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STRUCTURAL ELEMENTS & PROTECTION

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The Alaskan Way Viaduct demolition project eliminates a vulnerable structure and opens up Seattle's waterfront (*WSDOT*)

SURGICAL PRECISION

Contractors in the US city of Seattle are halfway through a bridge demolition project that is set to dramatically change the waterfront of the city. Helena Russell reports

In just a few months' time, contractors in Seattle will reach the end of a major demolition project that will transform the downtown waterfront and open up views that have not been seen for half a century. Removal of the Alaskan Way Viaduct marks the final step of a long-term project by the Washington State Department of Transportation to put highway traffic underground and free up space for landscaping and public realm improvements by the city authorities.

The viaduct was built in the 1950s to carry state route 99 through downtown Seattle. But the structure was damaged in the 2001 Nisqually earthquake, and despite being repaired and strengthened so it could continue to be used, it remained vulnerable to seismic activity. Hence a long-term project was launched ten years ago to build a new tunnel that would take the traffic underground, allowing the viaduct to be demolished.

In addition to eliminating a vulnerable elevated structure from a densely built-up urban area, the project frees up space on the waterfront, which the city

Below, left to right: the Colman Dock ferry terminal offers one of the best views as crews work their way along the waterfront. Cranes remove a girder from a section of the old Columbia Street on-ramp to southbound SR 99. Looking north from the Marion Street pedestrian bridge (*images: WSDOT*)

authorities intend to use to transform the downtown area.

Work on the new bored tunnel for the SR99 began in 2011 and it was completed at the end of 2018. With the final connections between the tunnel and the highway network finished at the start of this year, traffic was diverted and in February, contractor Kiewit Infrastructure West started the demolition of the double-deck concrete viaduct.

This delicate process is expected to take six months to finish, and the contract includes restoration of the area at street level, before it is turned over to the City of Seattle's Office of the Waterfront for the final stage of the transformation.

The highway project is being led by Washington State Department of Transportation, whose mega-project structural design engineer Tim Moore explains the detail of the ageing bridge that is being taken down.

"The Alaskan Way Viaduct is a complex structure consisting of single and double deck three-span reinforced concrete frames," he explains. "Span configurations vary but primarily consist of two span arrangements; 21m-26m-21m and 17m-21.5m-17m."

Moore goes on to explain that the cross-section is a series of cast-in-place longitudinal T-beams framed into cross-beams at each two column supports. Foundations consist of a pile cap, pedestal and driven steel H-pile, concrete cast-in-steel-shell and timber piles with concrete elements cast above them.

The viaduct originally had 178 rigid frame supports, of which 121 were still in place ahead of this most recent demolition contract, the rest having been removed when the southern part of the viaduct was demolished in 2011. Demolition of the remaining 2km of viaduct and a number of exit ramps is one part of the ongoing contract, which was awarded to Kiewit Infrastructure West last year at a cost of approximately US$94 million. Removing a major structure in a congested city centre environment was clearly going to be sensitive work, and it is no surprise that the use of explosives was vetoed from the start.

"Due to the constraints of the site, all demolition had to be mechanical," says Moore. "The possibilities were limited to use of hoe-rams, crackers, and high-reach concrete processing units for the majority of the bridge removal process." He adds that 'cut and pick' techniques such as saw-cutting girders and removing them with cranes are being used for any parts of the viaduct that are close to buildings or above active railway tracks.

This demolition is especially challenging for a variety of reasons, he says. "There are many existing utilities nearby - including power, water, gas pipes, and storm sewers, and there is also a heavily used highway next to the demolition site which needs to be kept open to vehicles, pedestrians and cyclists throughout the work.

"The BNSF railroad tracks underneath the viaduct are located on a steep hillside," he says, "and work above those tracks is heavily restricted to ensure there is no disruption of trains." In some cases the existing buildings are extremely close to the viaduct – less than 200mm from columns in some places. The contract places restrictions on the amount of debris loading, noise, vibration and impact from the work. It also requires construction easements and mitigations for buildings where access is severely restricted during demolition.

According to Alex Prentiss of Kiewit Infrastructure West, safety of crew and general public is the top priority, and that is always a challenge when working in congested urban areas. "The physical constraints of the site – including a very small footprint, as well as proximity to buildings, live highway, and pedestrians – have challenged the engineering team to develop work plans that can efficiently perform the work without endangering crews, the public, or property," she says.

