MAY 2009

Field Notes

The newsletter of the Infrastructure Technology Institute at Northwestern University

The Infrastructure Technology Institute is a National University Transportation Center supported under a grant from the US Department of Transportation’s Research and Innovative Technology Administration (RITA).
FROM THE DIRECTOR
The quality of the natural environment and, in the long term, global warming, are serious concerns for our society. The International Panel on Climate Change predicts a likely increase in the average global temperature of at least 2° C over the next 100 years, and for high-emission scenarios, 2.5 to 6.5° C\(^1\). The consequences of this temperature rise may be severe and widespread, including changing weather patterns and a substantial rise in sea level – on the order of a meter or more. Transportation plays a central role in this process: one-third of US CO\(_2\) emissions come from oil-based transportation fuel use; transportation emissions are projected to grow about 10% over next two decades.

Can transportation infrastructure research save the environment? Surely not alone – but it can make some important contributions. Some of the work done by ITI offers good examples.

**STRUCTURAL HEALTH MONITORING**

Structural health monitoring (SHM) contributes to better-informed decisions about investment in transportation infrastructure repair and rehabilitation. Continuous monitoring techniques – for bridge scour, foundation movement, and stresses and strains in steel and concrete structures – can give early warnings of the need for restorative action, and in some cases, for emergency shutdown and repair.

The value of early warning is time: time to set priorities that fit resource constraints, to plan the most efficient restoration actions, and to develop and implement traffic management plans that minimize temporary congestion. With sufficient advanced information, infrastructure managers may be able to coordinate multiple rehabilitation projects to avoid amplifying traffic disruptions. In the case of emergent problems, remote automated SHM may provide sufficient warning of incipient failure to allow better-planned closure and traffic rerouting.

*We have demonstrated the value of early warning with such applications as SHM of scour-endangered bridges using tilt meters, crack monitoring in a steel box girder bridge with acoustic emission testing, and autonomous strain measurements on a variety of steel bridges and bridge bearings. Most of these applications involve semi-permanent instrumentation, autonomous remote monitoring, and wireless communication to permit low cost continuous tracking of many facilities simultaneously.*

SHM can also identify non-threatening structural damage – isolating benign damage that can be ignored, thus avoiding unnecessary expenditures and disruptions. In statistical terms, this means avoiding Type II errors, where the conservative null hypothesis is that the infrastructure element is at serious risk, and the error is in accepting this hypothesis when it is not true. Such errors waste money and time that could be spent on other infrastructure projects.

*The ITI team has assessed a major bridge displaying a crack in a fracture critical top chord using acoustic emission testing to determine that the crack was inactive under load and thus there was no need for corrective action. The bridge has remained in service with the benign crack.*

**CONGESTION CONSEQUENCES OF INFRASTRUCTURE PROJECTS**

Reductions in traffic delays resulting from better infrastructure management, more focused rehabilitation projects, and avoidance of unnecessary work can produce substantial savings in fuel consumption.
Traffic management focuses on the critical issue of worker safety, but sometimes overlooks traffic operations and associated environmental consequences. This work is attempting to account for the impacts of transportation infrastructure projects on the full set of stakeholders to provide a basis for managing these impacts.

Advanced infrastructure materials and materials processing techniques can provide important environmental advantages. Concretes with higher strengths can mean reduced material quantities for infrastructure projects. Cements that make greater use of recycled materials release less CO₂ in the manufacturing process. New weathering steels eliminate the need for painting and repainting, not only reducing costs, but also preventing environmental hazards associated with field painting.

ITI faculty and students are studying the total cost of work zone congestion, particularly for smaller projects that do not always get the most advanced traffic management technologies (Intelligent Transportation Systems – ITS).

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ITI researchers are advancing the frontiers of both concrete and steel as infrastructure materials. Weldable, weathering, high strength steel developed at Northwestern with ITI support has been built into two highway bridges, and a third is in the planning stage. Our steel researchers are also proposing a version of this steel for guard rails that eliminates the need for galvanizing and/or painting. Through fundamental studies of cement chemistry, we are defining new manufacturing techniques and developing a better understanding of the long-term design strength of concrete.

