Damaged bridges will cry for help before they fail

The catastrophic collapse of a highway crossing of the Mississippi river has spurred the development of sensor networks to make such structures safer

Sujata Gupta

I AM standing in a hallway at Acellent Technologies in Sunnyvale, California, golf ball in hand. Before me is a hard, black plastic panel. I hurl the ball and it hits the panel with a loud "thwack". The computer on my left intones: "Impact detection on panel two… impact magnitude 86 pounds."

The panel is just one example of a new generation of smart components and structures that can report when they may have suffered mechanical damage or corrosion. Sensors designed to achieve this may soon be built into buildings, bridges and a slew of products, from cars and planes to body armour, so that crucial components can be replaced before they fail.

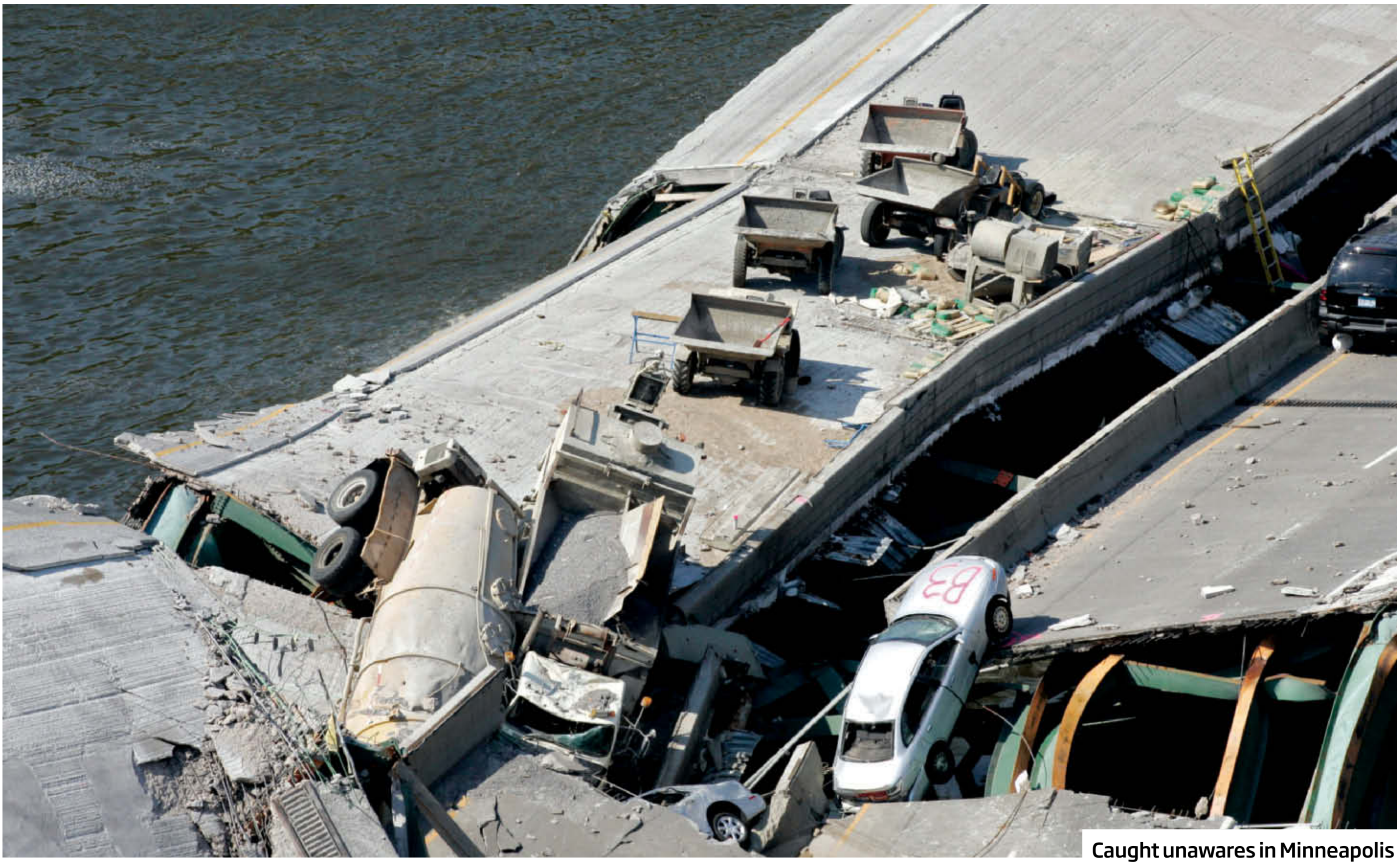
This approach has received particular attention in connection with the US's ageing transportation infrastructure. About half of all the country's road and rail bridges will have celebrated their 50th birthdays by 2020. "We're facing a baby-boomer bridge problem," says Jerome Lynch, director of the Laboratory for Intelligent Structural Technology at the University of Michigan in Ann Arbor. "We have an ageing demographic, and with age comes deterioration."

> **"What we are facing is a baby-boomer bridge problem. We have an ageing demographic"**

The big wake-up call came with the collapse of a bridge carrying the I-35W highway over the Mississippi river in Minneapolis, Minnesota, in August 2007. It failed during rush hour, killing 13 people and injuring nearly 150. An investigation by the National Transportation Safety Board put the blame on design flaws, but the collapse also highlighted the need for more stringent inspections.

