iSHM
Structural Health Monitoring

Sensitive. Stable. Autonomous.

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iSHM: Monitoring Structural Health

Why monitor?

Any large structure is subject to forces that will cause it to deviate from its original design. As a structure ages, components such as bearings will fail, cable stays will weaken and the cumulative effects of cyclic or exceptional loads will reduce the structure's resistance. Over its lifetime the structure must also cope with geological processes, such as settling of the foundations, soil pressure, slippage and erosion. These processes set up a series of forces on the bridge that will cause structural members to bend, change orientation, and shift position relative to one another.

Physical inspections of a bridge will detect these problems before they become a safety issue. However, full inspections are mandated every 6 years and a fault may not be noticed until is well advanced—and expensive to rectify.

Even the most thorough physical inspection only provides a snapshot of a bridge's condition. Transitory or intermittent faults will inevitably be missed; subtle changes that are part of a long-term trend, can all too easily be dismissed as measurement errors. Nor can daily or seasonal patterns be accounted for.

Our monitoring systems observe the bridge at hourly or daily intervals. For exceptional events, they can measure at up to 500Hz. Our clients can access up to date bridge data from their own workstation, receive reports (typically every six months) and, if there are significant changes in the condition of their bridge, they receive an immediate alert.

Ultimately, our systems are designed to help engineers make *informed* decisions. Engineers and bridge managers must decide when maintenance is conducted, whether a bridge's lifetime can be extended or whether a fault will be sufficiently serious to require rectification. All of these decisions are based on predictions of the bridge's future state. The predictions are, in turn, extrapolations from the most recent survey—which may have taken place years before. By measuring the current state of the bridge, our iSHM systems reduce the uncertainty associated with these decisions.

When is iSHM used?

An iSHM system can be used in a number of contexts:

- *Monitoring known faults*—if a non-critical fault has been detected during a physical examination, monitoring its effect on the geometry of the bridge allows an informed decision to be made about the necessity and scheduling of repairs.
- *Bridges nearing the end of their life*—a bridge's design lifetime is a conservative estimate—the majority of bridges are taken out of service prematurely—this has economic and environmental consequences. An SHM system allows engineers to assess the status of a bridge and take corrective actions. With the appropriate information engineers can make decisions about extending the working life of the bridge.
- *Checking healthy bridges*—our systems represent an investment in the future of the bridge. By closely observing the geometry of the bridge, component failures and geological effects are detected early—and can be rectified either during planned maintenance with minimum disruption or with early intervention before the significant damage is inflicted.

The iSHM System

The technical challenge for a bridge logging system is to measure small changes over long periods; and to do so in a harsh physical environment with little infrastructure.

PSP systems are a collaboration between experienced electrical and structural engineers—they measure structurally meaningful data in a precise and stable way.

Our structural monitoring system has three components: an ensemble of sensors tailored to the structure; an on-site logger that interrogates the sensors and a remote server that analyses data and presents results on a web page.

