Hidden bridge defect investigation and monitoring

A definitive approach to managing hidden defects in bridges.
The detection and management of hidden defects in bridges has become an area of increased focus across the infrastructure sector.

New technologies and techniques make it possible to address defects, significantly increasing safety and the lifespan of the asset.

CIRIA, in conjunction with James Fisher Testing Services and other industry leaders have conducted extensive research into hidden defects in bridges. The resulting guidance offers clear advice to identify and manage a host of defects across different structural types.

The guidance concentrates on developing inspection techniques to improve defect detection and explores the difficulties that come in managing and maintaining these structures, making reference to best practice through numerous case studies.

At James Fisher Testing Services we have over 50 years’ experience in construction health monitoring and structural testing. Our position as an industry leader is bolstered by our research and development activities, drawing on extensive in-house expertise and the resources of the wider James Fisher group.

Our BridgeWatch® system, based on our Smart Asset Management (SAM™) software, is one of the most advanced monitoring, analysis and data management systems available. It provides a comprehensive monitoring solution for a wide range of structures, yielding data-rich insights into the condition of your construction asset.

BridgeWatch® has been deployed on assets worldwide, facilitating real-time monitoring and preventative maintenance on defects as they occur. Implementations at high profile sites include the Forth Road Bridge, Queensferry Crossing, Mersey Gateway Bridge and Penang Bridge, Malaysia. It is also widely used on other, smaller monitoring projects.

BridgeWatch® uses a highly sophisticated range of sensors, data acquisition equipment and James Fisher Testing Services’ SAM™ software to provide constant, real-time monitoring in an integrated manner.

The hardware system comprises:
- A modular network of data acquisition units (DAUs)
- Fully integrated systems including GPS, corrosion and weigh-in-motion
- Sensors including; strain gauges, accelerometers, temperature, tilt and displacement transducers
- Other data inputs, including inspector records

The sensors are distributed across areas of interest, resulting in an adaptive system that can be applied to any structure at any point in its life cycle for one-off testing or continuous monitoring.

With the sophisticated SAM™ data analytics system, users can run multiple analysis routines, produce reports and generate health indices for risk-based maintenance planning. A customisable user interface processes and manages all data generated, within a modular and scalable open framework architecture.

Key benefits:
- Quality data provides the opportunity to predict component failure
- Comprehensive reporting facilitates preventative maintenance planning and faster reaction time to maintenance needs
- Increased safety
- Reductions in costs, down time and unforeseen failures

BridgeWatch® is one of the most sophisticated systems on any bridge, certainly within the UK.

Mark Arndt, Amey account director for the Forth Road Bridge
The BridgeWatch® main displays are exclusively configured for every asset to meet your specific requirements.

The software and reports can be branded for your project needs, and is available securely over the internet via PCs and other mobile devices. The user displays can be based on maps, plans, drawings, sketches, photographs and 2D or 3D graphics, with animations representing the real-time movements.

Overview:
- Web-based access to data - anywhere
- Automated data collection and management
- Manual data input and management
- Sophisticated data processing and reporting in real-time
- Real-time alerts and alarms

Sensors and data acquisition equipment:
- Compatible with all James Fisher Testing Services’ monitoring systems, regardless of application, data acquisition system or sensor mix
- Compatible with third party monitoring systems
- Seamless integration with GNSS, ATS, WIM and corrosion monitoring

User interface and displays:
- Customised web-based user interface
- Secure log in to clients’ own project pages
- Fast navigation through user-friendly interface
- Displays configured to suit individual projects - maps, plans, 2D / 3D graphs, drawings etc.
- Data sorted by location, sensors and events

Analysis:
- Data processing modules provide suite of algorithms for calculation of commonly required parameters and correlation of data
- Easy to add further complex algorithms using simple scripting
- Processing scripts can be applied to data creating real-time plots of derived parameters

Manual data input:
- Manually read sensor data
- Manual survey data (total station, level)
- Photographs and inspection records

Reporting:
- Customised notification and alarm events
- Enables flagging of abnormal events and custom report generation
- Automatic custom report compilation from multiple information sources
- Dynamic interactive self-container reports
- Download full data sets

Servers, data management and storage:
- Servers can be on-site or cloud based
- Automated routines for checking validity of data
- Seamless integration of operational data store with the optional systems data warehouse
- Key system performance benefits
- Ability to create long-term data reports

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Metallic bridge applications

**BridgeWatch® in action**

BridgeWatch® is a tried and tested system that has advanced industry best practice and set new standards in structural health monitoring. The system has been successfully applied to a variety of structures in order to monitor defects in line with the areas identified by the CIRIA guidance.