"We are using several techniques depending on location. The primary method of demolition is mechanical, by which we mean that a hoe ram breaks up the decks, while an excavator with a special processor attachment breaks down the columns and caps until everything above ground is demolished. The processor attachment enables the rubble to be broken into fairly small pieces so it can be trucked south to Terminal 25 for additional crushing," she explains.

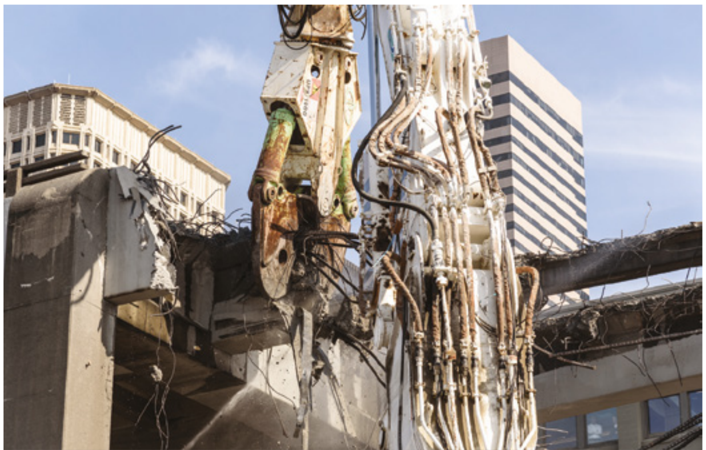
"In other locations, such as the Seneca and Columbia ramps, near and over the railway, and in close proximity to buildings, we are cutting the deck and girders into small pieces before using a crane to swing these pieces out. This method is more precise, but much, much slower," Prentiss adds.

In most locations, the contractor is required to remove the columns to about 1.5m below grade. This means they have to excavate and then backfill the resulting hole, paying careful attention to utilities. "Work is moving from south to north between Columbia and Pike [the central section of the viaduct], and from north to south between Yesler and Railroad Way [the southern section]," explains Prentiss.

"We fence the area when we begin site preparation, and work on four to five spans at a time, allowing the equipment to operate safely and efficiently," she adds. "Protecting properties and the public is our top priority, so we hang large nets up from cranes, which prevent any potential debris from exiting the work site and putting people or buildings at risk.

The contractor also uses a 'carpet' of 1,200mm of viaduct rubble below each area to absorb the impact from any falling debris and prevent it from bouncing out.

Below, left to right: the structure is being taken down one section at a time, south to north. A Sounder train travels under the remnants of the southbound lanes - in the background equipment can be seen removing the northbound lanes. Nets protect nearby buildings during demolition (*images: WSDOT*)


A concrete crusher eats through a girder that supported the upper deck (*WSDOT*)

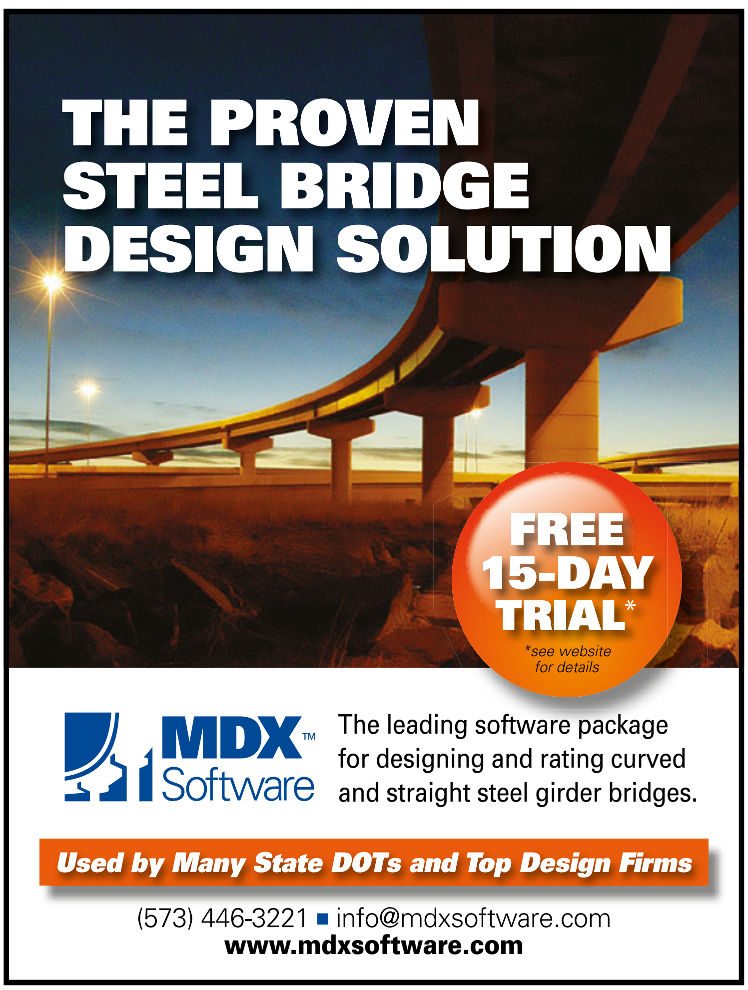
"We have hard barriers in many locations to prevent 'splashing', and there are up to five water hoses spraying the demolition area at any time to reduce dust. In addition, some crew members wear dust monitors so we can better monitor dust-control effectiveness," reveals Prentiss.