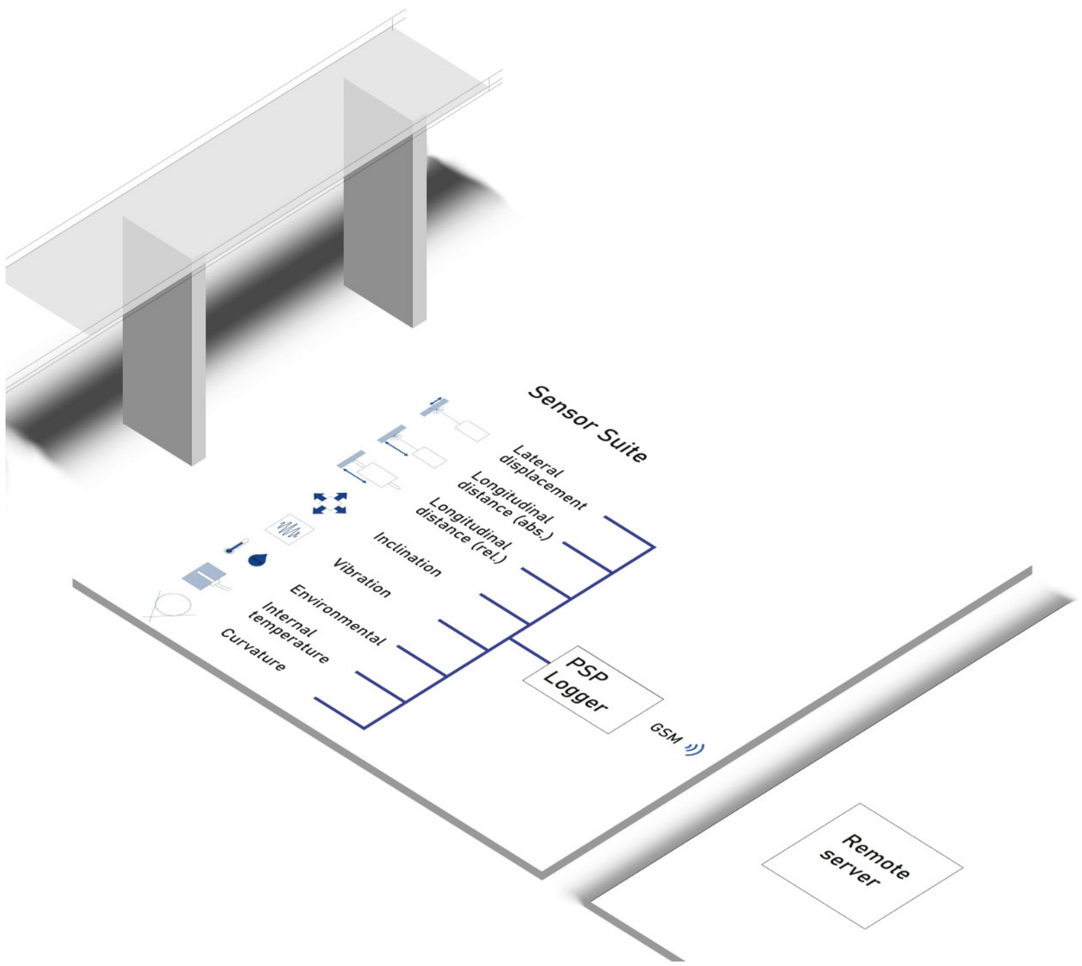
Sensors

The iSHM system is designed to operate with a wide range of sensors, both proprietary and third party; and is compatible with both current loop and Modbus standards. The choice of sensors varies with bridge and application. We offer sensors to measure geometric deviations in the bridge: deflection, displacement and inclination of the structural members. We also have sensors to measure vibration, the internal temperature of the bridge, air temperature and relative humidity. Other sensors are available on request

Inclination sensor

Lateral displacement sensor (laser and optical sensor)

Longitudinal displacement sensor (mechanical)

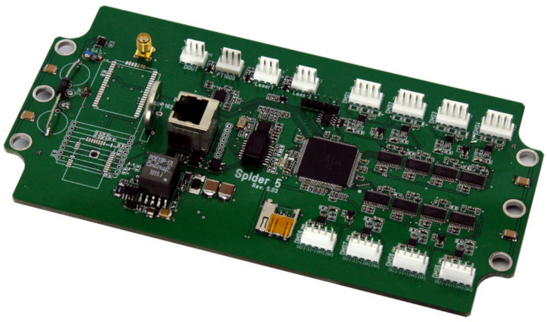


Smart Logger

The smart logger can measure up to 8 channels using a high precision 32 bit ADC and has 2 current loop channels. In addition, there is also a bus system than can measure up to 10 nodes. The sampling pattern is programmable: measurements can be taken at intervals ranging from 10s to 24 hours. Detailed snapshots of unusual events can be taken using short bursts of measurements at frequencies of up to 2kHz.

