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ITI Research Engineer David Kosnik presents at the 52nd meeting of the Acoustic Emission Working Group, sponsored by ITI and held in Sturgeon Bay, Wisconsin.
The theme of the Infrastructure Technology Institute is to develop strategies and tools to protect and improve the condition, capacity, and performance of the nation’s highway, railroad, and mass transit infrastructure systems.
The physical infrastructure of surface transportation (highways, bridges, pavements, signs and signals, intermodal facilities, etc.), is the most obvious and essential component of the nation’s transportation system. Transportation infrastructure is ubiquitous and extensive, supporting the ability to go anywhere and ship anything. Our transportation system and its infrastructure support our economy, the welfare of our society, and the security of our nation.

Because of the rarity of major failures, it is easy to take this transportation system for granted. Surface transportation infrastructure requires careful monitoring, planning, and management; continuing reinvestment to maintain condition and assure performance, safety, and security; capacity expansion, the addition of new connections and services; and the adoption of new technologies to improve efficiency and sustainability. All of these requirements necessitate a deployment of resources that is fact-driven, based on objective measures of physical condition, performance, and current and expected needs.

Northwestern University’s Infrastructure Technology Institute (ITI) is committed to ensuring our nation’s surface transportation infrastructure against failure by developing and deploying techniques and technologies to assess infrastructure condition and to improve that condition with new materials and processes. A primary focus of the work of ITI is structural health monitoring (SHM): developing and deploying technologies and methods to assess the condition of key transportation components and to convert this condition and performance data into information that is useful in decision-making.

ITI SHM research and development efforts gather data during different periods in the life of a structure – from construction through long-term utilization and life extension. Using static or real-time measurements, our engineers deploy powerful tools to capture, transmit, store, and display infrastructure data, often in challenging environments and over great distances.

ITI researchers are also engaged in the development of advanced structural modeling methods and the creation of new, designer materials that solve old transportation infrastructure problems and meet new needs. Much of the work of ITI is done in conjunction with external partners, usually owners and operators of major infrastructure facilities and systems, who bring us problems and a willingness to collaborate in the pursuit of solutions.

Founded in 1992 under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), ITI is a National University Transportation Center presently funded under the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy For Users (SAFETEA-LU). This report describes the activities and achievements of the ITI team for the period between September 1, 2009 and August 31, 2010, its third year of funding under SAFETEA-LU. It goes beyond our technology advances to describe our educational achievements and support of policy analysis and the infrastructure policy debate.
Center Staff

ITI is an interdepartmental center within Northwestern’s McCormick School of Engineering and Applied Science. ITI is directed by Dr. Joseph L. Schofer, Professor of Civil and Environmental Engineering and Associate Dean of the McCormick School. The Institute employs four administrative staff members to perform day-to-day operations, and a four-member Research Engineering Group with experience in non-destructive evaluation and remote monitoring of transportation infrastructure.

The Research Engineering Group (REG) supports faculty, staff, and students engaged in Institute-supported research projects. REG members possess exceptional skills and experience in development and field deployment of advanced instrumentation techniques for monitoring civil infrastructure facilities. Their experience is applied to the three-fold mission of the ITI REG:

1. Conduct the REG’s own research on development and deployment of innovative instrumentation and monitoring techniques to solve real and current infrastructure problems, in partnership with infrastructure owners and operators across the nation

2. Support ITI-funded researchers and their students with instrumentation, communications, and deployment expertise, ensuring that state-of-the-art monitoring and communication technologies are available for and deployed in ITI research applications

3. Support other ITI technical program functions as necessary, including teaching, conference communications, and outreach

Left: ITI Research Engineer David Kosnik installs a sensor at the Chicago Transit Authority Devon-Sheridan rapid transit overpass.

Right: ITI Director Joseph Schofer lectures high school students during the week-long summer infrastructure camp.

PRINCIPAL ADMINISTRATIVE STAFF

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ITI selects projects for funding based on an annual proposal solicitation and review cycle. Requests for continuing funding must be accompanied by progress or final reports as well as a list of publications produced with previous ITI support. Proposals are reviewed by our Research Advisory Committee, which meets annually to review, discuss, and recommend proposals for the upcoming funding period. The Director weighs the recommendations of the advisory committee against the Institute's strategic plan and available funding. As part of this review, the Director verifies the matching arrangements for each proposed project to ensure that match requirements will be met for the Institute's overall program. For field applications, the match usually comes from in-kind services provided by the deployment partner or client. For projects that do not have a collaborating partner that can provide substantial matching funds, other arrangements are made, including the use of internal expenditures by Northwestern University for activities that have a direct programmatic connection to the project and/or the ITI mission.

To track short-term research progress, identify opportunities for cross-linking of ITI projects, and support broader interaction between faculty, staff, and students, ITI hosts a monthly research meeting attended by all funded principal investigators, their students, other Northwestern University researchers and research administrators, and representatives of related centers (the Transportation Center, the Center for Quality Engineering and Failure Prevention, the Center for the Commercialization of Innovative Transportation Technology, and others).