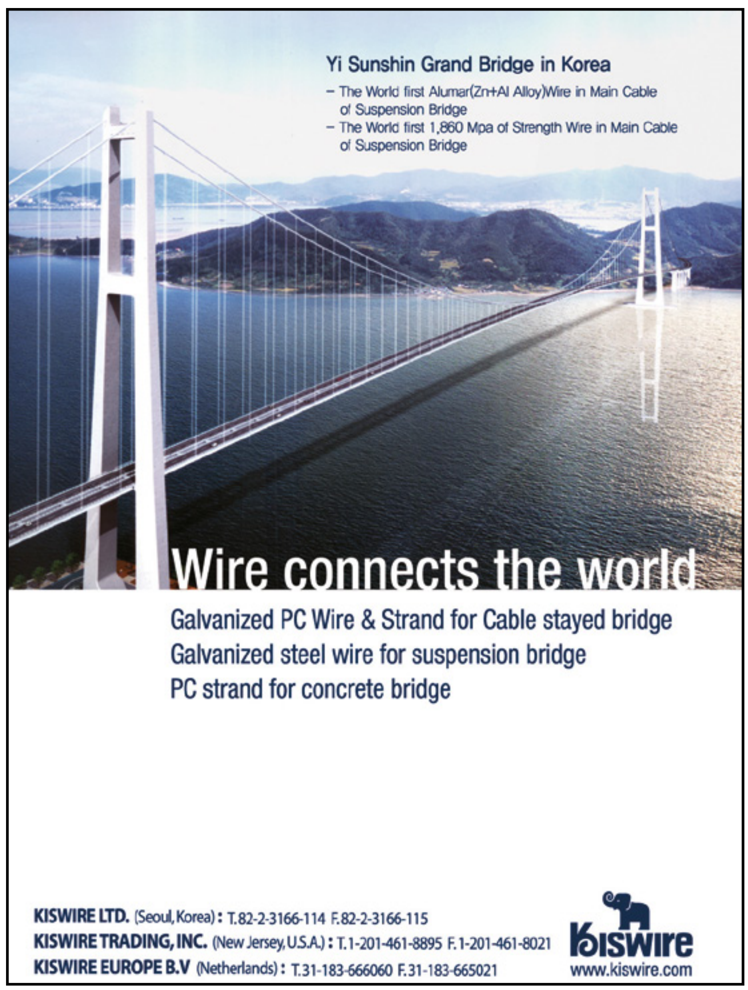
It takes approximately 30 days in each location to prepare the site for demolition, to carry out the demolition, and to restore the site. Preparation activities include putting water lines in place and setting up water catchment systems, identifying and protecting any utilities, and moving equipment into place. This can take up to a week. Demolition takes one or two weeks, and restoration, which includes footing removal and backfilling, as well as restoring the highway and footpaths for use, takes up to two weeks.

The processors and hoe rams are proprietary equipment that subcontractor Ferma developed for demolishing similar structures quickly and with minimal impact. Most are diesel-powered Volvos with modified attachments and vary in size depending on the type of work they need to accomplish, the access height and the thickness of the structure they are demolishing. "For example, we use the company's proprietary FE 200 to munch the columns and caps, but the much smaller FE 50 is employed to demolish the girders from the deck," says Prentiss.

The rubble from the viaduct is trucked to Terminal 25, where the concrete is separated from the rebar and crushed before getting trucked back north to fill the Battery Street Tunnel. All water from the site is collected in a water catchment system and this is treated and tested to ensure it is suitable for release into the sewer system.

