passed. The aim is to use similar statistical techniques to track these plots and other parameters over time and correlate the changes to deterioration.



Statistical plots highlighting the covariation in sensor network data over space and time

> Advanced statistical methods, including machine learning and artificial intelligence techniques, is the realm of data scientists and applying this to self-sensing infrastructure is an emerging area of research. Data is at the centre of the process, but it is not driving it alone. We want to see how we can create a model that is a synthesis of statistical and physics-based, or finite element, models.

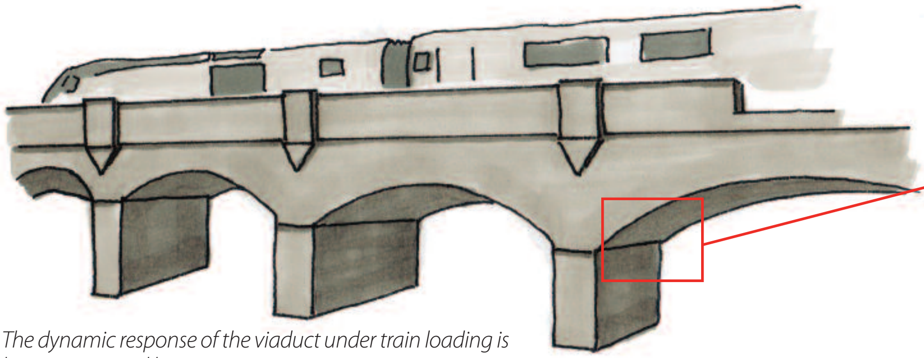
Dr Liam Butler, CSIC Research Associate and Group Leader within the Lloyd's Register Foundation Data-Centric Engineering programme at the Alan Turing Institute

Monitoring degradation of a Victorian viaduct

In September 2017 CSIC installed a long-term monitoring system at a viaduct in Leeds to evaluate deterioration of the structure and to determine the effectiveness of previous maintenance measures. This followed a short-term monitoring project that took place in July 2016 to understand the dynamic response of the viaduct under train loading, and to explain existing structural damage (see Figure 2 which shows data from 2016 and 2017).

The long-term monitoring system includes: a network of 80 FBG sensors to measure distributed deformation (at a sample rate of 1kHz) across three arch spans that exhibit a range of damage severity; acoustic emissions sensors (AES) at specific damaged locations, which are triggered by high frequency vibrations and capture the energy release when cracking occurs; high sensitivity accelerometers (HSA) to measure motion in the structure due to vibration caused by trains passing over the viaduct (see Figure 1).

Once the data acquisition system is fully operational, the sensing data will be sent remotely to the Alan Turing Institute and Imperial College for high level data analytics and statistical analyses. In short, the accelerometers aim to replace current methods of using deflection poles to measure displacements at critical locations, which require road closures and site visits for data collection and therefore are not useful for long-term deployment. The AE sensors aim to detect rates of cracking directly, and to see how these rates of cracking change with time and temperature. This is the first time these sensors will have been used with such extensive FO strain measurement, to be able to correlate local evidence of damage (AE) with both local and global changes in dynamic behaviour (FO). This will improve safety by allowing the development of effective alert systems.



The dynamic response of the viaduct under train loading is being monitored long term

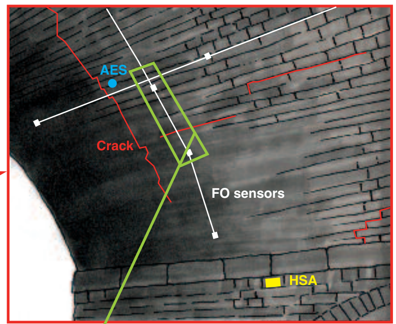
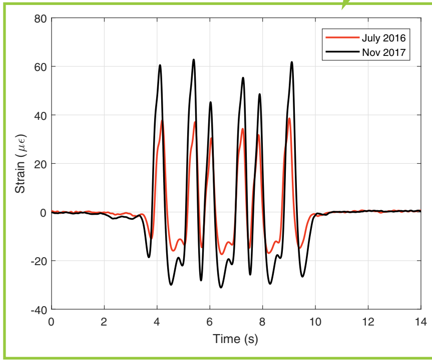


Figure 1: Snapshot of sensor location on bridge

CSIC data analysis

CSIC researchers have created software to identify and group specific types of trains, and to identify velocity, direction of travel, number of carriages and weight. Structural engineers aim to better interpret the behaviour through computational modelling of the masonry structure under simulated dynamic loading.

> Integrating the structural and data-centric engineering methods will form a clearer picture of the as-built performance of the new self-sensing bridges and the on-going degradation of the historical masonry viaduct, to improve both design practice and optimise maintenance intervention.
>
> Dr Haris Alexakis, CSIC Research Associate



Plot exemplifying the change in the dynamic response of the bridge (when a train passes over) between July 2016 and November 2017

Figure 2: Change in dynamic response of bridge

Looking to the future – the digital twin

Combining structural and data-driven engineering brings new opportunities to smart infrastructure. The structural engineer often works with a worst-case-estimate of what the actual load of a bridge may be, while the data-driven approach builds a statistical model from the data collected. Statistical models provide an effective tool to verify the physical models and confirm and measure best-guess estimates .Integrating these methods – a 'data centric' approach – delivers accurate and verified structural performance information to inform improved decision-making.

The next step is to combine advanced BIM modelling, advanced finite element models, and our data analytics to develop 'digital twin' bridge models (cyber-physical systems). The digital twin will exist alongside the physical asset and will be updated via a statistical process as new data is collected. These data-centric engineering-enabled models could potentially be used to perform 'what-if' scenarios providing asset managers with a powerful tool for improving resilience and assessing long-term risk.

Benefits to

Asset owners, asset managers, designers, end users

Impact and value

- design optimisation and cost efficiency
- better-informed, more effective maintenance
- reduction in disruption to travel
- structural alert systems to ensure asset and user safety

Project contact

Dr Haris Alexakis, Research Associate
Dr Liam Butler, Research Associate
Dr Matthew DeJong, CSIC Investigator (Leeds project)
Dr Mohammed Elshafie, CSIC Investigator (Stafford project)
Prof Campbell Middleton, CSIC Investigator (Stafford project)