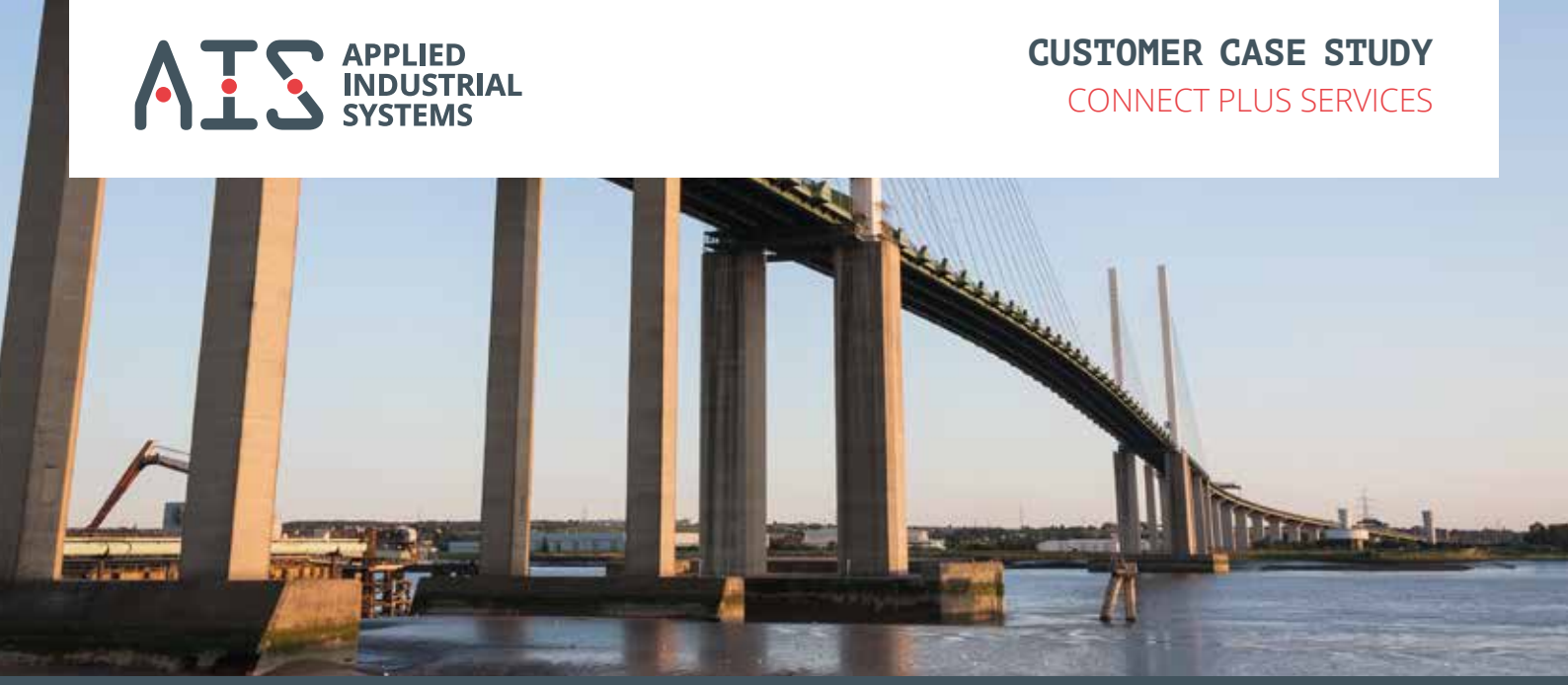
APPLIED INDUSTRIAL SYSTEMS

CUSTOMER CASE STUDY
CONNECT PLUS SERVICES



High speed system for monitoring complex structural response to wind

Verifying QEII Bridge health to optimise maintenance costs long term

AT A GLANCE:

STRUCTURAL HEALTH MONITORING (SHM) ON THE QEII BRIDGE

- Connect Plus Services (CPS), the maintainer and operator, has a requirement to ensure the bridge is maintained in good structural condition and to minimise future maintenance costs post 'hand-back'
- Vibration occurring on pylon and stays needed further investigation to quantify the fatigue demand on these components
- AIS developed a system to monitor the response of the various bridge components and classify each event according to prevailing wind characteristics
- Seamless integration of multiple control systems to a single user interface immediately alerts operators when an incident is detected
- Samples taken at 200Hz from accelerometers across the bridge, 25Hz reading of tilt meters on pylons and road deck, 1Hz readings of temperature, wind speed, humidity & rainfall
- Software & extraction system acquires data at high speeds and abstracts information with minimal post-processing
- Ultra-precise synchronisation of data to observe vibrations in different parts of the bridge simultaneously
- The system equips CPS with the ability to demonstrate bridge condition with high levels of confidence
- Supports users at the main Regional Control Centre and at the Backup Control Facility for full redundancy

Connect Plus Services
Better Journeys, All Round

When it was first opened in October 1991, the QEII Bridge over the River Thames was Europe's largest cable supported bridge. At 2.8km long and 130m high, the bridge is managed and operated by Connect Plus Services (CPS) on behalf of Connect Plus, as part of a 30 year contract awarded by Highways England.