The improvement that removal of the structure will bring to the city's waterfront cannot be underestimated, suggests Brian Nielsen, WSDOT administrator for the replacement programme. "The viaduct essentially created a concrete barrier between the city's waterfront and downtown. Now that the tunnel carries traffic underneath downtown Seattle, the city plans to transform the waterfront with a new multi-modal surface street that will be built on the footprint of the viaduct, along with 20 acres of public park, open spaces and elevated views of Elliott Bay" ■





The new crossings of the Mobile River Bridge and Bayway expansion project will be managed under a 55-year concession agreement

BAY WATCH

Updated details have been released for a planned US$2-billion expansion project that includes a major cable-stayed crossing in south Alabama, reports Lisa Russell

The Mobile River Bridge and Bayway expansion project, which is now to be built as a public-private partnership, involves increasing the capacity of the Interstate 10 highway by constructing a major cable-stayed bridge across the Mobile River to supplement the existing four-lane George Wallace Tunnel. It also includes replacing the 12km of bridges that run across the bay of the port city of Mobile with wider structures built at a higher elevation.

The design concept for the main river crossing is a 4km-long, six-lane bridge with a cable-stayed main span of about 420m flanked by side spans of 178m supported from two towers standing approximately 152m tall. Vertical clearance for the navigational channel has recently been increased to 65m to allow for the passage of larger cruise and container ships.

The original plan for the route across Mobile Bay had been to retain the existing four-lane bridges and build additional capacity alongside. However, subsequent analysis has indicated that much of the existing route is vulnerable to damage from storm surges and so the decision has been taken to replace the entire structure. As a result, construction of the new Bayway involves building 12km of eight-lane bridges with decks elevated above the 100-year storm surge level, making them up to 3m higher than the current route.

Representatives of Alabama Department of Transportation held public meetings in May to present the latest project information and images of the cable-stayed bridge and associated work. A supplemental draft environmental impact statement has also been published, setting out changes and additional studies since the original draft was produced in 2014.

Key additions since the original environmental impact assessment include the decision to replace the Bayway bridges, refinements to the preferred alternative and the conclusion that a public-private partnership should be used to deliver the scheme. The private partner will design, build, finance, operate and maintain the new Mobile River Bridge and Bayway under a 55-year concession agreement; ALDOT will then take over the maintenance and operations.

The original expectation was that federal funds would have been used to pay for 80% of the project, with the state funding the remainder. However, expanding the scope of the project to include interchange modifications and replacement of the Bayway resulted in a substantial increase from the original estimated cost of US$773 million.

Federal and state funding shortages mean that the project is now only viable if the corridor is tolled, said ALDOT. The toll revenues will help fund the project by covering capital costs, operation and maintenance, although ALDOT said that the tolls will not cover all project costs and that it will still need to invest in the project itself.

A preferred route has been chosen, though other 'build' alternatives and a 'no build' option also remain under consideration, said ALDOT. Final decisions will be made following evaluation of comments on the SDEIS and feedback from the public hearings.

ALDOT aims to award the project in March 2020, with construction due for completion in 2025

Design concept for the new 4km-long, six-lane Mobile River Bridge

PROTECTIVE COATING SURVEYS - NEW GUIDE

A new pocket-sized guide has been published that provides practical advice for those involved in the inspection of paint systems used for corrosion protection applications.

Fitz's Atlas of Coating Surveys is designed to assist engineers, surveyors, inspectors and asset owners to manage anti-corrosion systems and coating performance. It incorporates guidance for consistent protective coating assessments and visual evaluations, as well as for the production of detailed coating reports on bridges and other structures.

The 300-page handbook looks at common defects and explains how percentages linked to coating breakdown can be estimated, alongside full advice on approved field testing and sampling techniques.

Additional guidance is provided on the European and International rust scale, dry film thickness, adhesion testing and porosity detection, as well as coatings used as passive fire protection systems. The guide refers to ASTM, ISO, CEPA and SSPC standards for coating evaluation and includes illustrations of the European Scale of Degree for Anti-Corrosive Paint.

Also covered by the publication's 15 separate sections are health and safety requirements, the role of photography, documentation and reporting, as well as the industry standards and test methods that should be referenced.

The new guide is in the same style and ring-binder format as the Fitz's Atlas of Coating Defects.

Fritz's Atlas
www.fitzsatlas.com

PLASTIC WEDGES FOR NON-STEEL BRIDGE

Researchers in Japan are currently undertaking the detailed design of a high-strength concrete highway bridge that will incorporate newly developed plastic wedges as well as aramid-fibre tendons.

The seven-year-old project to develop the world's first non-metallic highway bridge is being carried out by Sumitomo Mitsui Construction and the West Nippon Highway Company.

