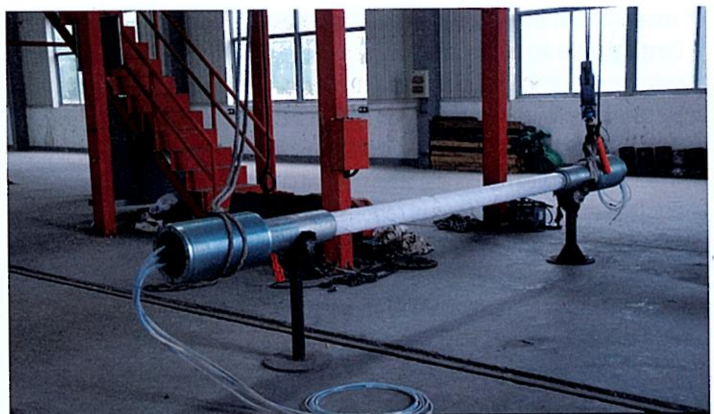
Bridge
DESIGN & ENGINEERING

TALL STORY
SPANISH BRIDGE REACHES LOFTY HEIGHTS

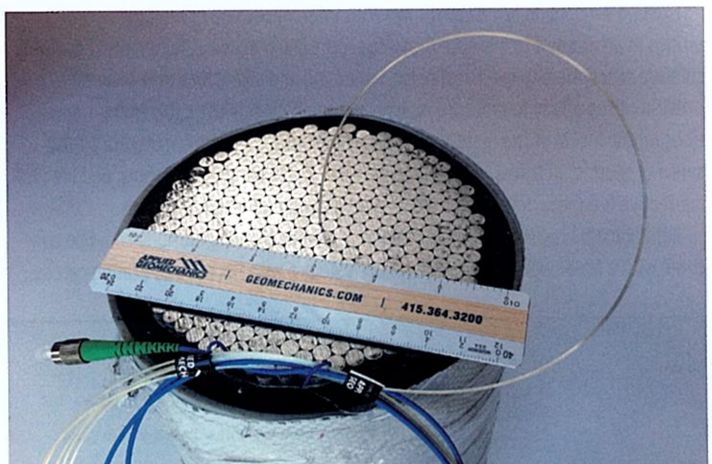
THE DEFINITIVE PUBLICATION FOR BRIDGE PROFESSIONALS WORLDWIDE | ISSUE NO. 63 | SECOND QUARTER 2011 | WWW.BRIDGEWEB.COM

SMART WORK

New cables with the built-in capability to measure load, temperature and humidity are being developed for the bridge industry. **Thomas Weinmann** reports



Test specimen with FBG sensors installed



Fibre optic sensor placed in interstitial space of PWS cable

If your cables could talk, they might tell you all kinds of things about their health, but would you listen? Shanghai Pujiang Cable Company is working to develop 'smart' cables with sensors that measure load, temperature and moisture/humidity. Continuous monitoring of these factors can help reduce long-term maintenance costs for cable-suspended structures, and in the long-term can provide valuable performance data for structures subject to event-driven conditions or potential for corrosion.

Many bridges have undergone extensive inspection programmes to assess the condition of their cables. Corrosion and load distribution are particular causes for concern; corrosion is often responsible for cable-section losses that can affect distribution of loads. Current cable force monitoring programmes are often performed on an 'as-needed' basis through vibration analysis. Another common practice is to use external accelerometers in conjunction with vibration analysis software to determine average forces over a set time period. However the latter can only provide information for a single data point at any given time, and may miss critical events of interest.

For moisture or humidity measurements, traditional analogue and digital sensors also present numerous problems due to their design and mode of operation. When installed within cable bundles, high radial compression forces can often cause conventional sensors to fail, and the exit wires may compromise protective cable moisture barriers. Analogue and digital sensors are also vulnerable to electrical transients, lightning damage, and signal noise over long sensor cable runs.

Fibre optic technology, however, offers effective alternatives to traditional cable monitoring techniques without the disadvantages of conventional methods and equipment. SPCC and its international sales agent Techstar have been working with Applied Geomechanics to develop and implement this technology through trial applications. SPCC's cable is a parallel wire system which offers the ideal cable geometry for the use of fibre optics for force, temperature and moisture/humidity monitoring.