**Metallic bridge applications**

- **Hidden defect:** Internal box sections
  - **Location:** M6 Bescot and M5 Oldbury Viaducts (CS4)
  - **Problem:** Concerns were raised regarding the condition of welded box sections on the bridge structure and their susceptibility to fatigue damage.
  - **Solution:** James Fisher Testing Services designed and installed unattended dynamic monitoring systems to measure the strain under live traffic loading over a one month period at each site. Each location was fitted with 150 gauges and the data collected was used to calculate the fatigue life consumption at both locations.

- **Hidden defect:** Deck plates, jack arches
  - **Location:** Trowse Bridge and Caerphilly Station
  - **Problem:** The degree of load transfer from the deck plates to longitudinal beams was unknown, causing assessment calculations to call for a weight limit to be imposed on the bridge.
  - **Solution:** James Fisher Testing Services completed controlled static load testing. The use of known weights combined with the measurement of displacement and strain enabled more accurate assessments to take place at the site.

- **Hidden defect:** Suspension bridge cables
  - **Location:** M48 Severn Bridge
  - **Problem:** The client wanted to conduct strain measurement testing on the main suspension cables.
  - **Solution:** James Fisher Testing Services undertook strain measurement testing under live load conditions, conducting measurements on the wires within the main cable.

- **Hidden defect:** Suspension bridge hangers
  - **Location:** Silver Jubilee Bridge, Newcastle HLB (CS7)
  - **Problem:** The client wanted to conduct load measurement testing on the bridge’s suspension hangers.
  - **Solution:** A programme of load measurement on the hangers of the bridge was undertaken using vibration measurement techniques in order to accurately confirm the dead load condition.
Metallic bridge applications

Hidden defect: Compression members
Location: Newcastle High Level Bridge
Problem: The client required data relating to the load upon cast iron compression members / wrought iron (hidden) hangers.
Solution: James Fisher Testing Services was employed to monitor the loads within cast iron compression members and wrought iron (hidden) hangers before and during hanger replacement. The purpose was to ensure that load redistribution during hanger removal was managed safely and then to ensure that new hangers were tensioned to the correct level.

Hidden defect: Fatigue cracking
Location: Forth Road Bridge
Problem: During a routine inspection, damage to the bridge was noted. This included the complete fracture of one element of the truss end link on the mains span section of the eastern leg of the north tower of the bridge, and the partial fracture of its counterpart. The bridge was closed whilst repairs were carried out.
Solution: James Fisher Testing Services deployed a comprehensive health monitoring system to the bridge, including more than 200 strain gauges, temperature and tilt sensors to measure stress in the bridge members. This monitoring enabled the identification of the root cause of the link failure; a seized pin, and a phased repair was implemented as a result of the findings.

Concrete bridge applications

Hidden defect: Pre-stressing wires / strands / anchorages
Location: A4 Hammersmith Flyover
Problem: Breakages of post-tensioning tendons meant that residual strength testing was required to monitor the effect of failures on the structure.
Solution: James Fisher Testing Services undertook programmes of in-situ stress measurement in the post-tensioned concrete structure. This was part of the assessment of the structure’s residual strength following well publicised breakages of post-tensioning tendons, as detected by acoustic emission monitoring. James Fisher Testing Services also set up instrumentation for monitoring the structure during re-stressing operations.

Hidden defect: Missing / inadequate rebar / pre-stressing
Location: M56 Bowden View
Problem: Risk of sudden bridge collapse.
Solution: James Fisher Testing Services ascertained the dead load condition within a segmental post-tensioned concrete bridge deck. A monitoring system was fitted to the bridge, including acoustic emission sensors to detect pre-stressing wire breaks. Strain and displacement sensors were employed to monitor potential crack development.

Hidden defect: Half joints
Location: M25 Kingston Bridge complex
Problem: The renewal of approach viaducts required strength testing to be carried out on existing half joints.
Solution: As part of a renewal of approach viaducts, a test to destruction of a half joint was undertaken, with monitoring by James Fisher Testing Services. This was used to provide information about any hidden strength and to give confidence about the likely condition of the dozens of other similar joints within the junction complex.
Concrete bridge applications

Hidden defect: Corrosion of embedded reinforcement
Location: M6 Lodge Lane Viaduct and Besancon Bridge, Huddersfield.
Problem: During resurfacing work, concerns were raised as to the condition of the exposed reinforced concrete decks.
Solution: James Fisher Testing Services conducted extensive half-cell potential measurements across the full deck areas. Colour contour plotting of the results highlighted several areas where high levels of corrosion activity were evident. Laboratory testing of incremental concrete samples extracted from these areas showed significantly high chloride values, also indicating probable corrosion activity. Removal of the surface concrete confirmed the problem with several reinforcing bars showing major loss of steel section leading to a reduction in strength. All chloride contaminated concrete was removed and additional or new reinforcement was installed prior to concreting and re-waterproofing.