Because the logger must operate from a battery, special attention was paid to power consumption during design. Since the GSM component consumes most power, the logger will cache the measurements on its own removable storage and will only transmit data if it has sufficient reserves in its battery. This means that data transmission will be delayed until the solar cell has been able to charge the battery to the required level.

Housed with a steel IP65 case, the logger is robust and reliable. Once installed, the logger typically runs six months without human intervention.



Remote Server

Data received by the remote server is archived, analysed and presented to the user. Data is archived in a secure SQL database. Regression and time series models are used account for temperature and to resolve meaningful data from background trends, such as daily or season temperature variation. The processed data is presented to users with an easy to use web page, it can also be relayed to the user in Excel files. The remote server is also able to re-configure the logger during the communication window.

Why choose iSHM ?

• Specially designed, proprietary sensors and electronics.
• Flexible: sensor ensemble is tailored for each bridge.
• Self-powered, only requires mobile telephone coverage.
• Sophisticated analysis algorithms, up to date results presented on secure webpage.

How is iSHM used in practice?

Our SHM systems are usually leased for two years. Installation is carried out by PSP and generally takes less than a day. PSP is responsible for maintaining the system. Clients have access to up-to-date data via a password protected webpage. The data can be viewed graphically on the website or the raw data can be downloaded by the clients for their own analysis.

For more information visit www.petschacher.at

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Case Study

Case study

Task

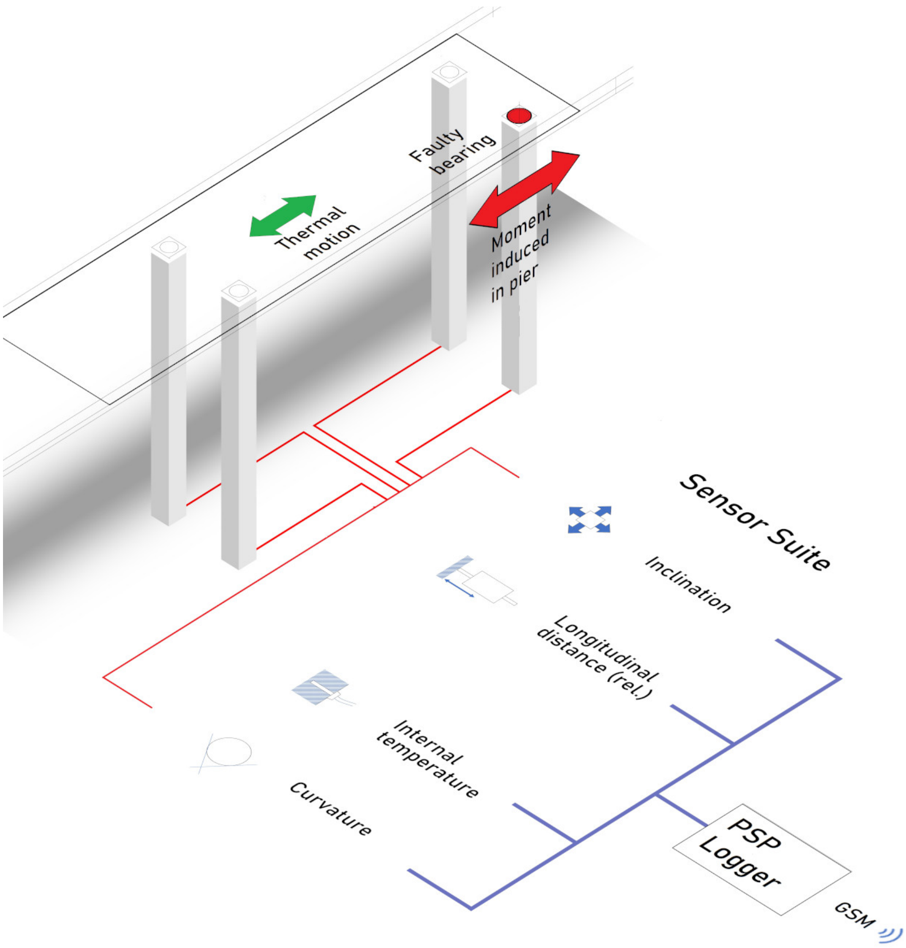
Our client owns two adjacent bridges, each is a 4 lane road bridge with a total span of more than 400m and piers arranged in pairs; at their highest points, the bridges are 20m above the valley floor. The bridges were constructed in the 1970's and typically support around 100,000 vehicle journeys daily. During a routine inspection of the bridges in July 2019 a fault was detected in one of the bridge bearings.

