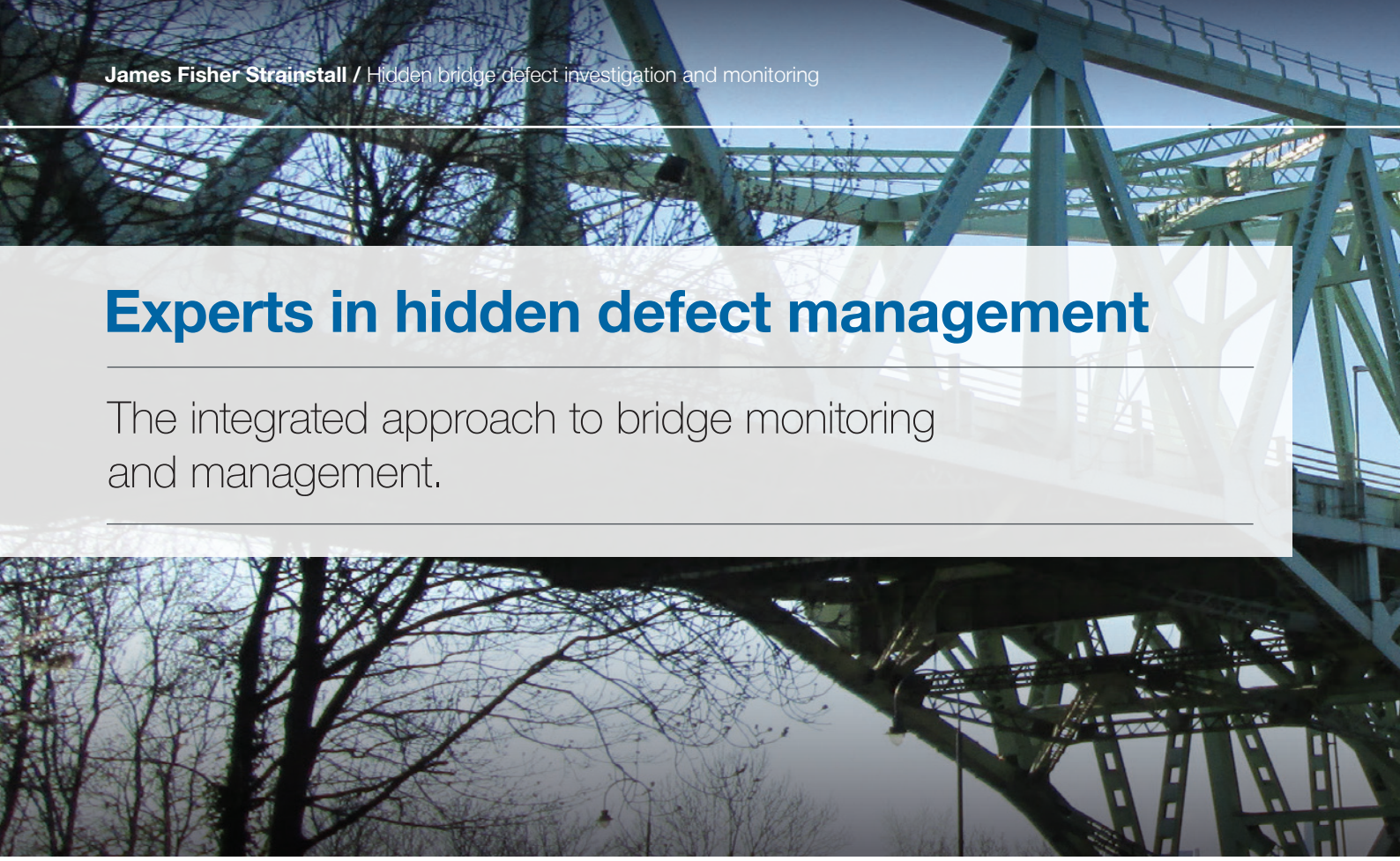
James Fisher and Sons plc
Pioneering Sustainably

James Fisher
Strainstall

Hidden bridge defect investigation and monitoring

A definitive approach to managing hidden defects in bridges.



Experts in hidden defect management

The integrated approach to bridge monitoring and management.

Undetected defects can have serious financial, professional and safety implications if not managed effectively as part of a risk based approach to long term asset management. In a time of significant budgetary pressure, it is critically important to clearly identify and prioritise repair and maintenance programmes.

Bridge managers must combine their professional know-how with the latest technical solutions in order to devise effective maintenance strategies.