Infrastructure preservation and rehabilitation programs and projects can be designed to reduce environmental impacts – pollution emissions, spills, and energy consumption – and, with the right choices can contribute to environmental benefits through anticipation of infrastructure problems, thoughtful project selection and scheduling, choice of the “greenest” materials, and sensitive project management. Driving infrastructure management and reinvestment decisions with objective data, and using the right materials for the job, can help ensure that we have the transportation capacity and quality that we need to remain economically competitive while protecting and enhancing the quality of our environment. This is the work of ITI.
ITI’s Research Engineering Group (REG) has partnered with the Kentucky Transportation Cabinet (KYTC) and the University of Kentucky (UK) since 2007 to address questions about the end bearing anchor bolts on the John F. Kennedy Memorial Bridge, a large through-truss structure which carries Interstate 65 over the Ohio River between Louisville, Kentucky, and Jeffersonville, Indiana. The bridge has two large bearings at each end which, due to the design of the continuous span, must resist substantial uplift forces. In a 2006 inspection, one of the four anchor bolts restraining one of these uplift bearings was found to have fractured, while measurable section loss was noted on the other three.

The results of a 2007 short-term strain gage study by ITI engineers (described in a previous ITI newsletter article, “Live Strain Measurement Aids Interstate Bridge Repairs”) contributed to a retrofit design by KYTC in which the remainder of the fractured bolt embedded in the concrete pier was drilled and tapped to receive a replacement anchor bolt. Four large “keepers” anchored directly into the concrete pier would provide additional redundancy. ITI was asked to monitor the performance of the replacement bolt and the entire bearing assembly during and after retrofit. ITI engineers installed a variety of instruments on the assembly, including strain gages to measure axial, torsional, and bending strains on the replacement bolt and displacement and acceleration transducers to monitor the overall movement of the bearing assembly. Load cells were also installed on the keeper anchors to indicate if the keepers became loaded due to movement of the bearing assembly. ITI returned to the bridge in late 2008 to install a continuous remote monitoring system at the troubled
This system logs and transmits readings from strain gages on the anchor bolts, load cells on the keepers, and displacement sensors on the bearing assembly itself, along with ambient temperature and humidity, back to ITI via a cellular data connection. This information is automatically processed and posted daily on the secure project website.

Within two months of installation, the continuous remote monitoring system recorded an event involving significant redistribution of loads on the bearing assembly, including the unloading of the replacement anchor bolt, indicating possible failure of the new bolt. Authorities were made aware of this anomaly promptly. ITI and KYTC engineers confirmed fracture of the new anchor bolt during a subsequent site visit. During that visit, ITI also installed two Internet-accessible cameras to provide visual confirmation of any future indications.

Through the use of continuous remote structural health monitoring, ITI was able to detect very quickly the fracture of a structural member in a bridge over 300 miles away without the benefit of an on-site inspection. When the next retrofit of the bearing is performed, KYTC will continue to use this successful monitoring technique. Demonstration of the benefits of monitoring technology to retrofit design and performance validation continues to be a major thrust of the ITI REG’s ongoing research.
In late 2008, construction began on a new high-rise condominium building in the fast-growing South Loop area of Chicago. The site of this planned 53-story reinforced concrete tower exemplifies the infrastructure congestion typically found in urban centers: the embankment of the East Roosevelt Road bridge is a mere six feet north of the site, and South Indiana Avenue, an abandoned water tunnel, and several underground public utilities lie immediately west of the tower. The City of Chicago’s Board of Underground laid out strict monitoring guidelines to ensure the safety of these nearby critical facilities.

The construction of the tower employs “top-down” methods in which the concrete slabs of the basement levels are constructed as the excavation progresses rather than after the excavation is complete. These slabs then act as bracing that prevents movement of the surrounding ground as excavation continues. The slabs are thought to be stiffer than the temporary bracing used in traditional “bottom-up” excavations, so infrastructure-damaging ground movements are minimized. This behavior, however, has never been proven because traditional monitoring techniques have not provided enough data for a complete analysis.
To investigate the effectiveness of “top-down” construction for reducing soil movement, ITI researcher Professor Richard Finno and his team have deployed a network of over 70 vibrating wire strain gages to monitor the loading of the different sections of each basement slab. Just before the concrete is poured, ITI engineers attach these gages to the reinforcing steel and immediately begin reading them. When the slab is poured, the sensors become a permanent part of the structure and provide critical information about how the slabs bear load as the soil beneath them is excavated.

