

THIS MONTH: CORROSION OF HIGHWAYS AND BRIDGES

NOVEMBER 2011

# **MIP** MATERIALS PERFORMANCE

**CORROSION PREVENTION AND CONTROL WORLDWIDE**

## **Fiber Optic Corrosion Monitoring of a Delaware Bridge**

**Anode Behavior Under Cyclic  
Immersion in Brackish Water**

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**Special Feature:**

*Challenges in Sustaining the World's  
Bridge and Highway Infrastructure*

# Material Matters

## Delaware bridge incorporates fiber-optic corrosion monitoring



A University of Delaware student routes cable from a conventional multiple-depth chloride sensor mounted on the bridge deck through the reinforcing steel of the edge girder so it can be connected to the equipment enclosure. Photo courtesy of Pablo Kobak, Skanska USA.

**W**hen construction is complete on Delaware's new Indian River Inlet Bridge, a permanently installed state-of-the-art fiber-optic structural health-

monitoring system will keep tabs on the bridge's structural performance, including the possibility of corrosion, and its maintenance needs over an expected service life of 100 years.

The new 2,600-ft (792-m) long, four-lane cable-stayed bridge with a protected pedestrian walkway, the fifth bridge to be built over the inlet between the Atlantic Ocean and Indian River Bay since 1934, will replace the existing steel girder bridge built in 1965. The new bridge is designed to withstand the harsh marine environment of the Delmarva Peninsula, including the salty air of the Atlantic seacoast and the potential for hurricane-force winds.

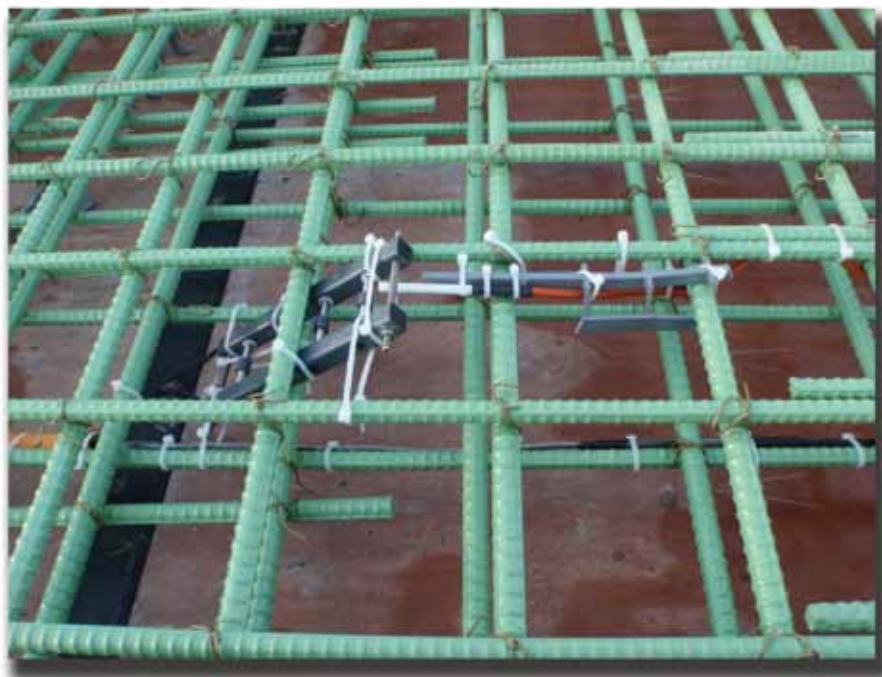
According to the Delaware Department of Transportation (DelDOT), the existing bridge is being replaced because of scour-related structural support issues. Severe scour from rapid currents increased the inlet's depth from ~28 ft (8.5 m) in 1965 to its current depth of more than 100 ft (30 m) and caused deep holes in the bottom of the inlet that exposed and undermined the existing bridge piers located in the waterway. Additionally, the steel H-piles that support these piers are exposed to salt water because of the scour and are corroding, which could cause loss of strength and affect the stability of the bridge piers in the long term.

To alleviate the concern over scour affecting structural supports, the cable-stayed design of the new bridge eliminates the need for support structures in the waterway. It features four 249-ft (76-m) tall concrete pylons (towers), located on

the inlet's embankments, and 152 stay cables attached to the pylons that hold up the bridge deck. The pylons are supported by 293 precast, 36-in (914-mm) square, ~100-ft long concrete foundation piles. The reinforcing steel in the concrete, including the edge girders and roadway deck as well, is coated with a layer of protective epoxy paint.

Helping ensure this new bridge will last for 100 years is a sophisticated fiber-optic sensor network that is being installed in the bridge as it is constructed. Funded by a \$1.1 million DelDOT grant in 2009 to the University of Delaware for design and installation, this structural health-monitoring system will measure and deliver real-time data on numerous variables that can affect the health of the bridge structures, such as strain, temperature, movement, vibration, inclination, and chloride ingress, and provide early warning signals of any potential structural problems. It is expected to monitor the structure throughout its entire lifetime.

“We believe this bridge is the first long-span, cable-supported bridge in the United States to be instrumented with a permanent structural health-monitoring system while under construction and we are sure this is the first permanent fiber-optic-based monitoring system to be installed on a bridge of this type in the United States,” says Harry (Tripp) Shenton, professor and chair of the Department of Civil and Environmental Engineering at the University of Delaware (Newark, Delaware) and part of the team responsible for designing and installing the structural health-monitoring system



**A prototype fiber-optic chloride sensor (right) is mounted adjacent to a conventional multiple-depth chloride sensor (left) in the bridge deck reinforcing steel so that data from the two sensors can be compared. Photo courtesy of Gary Wenczel, University of Delaware.**

on the Indian River Inlet Bridge.