At these meetings, members of the research teams present technical updates on work in progress and selected principal investigators give in-depth reports. This provides an important opportunity for synergistic interaction, generating new ideas about methods and projects, and providing a rich, interdisciplinary learning environment for students.
Chief Research Engineer Daniel Marron discusses the ITI REG’s instrumentation on the Chicago Transit Authority Devon-Sheridan overpass to participants in ITI’s summer high school infrastructure camp.
ITI’s educational objective is to enhance the understanding of civil infrastructure systems, particularly those critical to surface transportation, and to prepare undergraduate and graduate students for productive careers in infrastructure and transportation.
Undergraduate Involvement in Active Research

Northwestern Civil & Environmental Engineering undergraduate Ken Fuller, an ITI student employee who actively participated in the installation of the remote structural health monitoring system on the US-2 bridge over the Montreal River in Hurley, Wisconsin, completed an independent study project with ITI researcher Professor David Corr to investigate the effects of truck loads on the structure. Specifically, Ken investigated the correlation between input measures (such as vehicle speed, axle configuration, gross weight, and axle weight), and outcome measures, such as the observed strains, accelerations, and deflections of the bridge and its components.

As a member of the installation team, Ken combined skills he learned in classes, his field experience, the data gathered autonomously by ITI’s structural health monitoring system, the traffic and weight data from the weigh-in-motion-system, and industry-standard structural modeling software, to understand the behavior of this structure in great detail. Because the design of the Hurley bridge is typical of many small bridges throughout the country, Ken’s findings may have far-reaching impact on the understanding of thousands of other structures.

Student of the Year Jeffrey Meissner

ITI was proud to name Jeff Meissner, a senior in Civil & Environmental Engineering in Northwestern’s McCormick School of Engineering and Applied Science, its 2009 Student of the Year.

Beginning in his sophomore year, Jeff made valuable contributions to ITI-sponsored research projects under Professor Charles Dowding. Dowding’s Autonomous Crack Monitoring project evaluates the response of cracks in various structures to vibration and environmental changes. Jeff studied a residential structure in Naples, Florida, with the objective of reducing litigation costs for road aggregate quarry operators by demonstrating that cracks in nearby homes are affected much more by variations in weather temperature cycles than by blasting vibrations. Some of Jeff’s work was presented at the annual meeting of the International Society of Explosives Engineers. Jeff also assisted the ITI Research Engineering Group in field installations.

In addition to his engineering activities, Jeff coached and played for the Northwestern club baseball team throughout his undergraduate career. In Fall 2010, he entered a graduate program in structural engineering at the University of Illinois at Urbana-Champaign.
In mid-July of 2009, 14 Chicago-area high school students spent an intensive week in ITI’s 2010 Summer High School Infrastructure Camp, which provided an opportunity for curious teenagers to learn the basics of engineering, observe engineering at work, and try their hands at it themselves.

The camp offered students lectures and a bridge-building lesson from Northwestern engineering faculty members and graduate students, infrastructure walking tours with research engineers, a visit to an Illinois wind farm, and a chance to see ITI research at work at a Chicago Transit Authority railroad bridge.

The camp culminated with a river boat tour of Chicago architecture, during which Northwestern faculty and research engineers pointed out structural aspects of some of Chicago's most famous buildings and bridges.
Civil Engineering Capstone Design Course

The North Shore Channel (NSC) flows just west of Northwestern University’s Evanston campus, but few students are aware of its existence. Constructed as part of the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) drainage system, the original purpose of this man-made channel was to draw water from Lake Michigan into the Chicago River to help flush effluent downstream. The NSC now sits largely unused, since modern regulations allow very little Lake Michigan water to be diverted for this purpose. As a result, the water in the channel does not flow rapidly and consequently has a low dissolved oxygen content. There is significant interest on the part of MWRDGC and the surrounding communities of Evanston, Skokie, and Wilmette to increase dissolved oxygen because it will improve the aquatic ecosystem and also enhance the aesthetic qualities and recreational potential of the waterway.

Senior undergraduate students in Northwestern’s Department of Civil & Environmental Engineering addressed this issue in a capstone design course sponsored by ITI. Through a foundation of lectures and field trips, student teams investigated various methods of oxygenating the water. These methods included active means such as augmenting the flow and pumping air directly into the channel, and more passive means such as side-stream aeration, where cascading elevated pools provide oxygen through natural turbulence and mixing. The teams pursued “soup to nuts” designs, which included conceptualizing potential solution schemes, investigating aeration methods and sites, calculating design requirements, and tabulating final capital and operational costs of the project. Teams also pursued energy audits of their designs in the interest of making the selected aeration systems as environmentally friendly as possible.

In contrast with traditional university engineering courses centered around problem sets and exams, this course focused on the team experience through investigation of an open-ended problem. As they approached the culmination of their project and graduation from the university, the excitement among the students was easy to observe.

