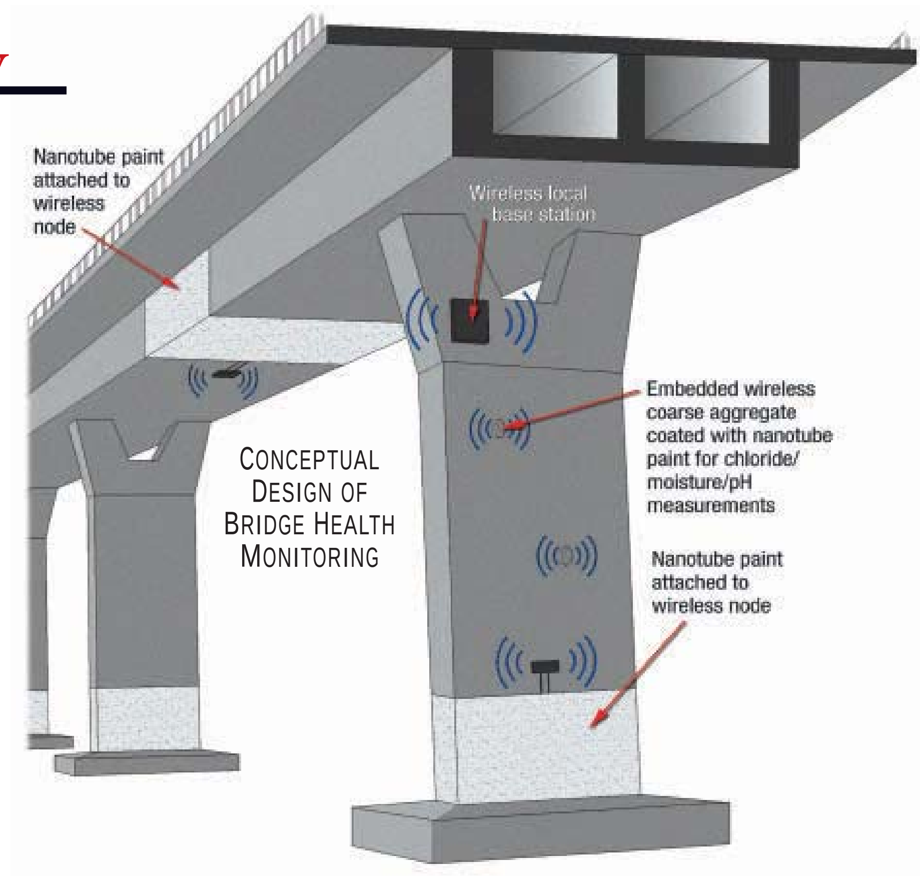
Structural Health Monitoring Tests Planned for Bridges



DAVID MCGAHON AND MOHAMED SAAFI, UNIVERSITY OF STRATHCLYDE

THREE BRIDGES—one each in Michigan, Maryland, and North Carolina—will be the sites of field tests this summer of new technologies for monitoring structural health. The Telegraph Road Bridge, a roughly 40-year-old steel girder structure with a concrete deck on Interstate 275 in Monroe, Michigan, will be part of an experiment sponsored by the National Institute of Standards and Technology and conducted by Jerome Lynch, Ph.D., M.ASCE, an associate professor of civil and environmental engineering at the University of Michigan. The test will involve a so-called sensing skin, a thin film material surrounded by electrodes that will be used in two locations to detect cracks and monitor corrosion on the steel girders, explains Lynch. The sensing skin was developed by Lynch and Kenneth Loh, Ph.D., A.M.ASCE, a former graduate student of Lynch's who is now an assistant professor in the civil and environmental engineering department at the University of California at Davis.

Testing of the other two bridges this summer will involve placing acoustic emission sensors in a piezoelectric paint that also will be applied to a plastic film material. The paint will be used to monitor fatigue-related cracks. One of the structures to be tested is a simple-span welded steel girder bridge in Maryland; the other is a steel swing bridge near the Outer Banks region of North Carolina, explains Chung C. Fu, Ph.D., P.E., F.ASCE, a research professor in the civil and environmental engineering department at the University of Maryland. The piezoelectric paint sensors were developed by Yunfeng Zhang, Ph.D., A.M.ASCE, an associate professor of civil engineering at the University of Maryland. The concept of the piezoelectric paint sensors began at least 10 years ago when Zhang was working at Lehigh University's Center for Advanced Technology for Large Structural Systems, but the technology has evolved and been improved since then, Zhang notes.

Tests will also be carried out on a miniature wind turbine and a solar panel system that will provide electric power to the sensor nodes that will have the task of transmitting data from the piezoelectric paint sensors on the Maryland and North Carolina bridges. These power sources were developed by Fuh-Gwo Yuan, Ph.D., the Samuel P. Langley Professor in the mechanical and aerospace engineering department at North Carolina State University.

The names of the bridges in Maryland and North Carolina will not be disclosed until the tests have been completed, notes Fu, the principal investigator on the project, which is being funded by the U.S. Department of Transportation's Research and Innovative Technology Administration.

The tests in Michigan, Maryland, and North Carolina will be conducted over the next year or perhaps a longer period.

On the Michigan bridge, the sensing skins will involve two patches of film, each roughly 4 by 4 in., attached to the surface of the bridge via an epoxy. The skins will feature a combination of carbon nanotubes and polymers that will make them sensitive to structural damage when they are electrically stimulated, explains Loh. The electrical stimulation will be generated via a sun-powered electric impedance analyzer, which also will be attached to the bridge. The analyzer will wirelessly transmit the test results to a sun-powered server at the bridge site that in turn will relay the results to researchers at the University of Michigan.

