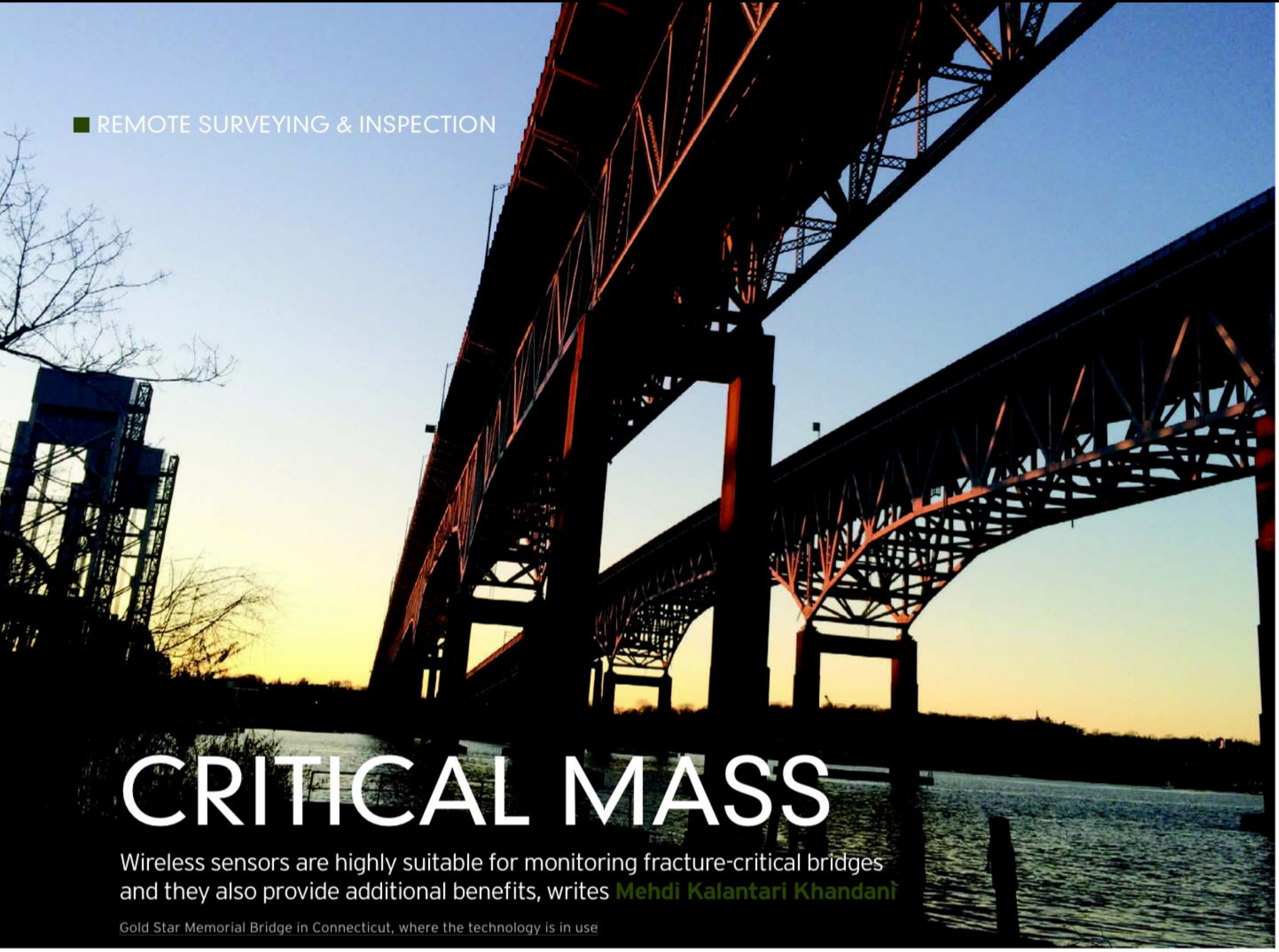


CRITICAL MASS

Wireless sensors are highly suitable for monitoring fracture-critical bridges and they also provide additional benefits, writes **Mehdi Kalantari Khandani**

Gold Star Memorial Bridge in Connecticut, where the technology is in use

The popularity of steel bridge designs in the 1960s and 70s which were subsequently revealed to be fracture-critical, means there are thousands of such bridges still in operation on major highways in the USA where traffic volume has increased significantly. According to the FHWA's National Bridge Inventory Database there are now more than 18,000 fracture-critical bridges in the USA. These structures are defined as having one or more steel members in tension whose failure would lead to partial or complete collapse of the bridge.