As temperature varies by hour and season, a bridge expands and contracts. The bearings allow the spans of the bridge to move relative to its fixed points. If a bearing resists this motion, the force will be transferred to the pillars of the bridge. This will cause the pillars to buckle and cause expensive structural damage.

Bearings are typically inspected every six years: a fault does not require the immediate closure of the bridge. However, the bearing will need to be replaced; it is only a question of when, and how the repair can be scheduled to minimise disruption. To make this decision, the bridge manager needs to monitor the deterioration of the bearing and its effects on the bridge.

Solution

PSP was asked to provide a monitoring system that could track the severity of the fault and alert the bridge owner if it approached a safety critical level. Our system monitors the curvature and inclination of the piers 24 times a day and reports values back to a remote server. We monitor both piers; measurements from the healthy pier act as reference values. The system was installed in one day with no disruption to traffic. Due to the limited infrastructure on the bridge, our logger is self-powered and communicates using the mobile phone network. Our logger typically runs for six months without maintenance. Analysis of the inclination and curvature of the piers takes place on a remote server. Data is made immediately available to the client via a secure webpage. Reports on the bridge status are prepared every six months. We categorise the bridge status as red, green or amber. Significant changes in the status of the bridge trigger an immediate physical examination of the bridge.



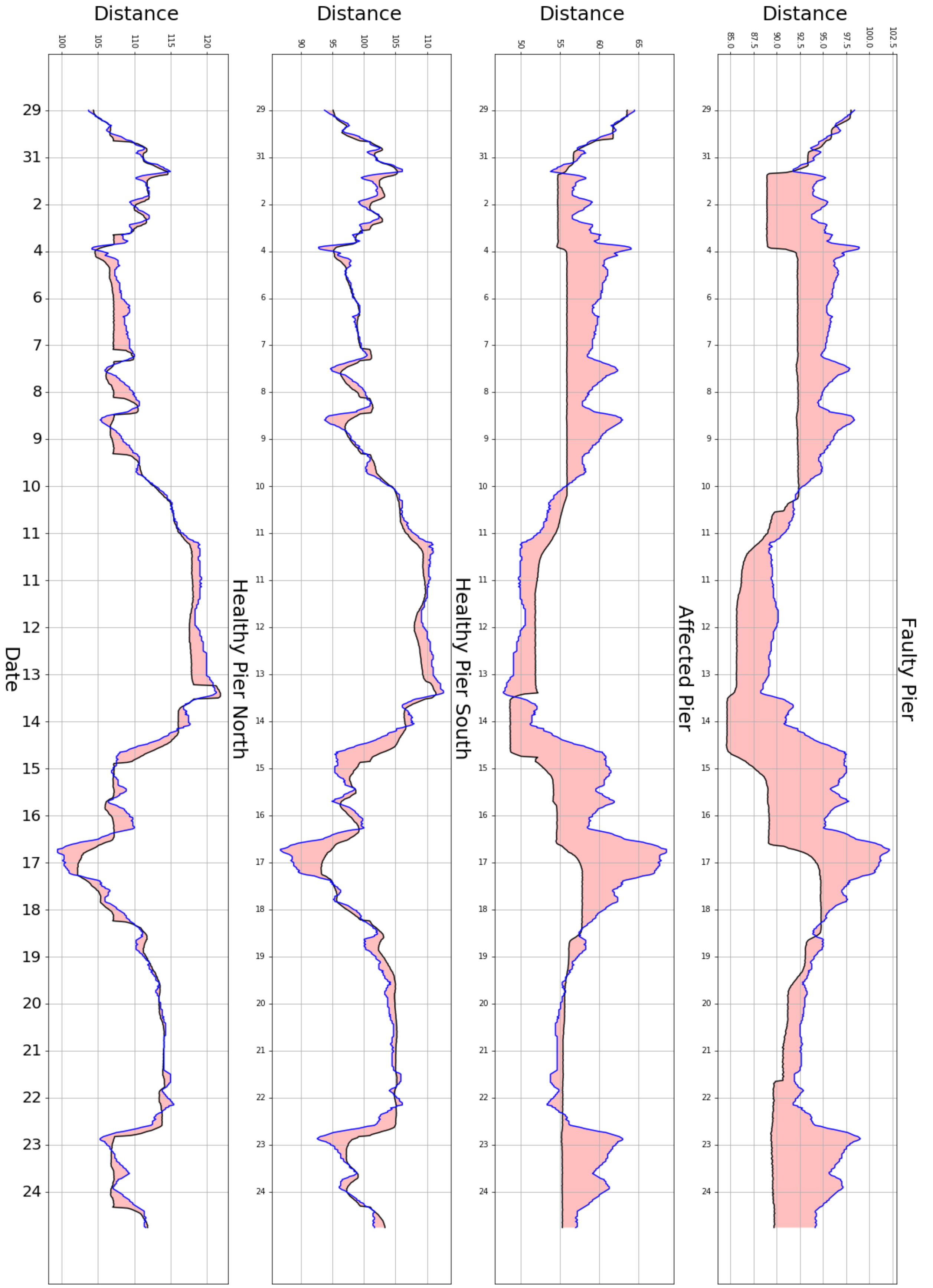
We placed instruments on four piers: the pier with the faulty bearing, the adjacent pier and two nearby but unaffected piers. Displacement sensors, to monitor the relative position of the pier to the bridge superstructure, were placed on all four piers. Inclination sensors to monitor the orientation of the piers, and curvature sensors to monitor their bending, were placed on the two affected piers. Sensors to measure the internal temperature of the bridge were placed on either side of the bridge.

