INNOVATIVE SOLUTIONS

RESEARCH GROUP USES TECHNOLOGY TO BUILD BETTER ROADS, BRIDGES AND OTHER CIVIL INFRASTRUCTURE

By Sharon Chisvin • Photography by Marianne Helm

The first thing you notice about the model bridge is its size.

Even here, inside a cavernous laboratory at the University of Manitoba, the structure – which stands about 1.5 metres high, 10 metres long and consists of a sheet of plexiglass resting on a series of steel cross-members and concrete piers – takes up a lot of space.

Yet the most interesting thing about this model bridge is not its dimensions, but what it does.

As it turns out, the model is a key component in a research project currently underway at the U of M's Structural Innovation and Monitoring Technologies Resource Centre, also known as SIMTReC.

Led by Aftab Mufti, Scientific Director at SIMTReC and professor emeritus at the U of M, the goal of the project is to develop a method for using strain measurements to calculate the weight of trucks crossing a bridge. This would provide officials with a means to better estimate the loads being carried by trucks crossing a bridge and what effect all that weight might have on the health of the structure.

As Mufti explains, bridges are built with an estimated life span. "When you design a bridge, you might say it is going to last 75 years," says Mufti. "But now we find that sometimes a bridge component doesn't

SIMTReC Director Dagmar Svecova, associate director Doug Thomson and Basheer Al-Gohi with the model bridge at the University of Manitoba. INSET: Sensors used to detect strain in the model bridge.

last 30 years. So we are asking questions to find out how we can predict the lifecycle of a bridge more accurately. In order to do that, you not only have to look at the strength of the bridge, you also look at the load on the bridge."

Although much of the research for this project is being carried out in the field by monitoring real-life truck traffic on a real-life bridge, there are some questions that come up every now and then that are best answered in a controlled setting such as a lab.

That's when the model bridge comes into play.

Patterned after the South Perimeter Highway Bridge, the model was built by civil engineering student Sofia Faraz and is designed to mimic every structural characteristic of its real-life counterpart. It also comes with an electric truck that can simulate the weight and speed of a full-sized vehicle.

When the truck rolls across the bridge at a certain speed, carrying a certain weight, tiny sensors embedded underneath the plexiglass roadway and attached to the side of the structure record the effects of the load on the model. That data can then be used to estimate the effects of truck traffic on a real-life bridge.

One advantage of using the model is that the environment can be controlled, which means researchers can adjust the temperature around the model bridge or the weight that is placed on it, says Mufti.

Officially known as the Bridge Weigh-in-Motion project, it is just one of several research studies underway at SIMTReC, which is headquartered at the U of M, and features six principal investigators and 30 researchers.

Dagmar Svecova, Director of SIMTReC, says the group is dedicated to the idea of building longer-lasting roads, bridges and other infrastructure through the use of structural health monitoring and the promotion of fibre-reinforced polymers in construction materials.

Structural health monitoring involves the use of sensor technology and data analysis tools to keep tabs on the structural health of bridges, roads and other civil infrastructure projects. Fibre-reinforced polymers are composite materials made of carbon, glass or other fibres that are resistant to corrosion and can be used in place of steel rebar to strengthen concrete.

"The main purpose of the centre is to advance civil engineering to a world leadership position in the use of structural health monitoring and the commercialization of the use of fibre-reinforced polymers," says Svecova, who is also a professor of civil engineering at the U of M.

Given the important role infrastructure plays in economic growth, it's no surprise that the work taking place at SIMTReC has caught the attention of Research Manitoba. The agency, which is responsible for supporting research in health, natural and social sciences, engineering, and the humanities, recently provided the network with $855,000 in funding for the next three years. Other contributors to SIMTReC for various projects include: Manitoba Infrastructure ($920,000, 2015 to 2020); Capitol Steel ($70,200, 2015); and Vector Construction ($156,000, 2015). Researchers at SIMTReC also bring in about $250,000 a year in funding from the Natural Sciences and Engineering Research Council of Canada.

In addition to the bridge project led by Mufti, Research Manitoba funding will also support five other local engineering projects, including one to find a cost-effective way to reduce the heat loss through concrete balconies in high-rise buildings and another to develop a sensor to detect the onset of cracking in steel girders. The common goal of each one of the half-dozen projects is to improve infrastructure sustainability and safety while reducing maintenance and replacement costs, and the potential for accidents and disasters.

Svecova says the work being carried out at SIMTReC can help government and industry alike.