Closures of the Forth Road Bridge (Dec 2015), A52 Clifton Bridge (Feb 2020), Hammersmith Bridge (Dec 2011 and April 2019), and the collapse of the Polcevera Viaduct in Genoa (Aug 2018) are just a few examples where hidden structural problems led to substantial repair bills and huge losses to local economy. In the case of Polcevera, such defects led to 43 fatalities.

Whilst normal inspection regimes are sufficient to identify visible defects, how can a bridge manager be sure that the structural characteristics are fully understood and effectively examined? The number of known substandard bridges has beeen reported (see below), but what about those with unknown defects?

Over 3,000 bridges in the UK are substandard

> A 2021 analysis of UK council maintained road bridges has identified over 3,000 bridges as being substandard. The RAC Foundation analysis used data from 199 of the 206 local authorities and found that 3,105 were unable to carry some of the heaviest vehicles on the road network. This represents 4.3% of the local authority bridges.
>
> The councils also reported that at the time they responded, ten bridges had fully collapsed in the previous 12 months and a further 30 had partially collapsed.
>
> The estimated cost to bring all the substandard bridges back to perfect condition is £985M, as part of a one-time cost to clear a maintenance backlog on all 71,656 bridges of £5.54bn.
>
> **RAC Foundation, substandard road bridges, January 2021**

> Our monitoring solutions can be tailored to the need of each structure, meaning that a solution can be installed to meet specific structural and budgetary requirements without compromising on accuracy or performance.

Have confidence in the condition of your structure

JF Strainstall experience and specialist technical knowledge is a result of decades working with bridge managers all over the world. We use proven structural investigation techniques and have developed a range of affordable and reliable monitoring solutions for hidden and
visible defects.

Key benefits:

- Demonstrates due diligence for owners / operators
- Protects public safety
- Reduces the risk of structural failure / asset downtime
- Provides long term savings on maintenance costs
- Informs preventative maintenance strategies

Solutions for every bridge configuration

We have experience of a very wide range of structural types, configurations and sizes. Our solutions can be applied across both road and rail, and can be installed at any stage in the bridge's operational life. These include:

- Crack monitoring
- Deflection and displacement monitoring
- Flood monitoring
- Scour monitoring
- Strike monitoring and prevention
- Load testing

Our team can complete a full bridge appraisal to gauge overall condition, highlight potential points of interest for remedial works and identify the most appropriate monitoring solution for the structure.

SAMS™

Setting the standard in structural health monitoring.

We use a highly sophisticated range of sensors, data acquisition equipment and James Fisher Strainstall's SAMS™ software to provide constant, real-time monitoring in an integrated manner.

James Fisher Strainstall's Smart Asset Management System (SAMS)™ 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.

SAMS™ has been deployed on bridges 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 bridges.

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.

> "SAMS™ 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 hardware system comprises:

- A modular network of data acquisition units (DAUs)
- Fully integrated systems including GPS, reinforced concrete corrosion and dynamic weigh-in-motion
- Sensors including; strain gauges, accelerometers, temperature, tilt and displacement transducers
- Other data inputs, including inspection records

Sensor layouts are generally devised to enable the principle loading effects to be observed alongside the structural responses. This will often include sensing for general bridge responses (displacements, mode shapes) and detailed responses (joint/beam movement, fatigue life consumption).

With SAMS™ sophisticated data analytics, 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.

Real time alerts and warnings can be generated by the system based on data derived from the sensors which can be used for operational management services.

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, downtime and unforeseen failures

Monitoring with SAMS™ in action

SAMS™ 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 CIRIA in their 2017 publication, 'Hidden Defects in Bridges: Guidance for Detection and Management', as the following case studies demonstrate.

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 Strainstall 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 Strainstall 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 Strainstall 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.

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 Strainstall 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 Strainstall 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.

Hidden defect: Brittle fracture

Location: Albert Edward Bridge

Problem: Cracked cast iron spandrel posts.

Solution: James Fisher Strainstall set up a system to monitor a cracked cast iron arch bridge in order to determine whether the structure was further deteriorating. Cracks existed at the top and bottom of integral spandrel posts and the problem was originally managed by frequent roped access inspection. The monitoring regime substantially reduced the inspection frequency and has provided a cost-effective method for managing the problem for over 11 years.

Hidden defect: Bolting and rivets

Location: Comberford Hall Bridge

Problem: The effectiveness of riveted flange plates was called into question following an assessment of the bridge structure.