Finno’s team will use the data collected from these embedded strain gages, as well as from inclinometers and survey points around the construction site and from four previous construction projects around Chicago, with the aim of developing design recommendations for protecting nearby infrastructure from excavation activities.
The Ohio Department of Transportation (ODOT) is deploying a continuous remote monitoring system developed with ITI support to safeguard a section of Interstate 70 in Muskingum County that is threatened by collapse of an abandoned coal mine beneath the highway. This deployment, a cooperative effort between ODOT, ITI, and Geotechnical Consultants, Inc. of Westerville, Ohio, represents the continuation of ITI’s previous work in geotechnical applications of time-domain reflectometry (TDR) technology pioneered by ITI researcher Prof. Charles Dowding, and the successful transfer of TDR monitoring technology from university research to practice.

TDR may be thought of as “cable radar”: a radio-frequency pulse is sent down a coaxial cable and the reflected signals are analyzed. In geotechnical applications, TDR cables are typically grouted into boreholes in soil and rock; the pulse will be partially or completely reflected by localized shearing of the soil or rock, complete severing of the TDR cable, or upon contact with the ground water table. In their book, Geomeasurements by Pulsing TDR and Probes, Prof. Dowding and Dr. Kevin O’Connor cited a coal mining case study in which TDR detected subsurface movement four days before movement was detected at the surface1. Thus, TDR data may be used both to provide early warning of sub-surface failures and to evaluate the performance of mitigation efforts.

ITT’s TDR applications to highway subsidence in Ohio began in 1996, when a 10x12-foot section of I-70 near the city of Cambridge in Guernsey County suddenly dropped into a sinkhole formed by the collapse of an abandoned coal mine. After the highway was repaired and the mine was grouted, TDR cables were installed underneath the highway to monitor for any additional sinking of the roadway. ITI provided the TDR data acquisition system, and ODOT personnel interrogated the cables manually for several years. In 2001, ITI began autonomous remote monitoring of the site: each night, data were downloaded and posted on a web site – without human intervention – for easy comparison with historical norms.

Continuous Internet-enabled remote monitoring continued through May 2009, when the Guernsey County site was determined to be stable and remote monitoring equipment was removed.

The new Muskingum County site will feature an expanded instrumentation suite with five TDR cables installed in horizontal boreholes under the highway. The instruments will be remotely monitored before, during, and after the sealing and grouting of the mine to provide increased confidence in the safety and functionality of the highway.
In March 2009, members of Northwestern’s student chapter of the American Society of Civil Engineers (ASCE) took an alternative spring break trip to San Francisco to tour the region’s unique transportation infrastructure. The trip, jointly sponsored by ITI, the Illinois Section of ASCE, and the students themselves, built upon the successful San Francisco tour undertaken by Northwestern students in 2007. Eleven undergraduate engineering students and three ITI staff members spent four days exploring bridges, public rail transit, public ferry transit, sustainable building design, seismic research, and urban planning.

On the first day of their tour, the group visited the new California Academy of Sciences building, which not only engaged their engineering education with its exhibits but also served in itself as an example of sustainable design and green building technology: it is a LEED platinum-certified building, with a green roof, solar panels, and extensive use of recycled materials to minimize its CO₂ footprint. The students then proceeded to the Golden Gate Bridge where they examined one of the world’s most iconic structures at arm’s length.
The trip also featured a guided tour of seismic enhancements to the San Francisco-Oakland Bay Bridge, including the replacement of the entire eastern span, a portion of which collapsed during the 1989 Loma Prieta earthquake. Hosted by members of the construction and design teams, the tour taught students about the structural design and construction of the span as well as the management and environmental impact of this immense transportation infrastructure project.

The next day, the students rode Caltrain commuter rail to San José. A group of public officials, architects, and transportation experts rode with them, fostering an *en route* discussion of transportation infrastructure and service design. The students heard a presentation from Rod Diridon, former Santa Clara County Supervisor and champion of California’s new high-speed rail initiatives. The group then toured Caltrain facilities, including the San José-Diridon passenger station and the new state-of-the-art locomotive maintenance facility before boarding an Amtrak train to Oakland and a ferry back to San Francisco.