"Our current infrastructure is getting older, and the provinces do not have sufficient funding to keep up with repair and replacement costs," Svecova says. "Our solution – which is to monitor it to see the exact state of the structure scientifically and to use new materials that do not corrode, such as fibre-reinforced polymers – will alleviate the pressures for structural rehabilitation and replacement so the available funds can be used on the most critical structures."

Subpar infrastructure and insufficient funding is a universal concern. According to the Canadian Infrastructure Report Card released in January 2016, one in nine bridges in North America is rated as structurally deficient or obsolete.

"The deterioration of infrastructure and the ability to provide diagnostic information for people to be able to manage infrastructure is a world-wide problem," says Doug Thomson, SIMTReC's associate director and a professor of electrical engineering at the U of M. "And it is getting worse as time goes on."

Manitoba is no exception. Although the infrastructure here, according to Svecova, is still relatively healthy, deterioration as a result of aging, misuse, extreme weather, and outmoded materials is unavoidable.

This deterioration was in evidence in Winnipeg this past summer when, to the chagrin of motorists, cyclists and pedestrians alike, detours and delays were frustratingly commonplace as almost every major transportation artery in the city was being repaired or replaced.

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Structural health monitoring, however, can help to alleviate that frustration by observing and keeping track of any structural decay as it occurs and ameliorating the damage from the decay before it becomes a major problem or public safety issue.

Referred to in the industry as SHM, structural health monitoring relies on a wireless computer-based system of data collection, and checks and balances, to identify the health, integrity and safety of civil engineering structures.

The technology, which is relatively inexpensive and easy to install, automatically detects damage and stresses to structures and relays that information on an ongoing basis over a period of time to those responsible for the structure's integrity and performance.

Once analyzed, this information is used to determine which transportation routes, for example, are being overused, are in need of repair, or are performing well. Structures that are better maintained are safer to use and more likely to enjoy longer life spans.

> "We have sensors that are capable of monitoring any strains or any response in the structure."

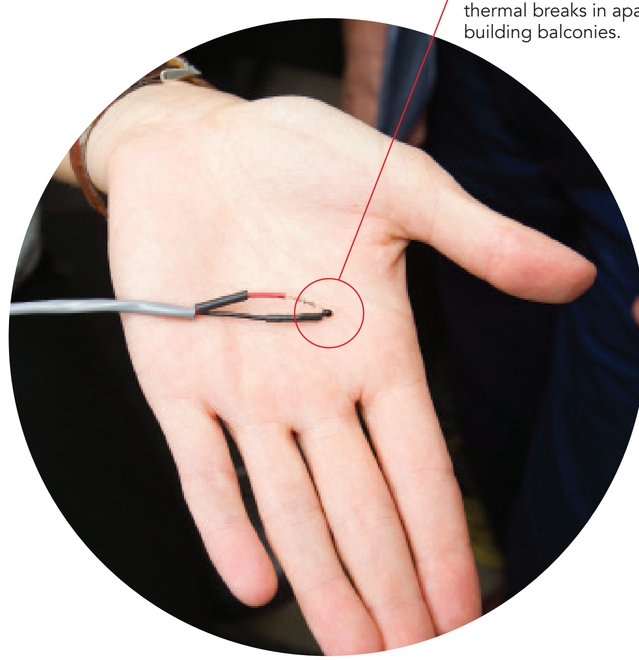
Among its ongoing projects, SIMTReC uses SHM to monitor Manitoba's iconic Golden Boy atop the provincial legislature, for temperature, strain and frequency of vibration.

"We have sensors that are capable of monitoring any strains or any response in the structure," Svecova explains. "We can get ongoing information about the structure's performance, and whether there are any problems or structural defects."

In most cases, these sensors – which look to the uninitiated like small pieces of tape – are attached to the exterior of the structure being observed. Occasionally, they are embedded into the structure.

"The sensors are fairly small," Thomson says. "You adhere them to the structure and they each have a couple of wires coming off of them and those attach to electronics – that might be the size of a cell phone – and those electronics transmit information to a kind of central hub that then gathers up the information and packages it all together and sends it through the Internet."

Then, at the other end,



A sensor that is used to test thermal breaks in apartment building balconies.

Building a sensor: Engineering student Sarah Boila prepares a sensor that will be used in a project to reduce energy consumption in residential buildings.

SIMTReC Director Dagmar Svecova (right) and associate director Doug Thomson inside the massive McQuade Structures Laboratory at the University of Manitoba.

engineers gather up the data, analyze it and extract information about what is happening to the road, or bridge or overpass in question.