Since its contract began in 2009, CPS had been receiving anecdotal reports highlighting incidences of vibration occurring on the pylon and stays in certain wind conditions. Due to the anecdotal and subjective nature of the information sources, CPS needed to investigate to provide a clearer understanding of the fatigue demand in critical areas of the structure. The company embarked upon a structural monitoring programme with the primary goal of ensuring that the QEII Bridgewill remain in good structural condition, to minimise future maintenance costs.

Multiple effects of wind excitation and gust buffeting

In 2012 structural engineering specialists COWI performed an initial desk study and temporary monitoring exercise. This identified a potential susceptibility to vortex-induced wind excitation of the bridge pylons, which in turn seemed to cause excitation of the stays. Dry- and rain-wind galloping of the stays was also identified as a risk, due to low measured intrinsic damping.

> *AIS have written a software database & software extraction system that includes a configurable calculator to acquire data at very high speeds, store it in a way that is useful to engineers & allows relevant information to be abstracted with minimal data processing. Not all instrumentation contractors offer the same strength-in-depth capability.*
>
> **Neil McFadyen**
> Technical Director at COWI

For these mechanisms of wind-induced excitation, the magnitude of the response is known to be sensitive to the specific environmental conditions, for example the speed, direction and turbulence of the wind and the intensity of rainfall. To gain an accurate understanding of the fatigue demand on the structure, it is necessary to understand how often significant response events occur and quantify their severity. By correlating structural response against measured climatic conditions, insight is gained into the specific conditions and mechanisms that are causing the vibrations.

Simultaneous analysis of multiple behavioural variables

CPS invited Applied Industrial Systems to work together with COWI and devise a scheme that included tendering for the sensors' design and supply as part of a permanent structural health monitoring programme (SHMP). The SHMP needed to measure and simultaneously analyse five aspects of bridge behaviour, by collecting data continuously at very high speeds. Variables to be monitored included:

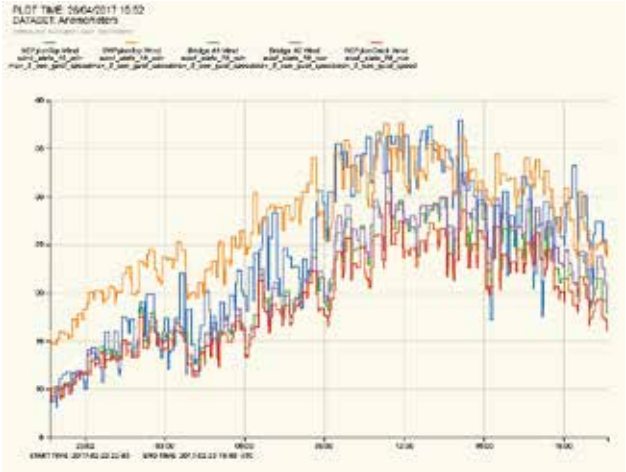
- Stay responses, in order to derive deflection amplitudes and modes correlated to wind intensity, turbulence and direction, also in conjunction with rain
- Stay response as a result of pylon vibrations and to observe patterns of stored energy transfer between pylons and to understand the causal mechanism (and incidence
- Synchronised response to the impact of corresponding wind, turbulence, rain and thermal measurements
- Deck response, which is measured because this may have a contributory role in the transfer or storage of energy
- Wind is measured at both deck and pylon-top levels for speed, direction and turbulence.

"The best way to remove speculation and subjectivity about demand on the bridge is to instrument and accurately measure what is happening and how the bridge responds during different combinations of weather conditions," says Neil McFadyen, Technical Director at COWI, who was responsible for the performance design.