Near the end of the trip, the group visited a seismic research facility at the University of California-Berkeley, where they witnessed a demonstration of the laboratory’s five-story tall earthquake simulator.

This tour showed engineering students the inner workings of a variety of key transportation infrastructure facilities and systems in action and under construction. They learned directly from planners, engineers, managers, and political leaders about the challenges facing today’s transportation systems and creative strategies for meeting them.
Steel is here to stay. It’s abundant – 5% of the earth’s crust is iron, and extracting iron from ore is cheap, relatively speaking. Steel is highly recyclable; all steel made today is partially recycled, perhaps 90%. It is a huge class of alloys and can be used in a wide range of applications. It is not going anywhere.

WHAT DO THINK FUTURE STEELS WILL BE LIKE? WHAT CAN WE EXPECT? WHAT ARE KEY TRENDS AND WHAT IS DRIVING THEM?

I think it will continue to move in the direction of more desirable properties for less cost. Such is the case with what Semyon [Vaynman, Research Professor in the Department of Materials Science and Engineering] and I are working on now – steel with high strength, improved weatherability, improved weldability, and high fracture toughness that is also low-cost. All of these factors are desirable, especially corrosion resistance, and this will drive future developments in steel.

IS THERE A LIMIT TO WHAT WE CAN DO WITH STEEL PROPERTIES - STRENGTH, TOUGHNESS, WELDABILITY, CORROSION RESISTANCE?

Sure, there is probably a limit, but we haven’t found it yet. How do you know when you’ve found the limit? Steel has been studied for a long time and there is still much we don’t know about it.

YOU HAVE THE CAPABILITY TO MAKE SUPER HIGH STRENGTH STEELS - 100 KSI STEELS, BUT SOME OF OUR PARTNERS ARE ONLY INTERESTED IN 50 KSI STEELS. WHAT IS THEIR REASONING?

We have the capability to make much stronger steels than 100 ksi, but it just depends on what market you are targeting. When speaking about building infrastructure, I believe the main factor is still cost. In the automotive industry, they are always interested in very high strength, but in infrastructure there are additional factors to consider – weatherability being key. Our steels have copper added to make them corrosion resistant, but the currently used 50 ksi steel still costs less to produce than our 70 ksi steel. If they are interested in keeping costs down, they will choose...
the lower strength steel and still have some corrosion resistance. You also have to remember that 50 ksi is still strong compared to earlier steels (normally around 36 ksi) historically used to build bridges.

WHAT DOES THE CORROSION RESISTANCE OF YOUR STEEL MEAN FOR THE LONG-TERM COSTS OF USING THIS STEEL FOR INFRASTRUCTURE?

Because of the increased weatherability of our steel, it does not need to be painted. This provides a significant savings in construction and maintenance costs over the life of a structure.

IS THE US STEEL INDUSTRY WILLING AND ABLE TO MAKE YOUR NEW STEELS? ARE THERE OBSTACLES TO MOVING THEM INTO THE INFRASTRUCTURE MARKET?

Certainly the US steel industry is able to make our ASTM A710 B steel. Five hundred tons were made for the Lake Villa Bridge on Route 83. There is a competing 70 ksi yield strength steel that was developed by the steel industry that has found bridge applications.

The manufacturers of the competing steel are not looking for a new steel. There are fixed cost issues. However, one of them did reluctantly make the 500 tons for the Lake Villa Bridge. At this time, several mini-mills would make A710 B or the less expensive, not-as-strong alternative steel if they had an order. Hopefully, the Illinois Department of Transportation will specify the lower-cost alternative for a bridge to be built in Illinois. One heat of steel costs more than $100,000. There has to be a certain application before a steel mill will undertake the expense of making a heat of steel. We have been able to obtain up to 300-pound laboratory-made heats for evaluation.

YOU HAVE BEEN A PROFESSOR AND NOW PROFESSOR EMERITUS FOR A LONG TIME. WHAT CONTINUES TO EXCITE YOU IN MATERIALS AND METALLURGY?

Well, what else should I be doing? Being here, I get to talk to interesting people and I get to continue my work. It is better than the alternative.
Undergraduate students from the Structural Steel Design course in the Department of Civil and Environmental Engineering have joined the ITI team for a new structural health monitoring (SHM) project. The students have repurposed a small steel bridge built several years ago for a student design competition as a mockup for a bridge in Hurley, Wisconsin, where ITI and the Wisconsin Department of Transportation will install a SHM system later this year.