According to Shenton, the structural health-monitoring system comprises 189 strategically placed fiber-optic sensors—accelerometers, expansion joint displacement gauges, tilt meters, chloride sensors, and strain gauges—that are either embedded into the concrete structures (pylons, edge girders, and road deck) or mounted on the surface of various bridge components, including the stay cables, pylons, and road deck. He explains that the number and type of sensors, as well as their location on the bridge, were driven by the desire to gather the type of data that would offer the most assistance when making decisions for the long-term maintenance of the bridge. Although the fiber-optic monitoring system is capable of generating 1,000 readings per second, the frequency of sensor readings is yet to be determined and Shenton expects the sensors will be interrogated several times a day with more frequent readings being taken during specific events such as a hurricane or nor'easter. One exception is the interrogation rate of the chloride sensors, which will be done less frequently until the time that a concentration of

chloride ions is measured in the concrete.

One of the key advantages of the fiber-optic system, Shenton observes, is that the sensors don't require electrical power to operate. All the fiber-optic sensors are activated by a light pulse (produced by a piece of equipment by Micron Optics known as an interrogator) that travels along a thin glass optical fiber; and measurement data in the form of reflected wavelengths of light are returned to the interrogator through the same fiber. Separate wiring for power and data transmission is not required.

Another benefit of using fiber optics is the longevity of the components, says Keith Chandler, chief executive officer of Chandler Monitoring Systems, Inc. (Lawrenceville, Georgia), the company working jointly with Shenton and his team on designing, installing, selecting, and procuring the structural health-monitoring system components for the new Indian River Inlet Bridge. Because it is constructed of glass, Chandler notes, optical fiber is not susceptible to corrosion and it has a history of long life in underground service in the telecommunications industry.

All the fiber-optic sensors on the



**Construction of the new cable-stayed Indian River Inlet Bridge with the built-in fiber-optic sensor network is expected to be completed in spring 2012, with two lanes of traffic opening in December 2011. The existing bridge can be seen behind the new bridge. Photo courtesy of Gary Wenczel, University of Delaware.**

bridge are based on fiber Bragg grating (FBG) technology, which uses reflectors in the sensor optical fiber to reflect particular wavelengths of light, says Chandler. Depending on how it's mounted to the bridge, a particular sensor will stretch in response to the variable it is measuring, such as strain, temperature, or vibration, which affects the distance between the reflectors in the sensor, he explains. Basically, the intensity of the variable affects the degree of stretch in the sensor and the distance between the reflectors, which is indicated by the light wavelength reflected back to the interrogator. Specially developed software interprets the raw data from the different types of sensors and translates it into meaningful reports.

During construction, a main fiber-optic cable, called a trunk line, was installed along the length of the bridge. Before the concrete was poured, the embedded sensors were mounted to the reinforcing steel and connected to the system with fiber-optic cables that were fusion-spliced to the trunk line. The trunk line will be connected to the interrogator. When construction is complete and the

monitoring system is operational, the interrogator will send a light pulse to all the sensors on the bridge and receive the reflected light waves back from the sensors through the fiber-optic cable network embedded in the bridge. The raw data will be processed by a central computer located off site.

Chandler notes the fiber-optic-based chloride sensor used on the Indian River Inlet Bridge, which Chandler Monitoring developed jointly with QPS Photonics, is a prototype and the only one of its kind. "It's revolutionary in the sense of being able to monitor chlorides," he adds. When a concrete structure is exposed to deicing salts, salt spray, or seawater, chloride ions will slowly penetrate the concrete, eventually reaching the reinforcing steel and accumulating to a concentration level that damages the steel's protective film and leaves it vulnerable to corrosion if moisture and oxygen are present at the steel/concrete interface.

The fiber-optic chloride sensors embedded in the new Indian River Inlet Bridge deck will measure the concentration of chloride ions in the concrete covering the reinforcing steel on the

roadway. To do this, the chloride sensor has multiple specialized coatings on the outside of the optical fiber. As chloride ions enter and accumulate in the concrete near the sensor, the coatings will swell and the sensor will stretch, which affects the distance between the reflectors in the sensor. If the chloride ions dissipate, the coatings on the optical fiber will shrink and the sensor will relax. These changes are indicated by the light wavelengths that are reflected from the sensor.

Although the prototype fiber-optic chloride sensor has undergone extensive testing and reportedly is able to accurately measure chloride ingress in concrete, DelDOT made the decision to also install a conventional, widely used multiple-depth chloride sensor that detects chloride contamination through a galvanic current between carbon steel and stainless steel electrodes, notes Shenton. Ten locations in the concrete bridge deck will be monitored with the conventional chloride sensors. At five of those locations, a fiber-optic chloride sensor is mounted adjacent to the conventional sensor in the bridge deck reinforcing steel so that data from the two sensors can be compared to see if the readings are similar. The conventional chloride sensors are connected by a separate cable to an equipment enclosure on the bridge where readings will be taken manually several times a year. If chloride ingress occurs, it will be a slow process, Shenton says. Data comparisons from the two types of chloride sensors may not be available for a year or so after the bridge is completed.

Two lanes of the new bridge are expected to open in December 2011, although recent hurricanes, tornados, and inclement weather have challenged the construction schedule. All four lanes will open to traffic next spring, and the demolition of the existing bridge is expected to begin once traffic is shifted to the new bridge.

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