While replacing such bridges is often not an option due to the significant direct cost and indirect consequences, the lack of load distribution redundancy makes them vulnerable to corrosion, fatigue and violation of bridge load rating.

The catastrophic collapse of the Minneapolis I-35W Bridge in 2007 was a stark example of the extreme outcome of failure in fracture-critical bridges, but less dramatic failures happen every day, compromising public safety and leading to partial or complete shut-down of bridges. Early detection of structural problems in these bridges is imperative to ensure public safety.

A new practice for the effective monitoring and condition awareness of fracture-critical bridges is the use of wireless sensors, such as those offered by Resensys. The technology was developed through several years of collaborative work with the University of Maryland with the support of the National Science Foundation and resulted in Senspot, multi-sensor devices that concurrently monitor strain, temperature and tilt on the structural members of highway bridges.

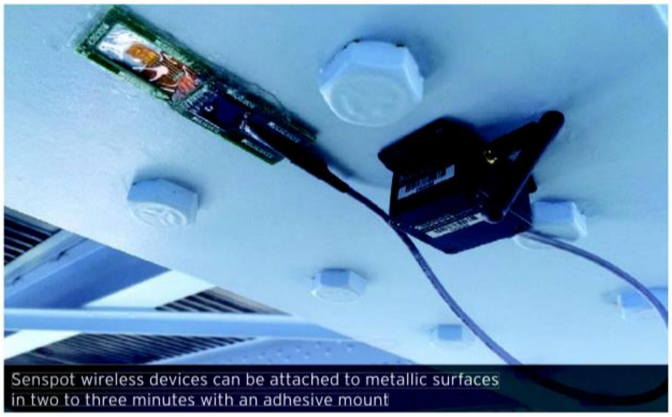
One feature that makes Senspot suitable for long-term monitoring is that it offers more than ten years of battery life, making it virtually maintenance-free. Another benefit is its ease of installation. Devices measure 50mm by 50mm by 25mm, which is relatively small, and they have an adhesive mount by which they can be attached to steel and other metallic surfaces. Installation is straightforward and takes only two to three minutes, making the devices attractive for large-scale monitoring where they can be attached to as many fatigue-prone points on a given bridge as required, or indeed on a large number of bridges. Sensors that are attached to structural elements with tension, such as truss members, girders, floor beams, stringers and gusset plates continuously report the strain.

The analysis of strain data from these sensors on fracture-critical bridge elements has shown how two components contribute to long-term strain.

The first component is thermal strain, a slowly-varying strain that is largely caused by temperature differences in various parts of the structure. This might be caused for example by the top or upper portion of a bridge deck being warmer than the lower portion. It could also be caused by friction or restricted movement in the bearings or expansion joints.

The second component consists of the strain spikes caused by live loads, demonstrated in the diagram where the raw strain values are shown alongside the temperature readings of a Senspot for a period of one week. This data is from a bridge on Interstate I-95 close to the east coast of the USA. The other part of the strain reading consists of brief, spike-like variations due to the effect of traffic passing over the bridge, heavy trucks in particular.

The second diagram shows thermal strain, which often changes in the opposite direction of temperature; the thermal strain increases when temperature drops, and vice versa. The third diagram shows the strain values caused by passing trucks. The data shows quasi-repetitive effects where the number and the amplitude of spikes are higher during morning hours, caused by peak-hour traffic; by contrast, the number of spikes on the weekend are considerably smaller.



Senspot wireless devices can be attached to metallic surfaces in two to three minutes with an adhesive mount

The Robert O Norris Bridge in White Stone, Virginia is nearly 3km in length and carries over 11,000 vehicles per day over Rappahannock River. This fracture-critical structure, which is more than 50 years old, connects Lancaster County and Middlesex County in Virginia and has a total of 44 spans. After identifying that several floor beams were suffering from significant corrosion and section loss, Virginia Department of Transportation applied retrofits to improve the strength of those beams.

Senspot sensors are used to monitor the strain on selected floor beams of the bridge from both categories of beams: with and without retrofit. Over a three-day period, a total of 25 strain sensors and two solar-powered data loggers and remote communication gateways were installed. Analysis of the strain data sample for February 2016 revealed varied levels of strain change in various monitored floor beams.

Comparing those beams which had been retrofitted with those that had not, the first observation was that the beams without retrofit showed considerably more strain that those with. Such data is a clear, quantified measure of the efficacy of the retrofitting.