The ITI engineering staff is working closely with the students, teaching them hands-on instrumentation techniques including strain gage installation and data acquisition methods. Using their knowledge of steel design, the students are installing strain gages at fourteen critical high-stress areas of the mockup bridge. ITI engineers will enjoy the benefits of access to a fully-instrumented mockup of the Hurley bridge: most importantly, the mockup will provide a platform for a realistic test of all sensors and electronics prior to deployment in the field. This will help ensure a smooth installation during the time allotted, which is strictly limited by the availability of access equipment. Future SHM efforts will also benefit from the availability of a corps of willing students with instrumentation experience.

Once the instrumented mock-up bridge is no longer needed for the Hurley SHM project, it will be deployed at various Northwestern events to showcase ITI’s SHM abilities and to spur interest in civil engineering careers among undergraduates and pre-college students.
Civil Engineering senior Alex Stack marks where he will weld a strain gage to the bridge mockup.
During his sophomore year, Jeff Meissner, a Civil Engineering senior from Rochester, Michigan, started working on ITI-sponsored research with Prof. Charles Dowding. Jeff met Dowding through Northwestern’s Engineering Design and Communication program in which freshmen work on real design projects to give them an early experience with engineering.

Jeff’s initial efforts with ITI research included assembling Prof. Dowding’s blast vibration literature into a searchable electronic library. After gaining familiarity with the literature, Jeff began to take an active role in analysis of data from ITI’s monitoring sites. He analyzed vibration and settlement data from a structure near a limestone quarry in North Carolina and co-authored a paper describing the results for presentation to the annual meeting of the International Society of Explosives Engineers in February 2009. Jeff also presented a poster on his work at the Northwestern Undergraduate Research Symposium in May 2009.

Currently, Jeff is analyzing the response of a structure in south Florida to wind gusts, thunder, and ground vibration from blasting. This summer, he will work full-time for ITI, continuing to study the dynamic response of structures to events such as blasting, heavy construction activity, wind gusts, and thunder. The summer will present ample opportunities for field work – both directly related to Jeff’s research as well as to other ITI projects involving instrumentation of civil infrastructure.

Jeff reports that research and coursework complement each other well, saying, “It’s fun to take concepts learned in the classroom and apply them to new and different situations.”

In addition to his coursework and research, Jeff is involved with the Northwestern student chapter of the American Society of Civil Engineers and is president of Northwestern’s club baseball team. Following graduation, he plans to pursue graduate study in structural engineering.

ITI regularly employs undergraduate engineers in its research projects to enhance their education and to draw more young professionals into infrastructure engineering.
TRANSPORTATION RESEARCH BOARD
SPOTLIGHT CONFERENCE, NOVEMBER 12-13, 2009.

To learn more about transportation infrastructure preservation and renewal, and to contribute to defining a new agenda for research in this important area, plan on attending “Developing a Research Agenda for Transportation Infrastructure Preservation and Renewal,” sponsored by the Research and Innovative Technology Administration of the US Department of Transportation and organized by the Transportation Research Board, to be held in Washington, DC on November 12-13, 2009. More information is available at:


ITI TO HOST ACOUSTIC EMISSION WORKING GROUP
MEETING IN STURGEON BAY, WISCONSIN

ITI has a long-standing relationship with the Acoustic Emission Working Group (AEWG), the primary technical organization supporting the international acoustic emission community. AEWG seeks to advance acoustic emission technology through exchange of technical information, defining and promoting standards, holding technical symposia, and promoting technical interchange with other groups interested in acoustic emission and its applications. ITI will host the 52nd meeting of AEWG in Sturgeon Bay, Wisconsin, October 19-21, 2009.

http://www.aewg.org/
The Infrastructure Technology Institute is a National University Transportation Center supported under a grant from the US Department of Transportation’s Research and Innovative Technology Administration (RITA). If you are interested in working with ITI, please contact Chief Research Engineer Daniel Marron:

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Above:
A locomotive under repair in the Caltrain maintenance facility in San José, California

Cover Photo:
Members of the Northwestern ASCE student chapter and ITI staff pose in front of the San José-Diridon Caltrain station during the San Francisco Infrastructure Tour in March, 2009.

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