Solution: The effectiveness of riveted flange plates on a multispan through girder rail bridge was monitored by James Fisher Strainstall. According to assessment codes, the lap length where plates were built up to resist bending moments was insufficient, resulting in the bridge failing its assessment. The monitoring project established that there was hidden strength and the assessment could be amended.

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.

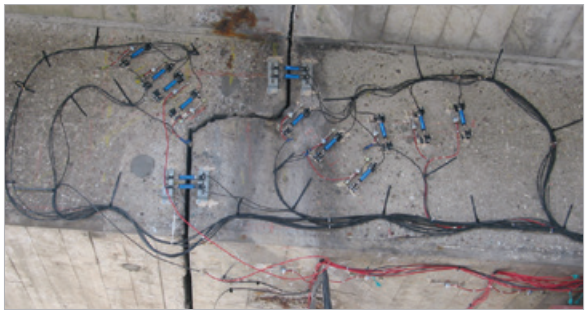
Solution: James Fisher Strainstall undertook programmes of in-situ stress measurement in the post-tensioned concrete structure. This was part of the assessment of the structure's residual strength following well publicised breakages of post-tensioning tendons, as detected by acoustic emission monitoring. James Fisher Strainstall 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 Strainstall 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: M8 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 Strainstall. 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.

Hidden defect: Half joints

Location: A14 Huntingdon Railway Viaduct

Problem: Deformations of the concrete half joint and potential failures of hidden half joints.

Solution: James Fisher Strainstall designed and implemented a system to monitor deformations of the concrete half joint, as an indicator of impending failure of the hidden half joint.

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 Strainstall 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 Strainstall 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 Strainstall 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 Strainstall 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.

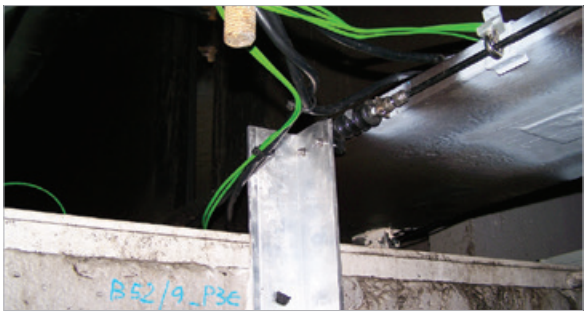
Bearing and expansion joint applications

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 Strainstall 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.

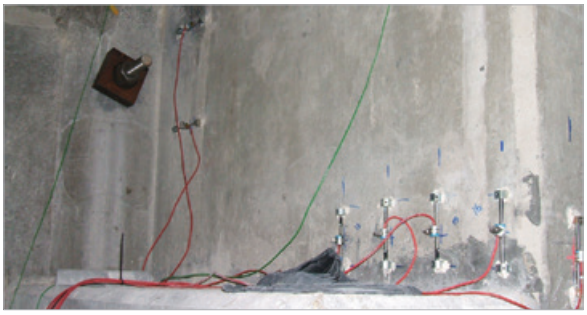
Solution: James Fisher Strainstall instrumented a ten span section of the bridge, enabling long term monitoring. The piers were slender and there was no evidence of movement in the steel bearings. In order to record any movement between the piers, monitoring included displacement between them so that 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 Strainstall 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 Strainstall 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 Strainstall 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.

Sub-structure applications

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 Strainstall 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.

About JF Strainstall

James Fisher Strainstall (JF Strainstall) is a world leader in the development of innovative monitoring solutions to enhance the safety and performance of your assets.

Drawing on more than 50 years' experience, we develop and apply our innovative technology, including load, strain and stress measuring techniques, within a wide range of sectors including marine, offshore, civil engineering, rail and aerospace.

In 2016, JF Strainstall celebrated 50 years at the forefront of developing innovative monitoring solutions for our customers.

We specialise in the design and manufacture of standard and bespoke load cells, strain gauges and integrated systems, which are proven to perform year after year in hostile and hazardous environments.

Whether a project is large or small, we provide a range of services including hull stress monitoring, crane weighing and overload, tendon and riser tension monitoring in TLPs.

Our instrumentation and software systems capture and analyse data on parameters such as strain, displacement, inclination, temperature, vibration and water levels to provide asset owners and operators with a comprehensive and real-time overview of events to realise optimum performance.

JF Strainstall has been part of James Fisher and Sons plc since 2006. James Fisher is a leading provider of specialist services to the marine, oil and gas and other high assurance industries worldwide.

Construction and temporary works monitoring

Data services

In-situ stress measurement

Smart asset management SAMS

Straingauge

Test equiptment

Weather monitoring

Safety and control systems

Structural investigation

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