"The early notification of structural health conditions can save on maintenance costs, ensure the integration of the whole mechanical and civil structures, and extend the structures' safety and service life," reiterates Dr. Nan Wu, a SIMTReC team member developing sensor technology for the motor coach industry.

In addition to the bridge study, Mufti is also working on a related project involving the development of sensors that can detect minute cracks in the concrete and steel girders that support a bridge. "Eventually, what these huge trucks do is leave some fracture in the steel girders (supporting the bridge). So we are developing a sensor which will alert us to when that has happened."

Prior to the development of wireless sensor technology and SHM, structural problems on roadways and bridges would only have been noticed and noted in the course of a visual inspection. Although structural health monitoring does not fully replace these regular visual inspections, it does relieve much of the pressure and room for human error inherent in the task.

"Visual inspections are still done on an annual or bi-annual basis," Svecova says. "Structural health monitoring is not replacing that, it is just giving engineers a little more information."

Visual inspectors, adds Thomson, can certainly determine if a structure is still functional, but they also can miss cracks that have begun but are barely perceptible,

ABOUT SIMTReC

The Structural Innovation and Monitoring Technologies Resource Centre (SIMTReC) has helped revolutionize the design of bridges and structures through the use of new materials and design concepts. After more than 15 years of research and field demonstration projects, SIMTReC has created an awareness of the benefits of using fibre-reinforced polymers and structural health monitoring in the construction of infrastructure by developing:

- UNIQUE DESIGN MANUALS THAT WERE USED AS A BASIS FOR UPDATING THE BRIDGE DESIGN CODES
- COMPLEMENTARY MATERIALS
- EDUCATION MODULES
- DURABILITY MONOGRAPHS
- GUIDELINES FOR CERTIFICATION OF FRP PRODUCTS
- LIFECYCLE ENGINEERING AND COSTING MODELS

SOURCE: SIMTReC

and they cannot speak to the structural response. There is, he continues, a fairly complicated relationship between the visual inspection and the determination about the structural health.

A visual examination, for example, cannot really determine what the strain was on a particular element, or reveal effects on the structure that simply are not possible to see. The sensors collect more quantitative information about the structure that can then be used to produce a more accurate determination about the structural behaviour. And a full picture of what is happening to the structure is imperative for maintaining the safety of the structure.

Thomson has been working on the development of infrastructure instrumentation, sensors and monitoring since joining SIMTReC in 1987.

"I became involved because the centre had some issues related to some of the sensors they had been developing, and they needed to get some instrumentation developed," he recalls. "So I came in and helped with some projects along those lines, and once I helped them solve those problems, other problems became apparent."

Since then, Thomson has worked on a half-dozen different infrastructure instrumentation projects. Most recently, he has been collaborating with his colleague Svecova on the use of an acoustic sensor that will make it possible for inspectors to actually listen for damage within a structure's fibreglass rods.

"When the rods are becoming damaged, they get tiny fractures inside them," Thomson explains, "and every time the material fractures, they give off a little sound pulse. We listen to these pulses and, by analyzing these pulses, you can tell how close the material is to failing."

He also is working on a project to develop a sensor to detect the onset of cracking in steel girders.

"A lot of older structures are made of steel, and over time, the steel can crack," he continues. "When a structure begins to crack, you would like to detect that early so that you can repair it."

The cracks, he adds, tend not to form all at once but tend to start at a single point and then propagate out. "We would like to be able to detect them early in their life when they are not really causing any structural problems and before they grow into cracks that would cause a structure, for example, to be closed down or, in the worst of cases, collapse," he says.

Thomson's research, like most of the research carried out at SIMTReC, takes place both in the field and in one of the centre's several labs. The most imposing facility is the McQuade Structures Lab at the U of M, which features two 10-ton overhead cranes, a pair of hydraulic testing machines, four actuators, two walk-in environmental chambers, a universal steel reaction frame, and a system capable of loading full-scale prototypes. Research is also carried out at labs dedicated to machinery, electrical and mechanical testing that simulate field conditions and

SIMTReC'S SIX RESEARCH MANITOBA FUNDED PROJECTS

In 2016, SIMTReC received an $855,000 grant from Research Manitoba in support of the research, development and promotion of its emerging technologies.

The grant, payable over a three-year period in increments of $180,000, $350,000 and $325,000 is being divided amongst six research teams, with a small portion also being used for the centre's operation costs.