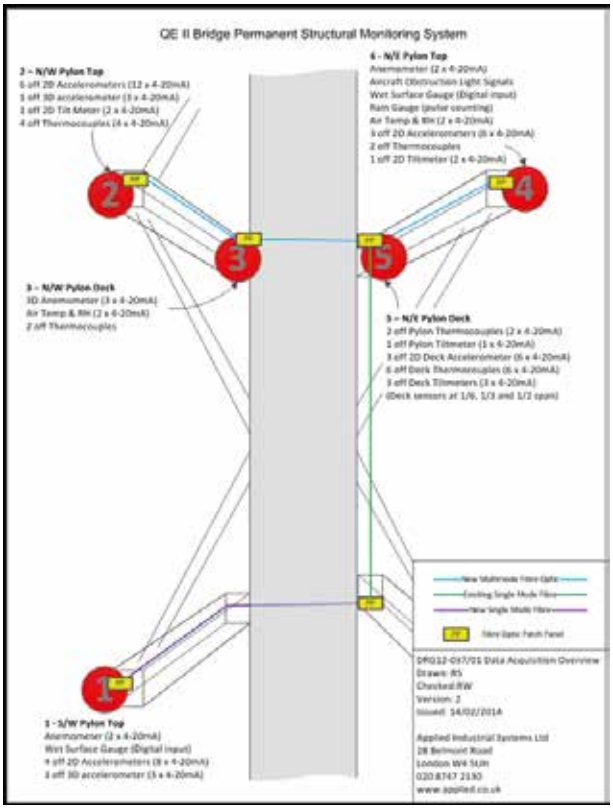
High speed synchronised data capture

Applied Industrial Systems was appointed to develop a structural health monitoring system. The company has a background in industrial measurement applications, scanning triangulating laser gauges over products and calculating profiles from readings taken at frequencies from 1kHz to 20kHz. In addition, AIS had also already worked with CPS, to provide the SCADA software responsible for monitoring life safety systems installed on the Dartford bridge and tunnel network.

By appointing AIS to provide the new structural health monitoring system, both systems could be integrated seamlessly to improve usability for CPS operators. In addition, alarms would be generated to a single user interface whenever an incident was detected to immediately alert operators to issues.



Trend reports showing wind gust impacts



System Architecture of SHM on QEII Bridge

Deck measurements are made by sensors located at at 1/6th, 1/3rd and 1/2 span. Wired anemometers are listed on two pylon tops and mid span (3D).

"AIS were already incumbent on the bridge as life safety specialists and had proved themselves to be particularly able software developers, capable of implementing operationally critical software and with a good understanding of our analysis objectives," says Neil McFadyen.

Intelligent monitoring reduces volumes of data captured

Ordinarily this would result in vast amounts of data, which due to volumes, could not all feasibly be stored or reviewed. The structural health monitoring system designed by COWI and developed by AIS, has been designed to counter these issues, by constantly examining whether data being collected is of interest.

"During the 200Hz acquisition phase, when data of interest is captured, this activates a trigger schedule for the relevant information to be stored for a set period of time, which enables wind build up impacts to be monitored.

Since this is taking place continuously, it's possible to examine historical information and compare impact during different weather conditions," says Simon Burras, Managing Director at AIS.

The system has another trick up its sleeve. The UK predominantly receives wind from the southwest, so COWI anticipated a faster accumulation of event packets where the wind is coming from that direction. However, using historical wind data from the Crossing instrumentation, it is possible to exclude data segments from the statistical processing data set in proportion to this historical incidence and thereby adjust the data set to accumulate an unbiased account of the effects of wind from nearly all directions and velocities. As a result, it then becomes much easier to state with confidence when the experiment is sufficiently complete and avoid unnecessary engineering analysis.

In addition, the system allows data to be synchronised, to simultaneously observe vibrations in different parts of the bridge structure. For example, monitoring aeolian vibration of the pylons forcing vibrations in the stays. The required synchronisation was achieved by using distributed Beckhoff EtherCAT I/O over fibre optic cables.

Currently in commissioning phase, the purpose of the new structural health monitoring system is to note whenever there is a response to wind by the pylons or stays, record the response and then classify it in terms of wind direction and speed. "Once we have captured a series of response events over an extended period, we will be able to identify two things; firstly the incipient wind conditions as events take place and secondly, how often they happen. Since we also know the historical meteorological patterns for the Dartford area, we can then make reliable probabilistic predictions about the amplitude of vibrations on the pylons and stays, plus their future frequencies of occurrence. This kind of predictive power can save significant amounts of actual value when one considers the costs of stay replacement or strengthening," says Neil McFadyen.

Optimising maintenance costs

With CP making the investment in a new structural health monitoring system, CPS aims to be in a position to accurately forecast likely longer term maintenance and operational costs in the shortest possible timeframe.

Once the data capture phase has been running for a few years, CPS will be able to demonstrate with a high degree of confidence, whether the bridge will be compromised by wind demand. More significantly, if it is, CPS will have the ability to take ameliorative action whilst plenty of residual fatigue life remains.

"Ultimately, all bridges are effectively prototypes and although theoretical modelling allows us to predict impacts in the future, bridge engineers inevitably lack the advantages of trial and error afforded to other engineering disciplines. Verification and condition monitoring are essential aspects of maintenance and ensure that any service disruption, plus the cost of managing inevitable structural wear and tear, can be kept to an absolute minimum," says Simon Burras.

Intelligent monitoring reduces the volume of data to be captured

The system is able to assess whether data captured is relevant and should be stored for long term trend analysis.

AIS' added value as control system integrators

- Track record in SCADA software & life safety monitoring systems
- Experts in developing operationally critical software, complex data processing & analysis
- Ability to integrate disparate control systems under a single user interface
- Background in industrial measurement, using triangulating laser gauges to measure product profiles at up to 20kH

APPLIED INDUSTRIAL SYSTEMS

www.applied.co.uk

London Office
IH 1.16 Q West, Great West Road
Brentford, TW8 0GP

Head Office
11 Church Road, Cheadle Hulme
Cheadle, Greater Manchester, SK8 7JD

020 8747 2130
info@applied.co.uk

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Siemens Solution Partner