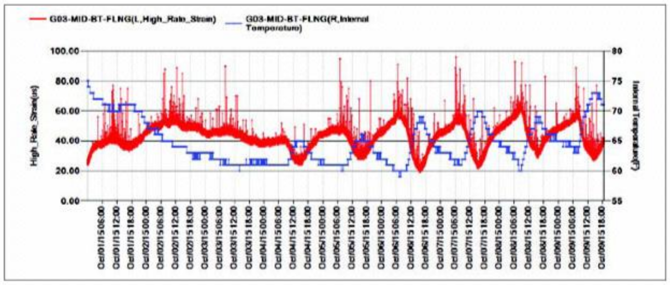
The second observation was that the data could be used to identify the members that had the highest strain spike – and thus the weakest beams. In massive bridges such as this, it may not be possible to spend a lot of time retrofitting all the beams due to budgetary constraints and identifying the members in the greatest need of retrofit could be significant. Strain data such as this provides a reliable method for identifying those members which would benefit most.

Comparing similar data for different months over time could provide valuable information regarding changes such as deterioration and formation of fatigue cracks. Such long-term monitoring and analysis is a powerful tool for early detection of issues on fracture-critical bridges.

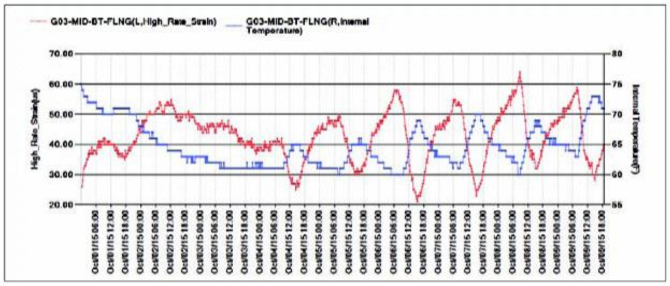
Another example where the technology is in use is the Gold Star Memorial Bridge, which is the largest bridge in Connecticut and carries more than 117,000 vehicles across the Thames River per day.

This fracture-critical bridge was built in 1943 and consists of 16 spans and 11 main deck truss spans. Resensys Senspot sensors have been present on this 1.8km-long bridge since December 2015 to monitor girders, truss members, gussets and bearings. The sensors are used to monitor strain in the members as well as tilt of the rocker bearings.

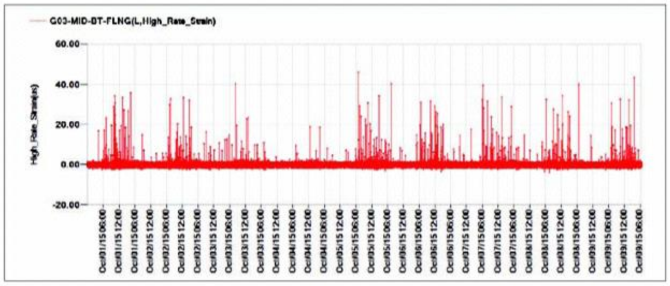
Data monitoring the tilting of one of the bridge bearings over a six-month period shows tilting of the bearing as a perfect linear dependence on temperature. In situations where such a relationship does not exist, the system detects lack of tilting in response to temperature change and produces an automated alert. Lack of movement in bearings can be caused by rusting, excessive friction, or debris. Another consequence of non-functioning bearings is an increased strain in members such as girders. Often such increased strain caused by non-functioning bearings occurs when the temperature drops. In such situations, the combination of bearing tilt, temperature, and strain can provide complete situation awareness and timely alerts about the issue before it leads to fracture, fatigue cracks or safety compromises.



Raw strain values and temperature readings captured by Senspot over a week on a bridge on Interstate I-95 close to the east coast of the US



Thermal strain increases when temperature drops, and vice versa



Strain values caused by passing trucks show an increase in spikes during morning hours, caused by peak-hour traffic

Although monitoring steel members is the primary concern in most fracture-critical bridges, variations of Senspot can be used in a wide range of other monitoring applications, including tilt, deflection, settling and instability in bridge piers; movement and displacement in expansion joints (with a special version of Senspot); vibration at critical locations of a bridge; as well as vibration for modal analysis and identification of the natural frequencies of structures.

Such technology offers easy-to-install wireless devices for long-term monitoring of fracture-critical bridges. It can monitor strain and temperature on girders, truss members, gusset plates, floor beams, stringers or other members to determine strain variations caused by temperature change and live traffic, which can be used for early stage detection of issues related to fatigue or formation of cracks. Senspot data can also help determine load-bearing capacity of a bridge as well as detecting occasional overstrains caused by vehicles violating a bridge's maximum allowed load. In addition to strain, Senspot sensors can be used to monitor bearings, piers, expansion joints or the status of existing cracks in a bridge ■

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