Here's a brief look at the six projects:

1 STRUCTURAL STABILITY OF HIGHWAY EMBANKMENTS IN CANADA'S NORTH, MAROLO ALFARO, CIVIL ENGINEER

This project focuses on the creation and installation of wireless instrumentation that will help mitigate the effects of climate change and advance the construction of the all-weather Inuvik-Tuktoyaktuk Highway in the Northwest Territories. The new technology will help create sustainable and easily maintained infrastructure in Canada's isolated north.

2 DAMAGE DETECTION AT WELDING JOINTS ON HEAVY GROUND VEHICLE STRUCTURES, NAN WU, MECHANICAL ENGINEER

In collaboration with the motor coach industry, Wu is looking at new ways to detect and identify cracks and fractures on the welding joints of buses and other heavy ground vehicles. The objective of his research on Damage Detection at Welding Joints on Heavy Ground Vehicle Structures is the development of a vibration-based damage detection method.

> "When a structure begins to crack, you would like to detect that early so you can repair it."

SIMTReC Director Dagmar Svecova and associate director Doug Thomson with civionics engineer Geoffrey Cao. The computer is used to monitor truck traffic over the South Perimeter Highway Bridge.

3 BRIDGE WEIGH-IN-MOTION, AFTAB MUFTI, CIVIL ENGINEER

This project involves developing a method for calculating the structural strain that occurs when vehicles cross over a bridge. The changes in the dimensions of the structure that result from the ongoing strain on the bridge can also be used to calculate the weight of crossing vehicles.

4 BINARY CRACK SENSOR FOR STEEL GIRDERS, DOUGLAS THOMSON, ELECTRICAL ENGINEER

Thomson is developing a sensor to detect the onset of cracking in steel girders. The sensor utilizes a small diameter-insulated wire bonded to a girder. When a crack reaches a certain width, it causes the wire to break, resulting in an increase in its resistance. This rise in resistance indicates the presence of a crack.

5 SCOUR MONITORING METHOD USING ULTRASONIC-BASED FLOW AND ADVANCED MACHINE LEARNING METER, YOUNG-JIN CHA, CIVIL ENGINEER

This project is designed to help improve both bridge efficiency and emergency management by detecting and classifying the levels of scour and scour refill – watery rock and sediment build-up – that compromises a bridge's integrity.

6 THERMALLY BROKEN CONCRETE BALCONIES, DAGMAR SVECOVA, CIVIL ENGINEER

This project involves looking at concrete balconies in order to help reduce consumption of natural resources and greenhouse gas emissions. The project's main objective is to create a thermal break system for concrete balconies in high rise buildings in order to enhance the building's sustainability and the comfort and safety of its residents.

alternately measure, record, and analyze temperature, force, motion, speed, and weight.

The labs, Svecova says, also serve as a critical training environment for engineering graduate students. "(They) learn how to instrument samples, test them, analyze them and draw conclusions based on their work."

Although SIMTReC does use sensors made elsewhere, it has also developed a reputation for producing high-quality devices at home.

"Living in Manitoba is actually challenging, not only for materials but also for the sensors," says Svecova. "When we want to use some of the existing sensors we can buy on the market, they do not always come with proper temperature range. This is sometimes challenging."

On the other hand, she adds, once SIMTReC identifies sensors that can effectively work in Manitoba's harsh climate conditions, the centre shares this information with other jurisdictions facing similar weather-related challenges.

SIMTReC, of course, also shares its own technology with other jurisdictions. Its sensors have been used to great effect in grain silos in rural Alberta, railway bridges in Ontario, and to determine the tonnage capacity of a bridge in the Bahamas. When no sensor exists for a particular problem, SIMTReC researchers try to fill the gap.

In its commitment to further develop and promote its system of structural health monitoring and fibre-reinforced polymers for infrastructure construction, SIMTReC researchers aim to help alleviate an assortment of problems and concerns that affect communities around the world.

Closer to home, the centre's success may have more immediate and visible benefits. As local roads and bridges are increasingly monitored wirelessly, and increasingly constructed with fibre-reinforced polymers, both their deterioration and their need for repair will be reduced. Not only will that lead to lower costs for infrastructure, it will also result in fewer road closures, re-routings and gridlock that have all become familiar features of the summer construction season.

Sharon Chisvin is a Winnipeg writer.

Mohammadhadi Shateri and Maha Ghaib prepare to subject a metal bar made of fibre-reinforced polymers to an acoustic emissions test. Fibre-reinforced polymers resist corrosion and can be used to strengthen construction materials.