In the US, human inspectors certify bridges every two years, but they can miss small cracks, problems in hard-to-access locations and internal damage. So the National Institute of Standards and Technology's Technology Innovation Program, set up three years ago to address "areas of critical national need", has funnelled hundreds of millions of dollars into developing sensors to monitor bridges.

PA/AP PHOTO/JIM MONE



Caught unawares in Minneapolis

Many of the systems now being tested are based on piezoelectric sensors. These devices can take on a dual role. As well as generating a small current when they vibrate, to passively monitor vibrations in the structure, they can also actively probe for faults. Just as a medical ultrasound scanner uses an acoustic signal to image internal organs, so an active piezoelectric sensor can send an acoustic signal into a bridge's interior. By listening for the returned signal, it can detect structural anomalies such as hairline cracks or areas of unusual strain.

Back at Acellent, Shawn Beard, the company's chief technology officer, shows me a diagram illustrating how piezoelectric sensors could be fitted to large, complex bridges. The diagram is pockmarked with red circles representing the sensors along the roadway, girders and trusses. Each red circle feeds into blue circles representing the routers that pick up data sent wirelessly by the sensors, which is then fed into a central computer.

A slightly different approach to the problem is being followed by Distributed Sensor Technologies in Santa Clara, California. It plans to use a single optical fibre to do the work of hundreds of discrete sensors. The idea is to stretch the fibres taut and attach them to the bridge. Cracks and other imperfections will alter the vibrations picked up by the fibre, which in turn will alter the way a beam of laser light travels along it. This information will then be analysed by a computer, allowing the problem to be identified and located.

Lynch has created a sensor of a different sort: a "skin" made of polymers and carbon nanotubes that changes its electrical resistance when deformed, and that can be painted onto a bridge or other structure. This year, he hopes to test it out on wear-prone portions of a bridge near the Ann Arbor campus.

For the tests, Lynch will apply the skin to a patch of the bridge and line the area with electrodes. Two of these will transmit an electrical signal while the rest measure how the signal changes as it passes through the skin. The results will allow a computer to generate a two-dimensional image that, like an X-ray, will reveal details of the inside of the structure, providing a map of any damage it may have sustained.

Victor Li, also at the University of Michigan, Ann Arbor, has a related strategy. He has mixed carbon black into concrete to make it more electrically conductive. Existing concrete is "very dumb", he says. Li's idea is that cracks and other damage to a bridge made of his concrete will show up as interruptions in an electric current, indicating where and how bad the damage is.

Bridges aren't the only objects being made smarter. At Acellent, Beard has fitted bulletproof armour with sensors that can indicate when the interior of the armour is damaged and must be replaced.

An even more exotic destination awaits the panel that felt the force of my golf ball. It is a piece of spacecraft – a sheet of the material that protects the craft from overheating when they re-enter Earth's atmosphere.

> **"Inspectors can miss tiny cracks, problems in hard-to-access locations and internal damage"**

A piece of debris damaged thermal protection tiles on the Columbia space shuttle when it launched in January 2003. The damage went undetected, and when the tiles failed on re-entry the shuttle was destroyed. Beard suggests that smart thermal tiles could have alerted the crew to the danger, so Acellent has built a prototype with collision-detecting sensors embedded in the material. "This technology can go into anything you can imagine," Beard says. ■


LUIS LOURO/ALAMY

The future of energy production?

Dragonfly wings hold the key to solving windy problem

THE way a dragonfly remains stable in flight is being mimicked to develop micro wind turbines that can withstand gale-force winds.

Micro wind turbines have to work well in light winds but must avoid spinning too fast when a storm hits, otherwise their generator is overwhelmed. To get round this problem, large turbines use either specially designed blades that stall at high speeds or computerised systems that sense wind speed and adjust the angle of the blade in response. This technology is too expensive for use with micro-scale turbines, though, because they don't produce enough electricity to offset the cost. That's where dragonflies come in.

As air flows past a dragonfly's thin wings, tiny peaks on their surface create a series of swirling vortices. To find out how these vortices affect the dragonfly's aerodynamics, aerospace engineer Akira Obata of Nippon Bunri University in Oita, Japan, filmed a model dragonfly wing as it moved through a large tank of water laced with aluminium powder. He noticed that the water flowed smoothly around the vortices like a belt running over spinning wheels, with little drag at low speeds.

Obata found that the flow of water around the dragonfly wing is the same at varying low current speeds, but, unlike an aircraft wing, its aerodynamic performance falls drastically as either water speed or the wing's size increases. As air flow behaves in the same way as water, this would explain the insect's stability at low speeds, Obata says.

Obata and his colleagues have used this finding to develop a low-cost model of a micro wind turbine whose 25-centimetre-long paper blades incorporate bumps like a dragonfly's wing. In trials in which the wind speed over the blades rose from 24 to 145 kilometres per hour, the flexible blades bent into a cone instead of spinning faster. The prototype generates less than 10 watts of electricity, which would be enough to recharge cellphones or light LEDs, the researchers say.

"It's a clever leap," says David Alexander, a biomechanics specialist at the University of Kansas. "In some ways it's more appropriate than using an animal wing model for an airplane. A wind turbine blade is just a wing, only it's designed to go in tight circles."

But Wei Shyy of the Hong Kong University of Science and Technology believes that while the dragonfly-inspired design may be more stable, it will also experience more energy loss in terms of drag. Winifred Bird ■