The overall aim of the project is to increase the durability of highway bridges and reduce their maintenance requirements through the replacement of steel girder bridge decks with non-steel decks and concrete barrier systems.

A pilot project was completed last year, when a temporary 16m-long simple girder bridge was dismantled after a three-year service life. The beam bridge on an access road for the Nagasaki Expressway Phase II road construction in Nagasaki City, featured high-strength, fibre-reinforced concrete with so-called 'butterfly' webs that reduce weight and rationalise the use of shear reinforcement. High-strength steel fibres enhance the shear strength of the concrete, so shear reinforcement can be eliminated.

The new Bessodani Bridge, a 25m-long single-span structure near Tokushima City on Shikoku Island, will carry the same design, but with a difference. The aramid fibre tendons will be pre-tensioned with reusable plastic wedges instead of the traditional method that involves high-strength mortar-filled steel tubes, which can only be used once.

Researchers are now focussing on the design of a permanent plastic anchorage system with a 100-year life for future bridge projects.

Fabrication of the segments, including butterfly webs, will begin in June. Construction of the Bessodani Bridge is due to start this autumn.

CONCRETE FIRE PROTECTION USING RECYCLED FIBRE

A new way of protecting concrete and steel reinforcement from fire damage using recycled materials has been successfully tested by researchers at the University of Sheffield, UK.

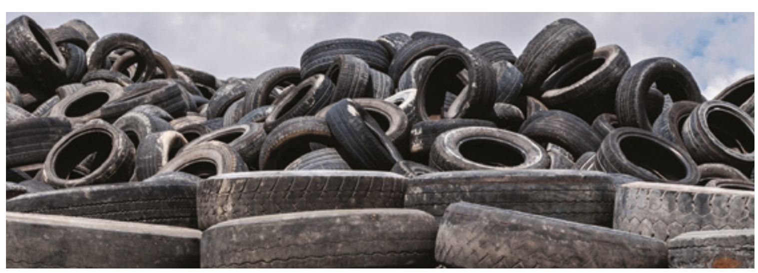
The team found that the fibres, extracted from the textile reinforcement commonly embedded into tyres, could reduce the concrete's tendency to spall explosively under the intense heat from a fire.

Polypropylene fibres are commonly used to protect concrete structures from damage or collapse if a fire breaks out. These fibres are used in large-scale engineering projects for protection against fire spalling in concrete.

The Sheffield study is the first to show that these fibres do not have to be made from raw materials, but can instead be reclaimed from used tyres.

The fibres melt under the intense heat from a fire, leaving networks of tiny channels. Moisture trapped within the concrete is able to escape, rather than becoming trapped and then breaking out explosively. "Because the fibres are so small, they don't affect the strength or the stiffness of the concrete," says Dr Huang. "Their only job is to melt when heat becomes intense. Concrete is a brittle material, so will break out easily without having these fibres help reducing the pressure within the concrete."

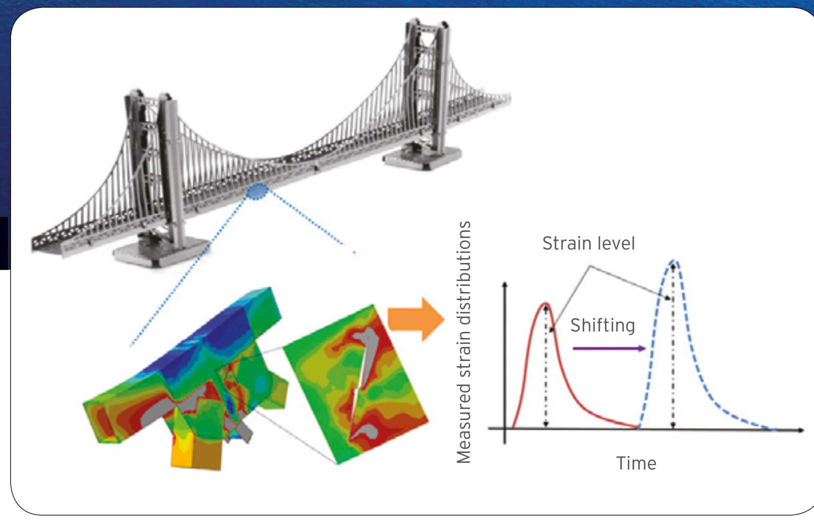
Protecting the concrete from fire spalling means that steel reinforcements running through the concrete are also protected.



When the steel reinforcements are exposed to extreme heat they weaken quickly, meaning a structure is much more likely to collapse.