If we treat the bridge as a system, then the driving function is the internal temperature of the bridge. Temperature drives the expansion and contraction of the bridge, and when that motion is resisted, it deforms the bridge. The bridge's temperature depends on the ambient temperature and on direct sunlight. Our client's bridge runs from east to west; the south side of the bridge is exposed to more direct sunlight and is significantly warmer than the north. Since expansion varies linearly with temperature, if the bearing is functioning, the relative displacement between the bridge and the pier will follow the same curve as temperature. If the bearing should fail, and the bridge and pier become locked together, there will be a discrepancy between our prediction and our measurement of position. The discrepency between where the bridge should be, and where it actually is, is taken up by the distortion of the pier.

Results

We plot the distances between the bridge superstructure and the pier at the bearings on the graph below. If the bearings are functioning correctly the displacement should track our temperature based prediction. However in the curves for the fault pier and the affected pier there are several plateaus, i.e. the bearing is sticking and the displacement is not changing. We can quantify the effect by measuring the difference between our measurement of the bridge's position and our prediction, coloured in pink. The discrepency between the thermal prediction and the measurement, represents the distance the bridge must accomodate by deformation. The healthy piers match the prediction well, however there are large discrepencies in the fault and affected piers. Should these discrepencies exceed pre-defined limits the responsible authorities will be alerted.

The PSPLogger costs approximately 0.1% of the value of the bridge and was quickly installed without disrupting traffic. By monitoring the bridge’s behaviour closely, bridge planners were able to confidently postpone replacement of the bearing to coincide with scheduled renovation work. This meant the replacement could be carried out more cheaply and with less disruption to traffic.


Distance
Distance
Distance
Distance
Date
Healthy Pier North
Healthy Pier South
Affected Pier
Faulty Pier

Notes

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