The concept of force and temperature measurement in the Smart Cable uses embedded fibre Bragg grating optical sensors installed during fabrication to monitor new and existing cable forces over time. The objective of the first phase of the programme initiated by SPCC was to develop and test techniques for installing these sensors during production, verify survivability during cable fabrication and verify measurements obtained during subsequent load testing.

Instrumentation and testing was carried out on a 223-wire cable specimen at SPCC's facilities in China. Multiple installation techniques were evaluated on a 4m-long cable test specimen, with all sensors exiting from the cable anchorage assembly. The fibre Bragg grating sensors were inserted and bonded into the wire bundle at depths of at least 1m. Some of the sensor cables were damaged in the vibration process during injection of the epoxy resin compound, but all remaining sensors survived the high curing temperatures required for the epoxy resin compound in the anchorage assembly.

A static tension test was performed on the cable specimen at the SPCC facility. The load was applied and increased in 500kN increments to a maximum of 40% guaranteed ultimate tensile strength or 5,500kN. Measured strains collected using a Micron Optics interrogator while tensile load was recorded manually. After achieving maximum load and unloading the test specimen to zero, a series of runs from 0-2,500kN were made to verify repeatability of measured response.

The results confirmed that fibre optic sensors can be used as a force measuring sensor in stay cables, while identifying issues related to temperature, bonding and coordination with fabrication. Phase one results identified optimal installation techniques for field applications.

Phase two is to evaluate the long-term performance of Smart Cable technology through real world application; refined installation techniques will be used on a stay cable installed on a bridge in China. SPCC has identified an opportunity to install FBG sensors in suspension bridge hangers to evaluate load measurements during ▶

installation and long-term performance during load cycling.

Currently, there are no specifications for moisture protection verification testing of main suspension bridge cables, such as those required for stay cables. Recent inspection programmes have shown how difficult it is to access internal wire ropes and parallel wire strand for visual documentation and repair. The results these programmes have initiated repairs and often resulted in implementation of dehumidification systems to mitigate the onset of corrosion.

Although current technology exists to monitor moisture/humidity in general, the application of this technology to main cables is restricted for a number of reasons. The sensors that are currently available are not suited to placement inside large bundles, and are generally too large in diameter to be placed in the interstitial spaces of wire ropes, strands or smaller bundles of PWS. Additionally these sensors have not been tested for survivability to the radial compressive forces that they would be subject to. Even if these sensors were placed inside larger bundles, they would require lead wires to exit the bundles, compromising the outer barrier wrap.

Existing sensors do not allow for in-series interconnection of multiple sensor strings in an attempt to mitigate those concerns listed above. Additionally these sensors are susceptible to electrical noise, lightening and signal loss over long cable runs.

Without the ability to measure moisture/humidity inside the cable bundle, conditions on the inside of the bundle are not truly identified. This can generate a false sense of security in terms of the integrity of the cable bundle as a whole, and lead to ineffective feedback control for sensor-driven dehumidification systems.

But engineers believe that all the above restrictions and limitations could be overcome with a fibre optic-type sensor. An optical fibre with fibre Bragg grating can be prepared in such a way that, when exposed to moisture/humidity, it expands or swells thereby 'choking' the sensor. The sensor would be exposed to radial compressive strains during this process, in much the same way it is when used to measure tensile or axial strains. This 'radial' compressive strain or wavelength change has been shown to be linearly proportional to humidity.

Shanghai Pujiang Cable Company has initiated a programme aimed at producing a reliable, proven fibre optic moisture/humidity sensor. Firstly engineers will determine protective measures to provide survivability of sensor in actual field installation applications. They will then determine applicable coatings that will provide repeatable, accurate measurements, before implementing it in field conditions on a limited basis. After verifying the field results they will identify a bridge for a permanent application.

For the initial phase of fibre optic moisture/humidity sensor evaluation, the sensor must be protected during the handling and installation to avoid the fibre optic sensor undergoing axial strain. To investigate installation techniques, SPCC is currently working with AGI to perform survivability testing during one of their dehumidification prototype tests at their facility. The objective is to install a string of fibre optic sensors in protective sheathing within and between PWS bundles without straining the fibre as this would interfere with the intended measurement of strain due to the moisture/humidity. These tests were due to be completed as *Bd&e* went to press.

Once a prototype sensor has been developed, it will enable comparison with existing technology. After field verification testing, it should be available for use in almost any type of cable/strand post-tensioned system.

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