Collaborating with Twincon, a Sheffield-based company that develops innovative solutions for the construction industry, the researchers have also developed technologies for reclaiming the fibres from the used tyres. This involved separating the fibres from the tyre rubber, untangling the fibres into strands, and then distributing them evenly into the concrete mixture.

The team plan to continue testing the material with different ratios of the fibres to concrete as well as using different types of concrete.



The Mackinac Bridge has hosted various sensing technologies since 2016. Inset: AI-based, damage-identification algorithms in development will isolate potential hot spots

LISTENING TESTS

In June the 8km-long Mackinac Bridge in Michigan is being fitted with 200 connected, self-powered sensors to test the large-scale application of the technology for effective condition-based maintenance of infrastructure, write Nizar Lajnef, Shantanu Chakrabartty and Kenji Aono

Since 2005, the larger portion of US infrastructure spending has been used for operation and maintenance, and as of 2014 this spending has exceeded capital investments by 30%. According to the 2017 statistics from the National Bridge Inventory, almost 9% of all US bridges are structurally deficient. The ability to monitor the condition of bridges and other civil infrastructure systems is of primary interest to all owners and operators. The most pressing need is to have precise and accurate information on infrastructure conditions before making decisions such as maintenance strategies or investments. Therefore, cost effective and reliable condition assessment and damage detection in civil infrastructure systems is essential toward establishing an efficient strategy.

The development of advanced structural monitoring methods is intended to facilitate the early detection of a possible structural deterioration, with the goal of extending the lifespan of structures. Timely information gathered from such technologies will undoubtedly help in the corrective and urgent decision-making process. Currently, state-of-the-art technologies and solutions evaluate the condition of a structure at a given instant presenting only a snapshot at the time where the measurements are taken, so results are highly influenced by the environmental conditions. Furthermore, bridge failure causes are either sudden such as floods and collisions, or due to the continuous deterioration and material fatigue over time, thus justifying the pressing need for an autonomous, continuous, and long term monitoring system.

The research conducted by a consortium involving Michigan State University, Washington University in St Louis, and several state departments of transportation is currently exploring a framework internet of infrastructural things based on low-cost sensor technology and a cloud-based structural intelligence algorithms. The research has been funded through several grants by the National Science Foundation and the Federal Highway Administration. The work by the research team aims to overcome the traditional limitations of structural health monitoring techniques by proposing a cost-effective, robust, local-to-global damage-identification mechanism that continuously assesses the health condition of bridge components over time. Successful development and deployment of this multi-metric sensing system could dramatically transform the economics of bridge preservation and ultimately improve the serviceability of bridges.

One of the significant challenges that have hampered the practical adoption of monitoring systems for damage detection in large structures such as bridges is the prohibitive cost involved in instrumenting sufficient number of sensors that can provide a high enough spatial resolution. This feature is the key towards capturing the propagation and detection of small cracks, which could serve as the precursors for serious structural damage. Also, operational constraints require that the sensors operate with minimal maintenance requirements, like replacement of batteries and the data from the sensors can be easily collected and assimilated. In this work, we have successfully demonstrated a novel self-powered sensor technology referred to as Piezoelectric-Floating-Gate capable of autonomous long-term monitoring of structural behavior. The technology is a novel way of capturing, computing and storing the strain and acceleration signals generated on a civil or mechanical structure. 'Piezo-' is borrowed from the piezoelectric transducers used in the technology. These materials are capable of converting mechanical energy, such as strains and vibrations, into electrical energy. The generated electrical signals, which are directly proportional to the mechanical excitation, are also used to power all electronics in the sensing system.

The innovative design enables the sensor to derive its power from the same signal it is sensing. The sensor electronics act like a large container of electrons. When the structure is loaded, the piezoelectric material generates a flow of moving electrons or current. Using that energy, some of the electrons are pushed through an insulator and get trapped onto an isolated conductive material layer, hence the name 'floating'. The process is called hot-electron injection. This acts as a permanent memory ▶

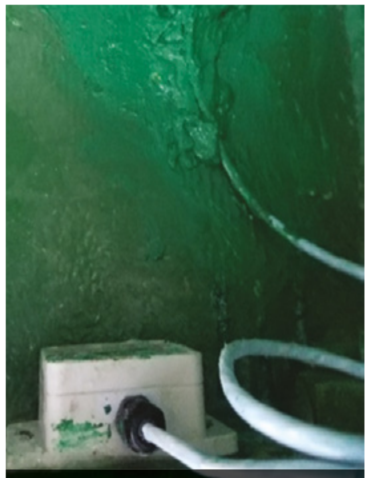
Improved prototype sensors were installed on the Mackinac Bridge in 2017

because the electrons are permanently trapped. Counting the number of captured electrons will convey the number of times the system was loaded and also the intensity of the energy, which is directly related to the number and amplitude of the external loading, for example, passing trucks on a bridge. This concept implements a power-efficient sensing system, and alleviates the need for a power source and all other interface electronics required in a typical sensor.