Hidden defect: Concrete delamination and corroded reinforcement
Location: Ribble Walton Bridge, Preston
Problem: General condition survey found large areas of delaminated concrete.
Solution: James Fisher Testing Services completed a comprehensive tap hammer survey to determine the full extent of the problem. Where concrete fell away the underlying reinforcement was seen to exhibit heavy surface corrosion. A full suite of testing was then carried out, including; cover depth, half-cell potential, resistivity, chloride sampling and carbonation depth testing. The cause of the problem was determined to be carbonated concrete down to the depth of the reinforcement, where reduced alkalinity had led to corrosion of the bars and subsequent concrete breakdown. All affected concrete was removed, the bars were cleaned, and spray concrete repairs were applied.

Masonry arch bridge applications

Hidden defect: Arch barrel
Location: Isle of Man
Problem: Deformations of the arch barrel.
Solution: James Fisher Testing Services implemented a camera-based system to monitor the deformation of the arch barrel under load. The resulting information gave an indication of load paths and locations of high strain, pinpointing areas where cracks could develop.

Hidden defect: Spandrels
Location: Bell Busk Viaduct
Problem: Longitudinal cracks had appeared beneath the spandrel and arch barrel interface.
Solution: James Fisher Testing Services undertook long term monitoring for deterioration and short term testing using special 3D displacement sensor arrays. These tests were used to identify whether new freight wagon arrangements were causing more distress to the structure due to a more concentrated load application.

Bearing and expansion joint applications

Hidden defect: Un-inspectable details
Location: M5 / M6 Midlands links
Problem: Data relating to bearing behaviour was required to plan maintenance work on multiple motorway links.
Solution: James Fisher Testing Services set up monitoring at four separate locations on the Midlands links in order to gather information about the actual behaviour of bearings and supporting structures, facilitating maintenance planning.

Hidden defect: Bearing seizure
Location: M6 Bromford
Problem: Data was required to measure long term structural articulation.
Solution: James Fisher Testing Services instrumented a ten span section of the bridge, enabling long term monitoring. The piers were slender and there was no evidence of movement in the steel bearings. In order to record any movement between the piers, monitoring included displacement between them so that any overall sway could be detected.

Hidden defect: Elastomeric degradation
Location: Warrington Bank Quay
Problem: Measurement of deformations in elastomeric bearings was required.
Solution: James Fisher Testing Services instrumented elastomeric bearings in order to measure the deformations in three dimensions under known traffic loading. This information was then compared with the design parameters.

Hidden defect: Setting out errors
Location: A14 Orwell
Problem: During the 1990's a bearing replacement was completed without full consideration of deck expansion between removal and replacement operations, resulting in a misaligned bearing that was at risk of 'falling off' under extreme conditions.
Solution: James Fisher Testing Services installed instrumentation and a live camera feed to accurately measure movement within the bearing prior to its replacement.
Moveable bridge applications

Hidden defect: Fatigue in track girders
Location: North Bridge, Hull
Problem: Longitudinal cracks were detected during a repainting contract. These were in angle sections connecting flanges to webs of the deep box section track girders, beneath the rolling part of the bridge.
Solution: James Fisher Testing Services devised a monitoring system comprising strain gauges and displacement sensors to track further deterioration and to detect whether any residual global deformations were developing. The bridge was maintained open for traffic in this condition.

Hidden defect: Articulation and load bearing issues
Location: Somerleyton / Reedham
Problem: General structural performance.
Solution: Monitoring was implemented in order to identify how the bridge was operating and where the load paths were under trafficking.

Hidden defect: Settlement
Location: Weetwood Bridge
Problem: Weetwood Bridge was suffering from leaning side walls.
Solution: The method to halt and arrest the movement involved excavation of fill from between walls and above the arch barrels; this was replaced with polystyrene fill and transverse ties were fitted. James Fisher Testing Services provided a movement and settlement monitoring system to measure any heave resulting from the removal of significant dead load.

Hidden defect: Scour
Location: Hedgeley Bridge
Problem: The bridge is located across an upland river which is subject to flash flooding and fast flowing water. Scour of the bridge foundations was a concern.
Solution: The risk of scour undermining the foundations had been mitigated by the construction of a concrete apron to channel the water away from the structure. However, this was being undermined by scouring action, indicating that there remained a risk of bridge foundation scour occurring. Sensors were installed in conjunction with a solar powered data logger to monitor inclination of the concrete apron and to provide a real time alert of possible scouring.

Smart Asset Management and BridgeWatch
Providing visibility of hidden defects through data driven insight.