Each system will have a distinct function. One will monitor cracking in the structure's steel by recording the changes in the sensing skin's electrical properties that occur when the steel structure is degraded. The other will feature a polymer that registers changes in the conductivity of the skin caused by the absorption of oxides or the agents that induce corrosion, including chloride ions. In each case, the electrical response of the skins will be measured, and an algorithm will be used to help create a sort of spatial map somewhat akin to a medical

X-ray or magnetic resonance image that, Lynch says, will provide"a spatial representation of what's going on in the structure."

Although a roughly 4 in. square patch might not seem sufficiently large for monitoring a long, tall bridge structure, the skins actually represent a "paradigm shift" over current structural health monitoring devices, Lynch says. Current tools, which include strain gauges, can measure only a single distinct point on a structure, akin to a single pixel in a digital photograph, Lynch says. By comparison, the sensing skins will provide distributed measurements over a full two-dimensional area and thus will be comparable to a complete photograph rather than that single pixel, he explains.

At the University of California at Davis, Loh is working on a similar sensing technology that can be applied to structures in the same way as paint or be embedded into such composite materials as fiber-reinforced polymers. Such polymers are used in a wide range of civil structures, for example, bridges, wind turbines, aircraft, and aerospace vehicles. "With visual inspections there is very little we can do to identify damage that is occurring in the structural materials," Loh explains. "But having a sensor be a part of the structure will allow us to essentially see into the material and understand how it's performing."

Although the Michigan bridge equipment will be powered by small solar panels attached to the structure's surface, Loh is also working on coatings that could collect solar energy directly. These coatings in essence would be sensing skins with photovoltaic properties to power themselves. Such self-powered sensors would be especially useful on, for example, offshore wind turbines, which otherwise would be difficult to power, Loh says. This project is being funded by the National Science Foundation, he adds.

The acoustic emission sensors that will form part of a flexible piezoelectric paint and be used to monitor the bridges in Maryland and North Carolina this summer also will have a low-profile film shape, measuring no more than 3 by 4 in., and will be applied as a piezoelectric paint on a thin polyimide film to control the quality and uniformity of paint thickness of the sensing material, explains Zhang. The sensor film will then be attached in small patches to the surface of the bridges at 6 to 10 key locations at which, on the basis of experience and analysis of traditional bridge inspection reports, cracks are most likely to occur, Zhang and Yuan explain. Approximately four of the acoustic emissions sensors will be located around the site of each potential crack area, along with one wireless sensor node that will transmit data to a small notebook-style computer at the bridge. The computer in turn will transmit the data to the researchers. The sensors will essentially "listen" for the energy, which will occur in the ultrasonic range, released by any cracks in the steel structures, says Yuan.

Yuan developed the piezoelectric-based wireless nodes for acoustic emissions, which take the form of cubes approximately 25 mm on a side. He also developed the small wind turbines, each only about 1 ft tall, that will power the nodes, as well as a prototype solar panel for the system.

The acoustic emission sensors are expected to detect cracks roughly 1 mm in length and will work on both concrete and steel structures, Zhang adds.

A much more sensitive paint-based system that uses nanotechnology to detect microcracks (less than 1 μm in length or width) in steel or concrete structures is being developed by researchers at the University of Strathclyde, in the United Kingdom. Initiated by David McGahon, a doctoral student there, the sensors are being developed by Mohamed Saafi, Ph.D., an associate professor of civil engineering. Here the nanotubes are combined with fly ash—a recycled waste product—and binding agents to form a paintlike material that can be applied directly to a structural surface either via paint roller or aerosol spray. An electric field is applied to the paint to align all of the nanotubes in the same direction to achieve greater sensitivity, and the application of ultrasonic sound is used to distribute the nanotubes uniformly throughout the paint, explains Saafi.

As in the Michigan, Maryland, and North Carolina projects, electrodes will be attached to the surface coated with the paintlike material containing nanotubes, and data will be transmitted wirelessly to researchers. But the Strathclyde paint seems to be able to monitor larger areas than the other two approaches. Saafi says laboratory tests have been conducted with sections measuring roughly 10 by 10 in. coated with the paintlike material containing nanotubes, and he expects that soon the paint will be able to cover an area larger than 1.5 by 1.5 ft. The nanotube paint should also be able to detect tensile-related changes in material even before actual cracks develop, Saafi predicts.

By combining the nanotube paint with a coarse aggregate material, the system could also be used to monitor corrosion by measuring the internal characteristics of concrete, including chloride concentrations, moisture content, and pH levels, Saafi says. Although the paint should work with both concrete and steel structures, steel has its own conductive properties, Saafi adds. Thus, a layer of nonconducting paint might need to be applied to the steel surfaces first, although this will not affect the paint's sensing capabilities, he says.

Large-scale laboratory tests with the nanotube paint are expected late this spring or summer. Although a battery is currently used to provide electric power to the system, Saafi hopes that small wind turbines or the use of piezoelectric materials in the sensor nodes will enable the system to harvest energy from the vibrations created by the vehicles that use the bridges.

In addition to bridges, the sensors could help monitor the structural health of tunnels, large wind turbines, pipelines, and other structures, especially the condition of such key elements as beams, girders, and gusset plates, Saafi adds. But he stresses that this technology should supplement, not replace, visual inspections. "The paint will give you some warning and tell you what to inspect first," he explains. "But even if you detect damage with the paint, you still have to go out and look at it in person." —ROBERT L. REID