The technology offers several features including ultra-low power requirements; battery-free continuous operation using energy harvested directly from the structure movements; possibility of deployment in dense networks near damage sensitive areas given the small size of the sensors; autonomous computation and on-board memory storage of the sensed response; wireless communication; and projected low cost, estimated at US$10 per unit for mass production.

Another related challenge in monitoring the health of a large structure is to make sense out of the large amount of data generated by the sensors. The possibility of deploying large dense networks, enabled by the novelty of the sensors developed in this work, provides a new method to image the response of different bridge components at high-resolution. The effect of each and every event experienced by the structure is detected locally by the dense network, and the data is compressed and stored on the sensors as a histogram of cumulative events. This real time processing significantly reduces the amount of data that needs to be transmitted and analysed. Advanced big data analytics and data management methodologies have been developed with the capacity to analyse and extract useful information for the condition assessment of the monitored structures. Structural artificial intelligence algorithms are developed to link the signatures in data shifts and changes to occurrence and propagation of damage in the monitored components. The used approach alleviates the need for finite element based models, and also bypasses the traditionally used global damage indicators that are typically insensitive to localized damage. The data storage scheme implemented by this novel technology allows the filtering out of all short-term fluctuations over the long-term monitoring period.

The Mackinac Bridge is the gateway that connects the upper and lower peninsulas of the State of Michigan in the United State of America. At the time of its construction in the 1950s it was heralded as one of the greatest engineering structures in the world, and claimed the title of longest suspension bridge. Decades later it remains the longest suspension bridge in the western hemisphere with a total structure length of 8km and a width of 21m, and a peak tower height of 168m with a mid-span roadway height of approximately 61m above water level. It is possible that the deck at center span could move as much as 11m, east or west, due to high winds under severe conditions. The scale of the bridge and its economic and historical importance, provide an excellent venue to showcase our advanced sensing platform, especially considering the harsh climate that the sensors will need to endure with months of sub-freezing temperatures.



PFG sensor/telemetry box attached to the monitoring site

Starting in 2016, we have installed and tested 20 sensors for survivability and reliability under the extreme conditions in the straits of Mackinac. We have also validated the reliability of different procedures for mounting the piezoelectric transducers to the steel super structure. These sensors were configured to operate in a quasi-self-powered mode, where the PFG device continuously recorded the strain events without any extrinsic powering and a battery-powered long-range wireless transmitter was only activated on demand to transmit the information recorded on the sensors memory. The first year tests concluded with the following observations: the PFG was able to cumulatively record strain events; a majority of the power was used to provide a low-latency wireless interface; data collection does not need to occur frequently; more than one layer of weather-proofing is required.

Improved prototypes were deployed in May 2017. These prototypes have been reliably collecting data on their onboard memories continuously for about two years now. The sensors are designed for an operational lifetime of over 25 years with any intervention. For this study, the wireless link was activated approximately every month, reading the statics of all the loading events within that month period, aggregated in a probability distribution function.

To showcase the ability of the quasi-self-powered PFG sensing platform to detect rare events, we focused on a particular event that is a characteristic of the Mackinac bridge. The PFG sensors proved that they were able to detect the increase in traffic due to the influx of bridge crossings that occurs during the annual Mackinac Bridge Labor Day Walk on 4 September 2017. The observations matched the traffic patterns provided by the Mackinac Bridge Authority.

Building on the success of the first phase, a major scaling up is planned. The next phase of testing will have two stages: a first phase with 200 sensors deployment beginning in June 2019, in which we test the practical aspect and logistics of large-scale production and deployment; and a second phase involving the deployment of 2,000 sensors planned in summer 2020. The main objective of this deployment is to demonstrate that the collected data could be used for improved cost-effective, condition-based maintenance of the Mackinac Bridge structural components, and to ultimately improve the structural behavior predictions. An important step would be to integrate the new system with existing asset management protocols used by the State DOT and bridge owners. We are also developing and implementing novel AI-based data interpretation algorithms that exploit the sensors' data collected from different parts of the large infrastructure, over a monitoring period, to isolate potential hot spots.

The participation of government agencies such as the Federal Highway Administration, the Michigan DOT, and the Mackinac Bridge Authority will provide critical feedback on sensor deployment constraints. It will also help validate the infrastructure internet-of-things framework showing the validity of the solution to other potential customers

Nizar Lajnef is associate professor of civil and environmental engineering/electrical and computer engineering at Michigan State University. Shantanu Chakrabartty is professor of electrical and systems engineering and Kenji Aono research associate; both are at Washington University in St Louis

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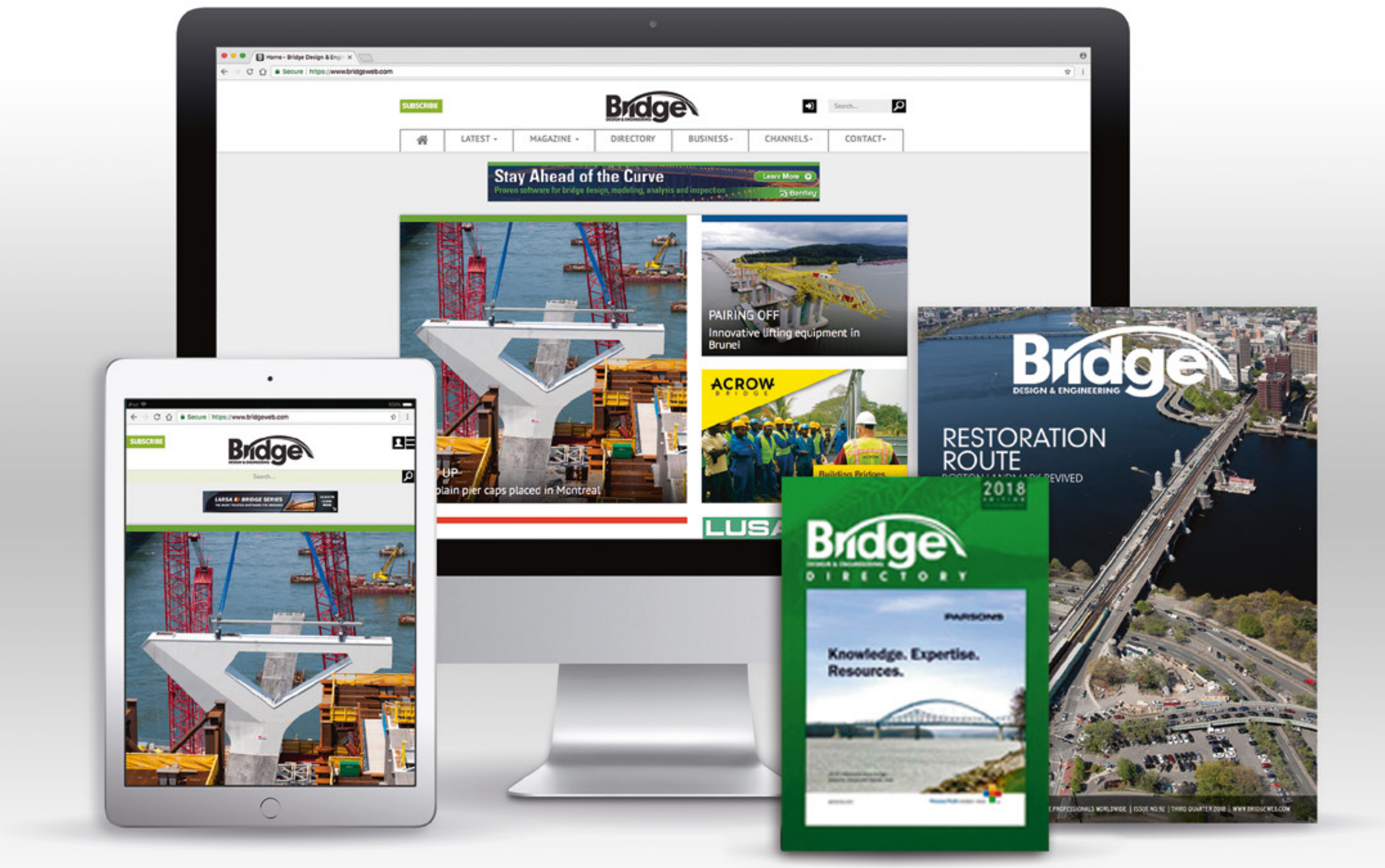

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