“Working on the NSC project allows me to hone my skills as a civil engineer in a real world application, understanding the intricacies of today’s society and how we, as engineers, can work to improve the life of others,” says Raymond Chan, a graduating student in the class, who has since begun a Ph.D. program in transportation engineering at Northwestern. It is the hope of all faculty and students working on this project that in coming years, the NSC will become a waterway that is increasingly enjoyed by Northwestern students and local community members alike.

Civil Engineering undergraduate capstone students tour the North Shore Channel.
Success in Technology Transfer
A primary avenue for technology transfer at ITI is our work in partnership with infrastructure agencies and owners to develop and deploy innovative structural health monitoring technologies to help those partners solve real infrastructure performance and condition problems.

Institute researchers work directly with partner agencies which, in turn, provide support and matching resources to the Institute's activities in three ways:

- Provision of on-site personnel and equipment to support ITI researchers in the installation and demonstration of SHM technologies
- Provision of engineering and other support services that are essential for conducting ITI deployment field work
- Occasional direct contracting with Institute researchers to provide technical assistance for field deployment of advanced technologies

Among the deployment partners with whom we worked in the past year are:

- Kentucky Transportation Cabinet
- Chicago Transit Authority
- New York City Metropolitan Transportation Authority
- Wisconsin Department of Transportation
- Ohio Department of Transportation
- California Department of Transportation
- Geotechnical Consultants, Inc., Westerville, Ohio
- Jones Mining Company, Naples, Florida
- GeoSonics Inc., Warrendale, Pennsylvania
- Vulcan Materials Company, Sycamore, Illinois
- STS AECOM, Vernon Hills, Illinois

These partnerships are usually initiated by the agencies and facility owners who have learned about our expertise through our web site, conference appearances, or publications. Occasionally we will approach a potential partner when we see a particularly challenging infrastructure monitoring problem, or, in the case of our material development work, where we can bring special expertise to bear on an infrastructure material need.

Our partners not only benefit from the resolution of a problem or need, but in some cases they acquire the knowledge, skills and technologies to conduct their own advanced SHM activities.

ITI has continued to develop and move material technologies into practice through the design of advanced steels for applications to bridges.
The Third Annual William O. Lipinski Symposium on Transportation Policy

Moving the Goods – Freight in the Chicago Region was the title of the Third Annual William O. Lipinski Symposium on Transportation Policy, sponsored by ITI, on November 2, 2009.

Chicago is critically important as a national freight hub, particularly for rail and especially intermodal freight. U.S. Secretary of Transportation Ray LaHood emphasized this point in his keynote remarks: “Chicago as our rail hub – it is an American priority, a non-partisan priority.” He observed that the safety and energy efficiency of railroads mean that resolving Chicago’s freight issues supports the Department’s Transportation Livability Initiative - a federal initiative to help communities across America grow in ways that ensure a better quality of life.

One-third of the nation’s rail and truck cargo passes through the region, and Chicago has been a dominant freight center for nearly a century. This pre-eminence as a hub brings the region a high level of national and international connectivity for goods movement, supporting local industries, markets, and jobs. At the same time, this role brings challenges, in the form of congestion on all modes, delays as freight is interchanged among railroads and between rail and truck, and consequent problems of safety and air pollution. Thus, freight issues in the Chicago area are of both local and national concern.

While Chicago faces numerous freight issues and challenges, there have been many improvements, and more are on the way. Michael Burton, CEO of C&K Trucking, pointed out that Chicago has been a “black hole” for intermodal freight. The city effectively imposes a two-day penalty on through-containers, and there are 11,500 trucks moving containers and trailers in and out of Chicago rail yards each day. However, operational improvements that have decreased rail yard dwell times, while equipment and technology upgrades, plus better blocking and scheduling of freight trains, have improved service quality over the last several years.

E. Hunter Harrison, then-Chairman of Canadian National Railway, talked about congestion in the Chicago region. He suggested that additional railroad mergers may provide a cheaper way to clear up congestion, increase capacity, and promote coordination and cooperation in the Chicago region.

The Canadian National purchase of the Elgin, Joliet & Eastern Railway, while controversial, is also likely to improve regional freight operations by shifting some freight movements to the edge of the city, relieving some central city congestion on the railroads and at grade crossings. Daniel Elliot, Chairman of the U.S.
Surface Transportation Board (STB), reminded participants that this acquisition comes at the expense of increased grade crossing congestion in certain suburbs – by as many as 23 trains per day in some places. These impacts are being monitored by the STB, which will publish performance reports monthly and quarterly on its Web site. Chairman Elliot stressed that it will be important for the railroad and public agencies to work together to mitigate and manage these impacts.

Participants at the symposium spent much time discussing CREATE, the Chicago Region Environmental And Transportation Efficiency Program, which is intended to provide substantial congestion relief when its various components are completed. It will separate rail and highway traffic, as well as rail freight and rail passenger services. CREATE is a collaboration between the Class I railroads serving Chicago and federal, state, and local governments.

Joseph Szabo, U.S. Federal Railroad Administrator, said that CREATE will "establish a national model for rail integration" as it upgrades corridors, grade crossings, and signals, and streamlines other operations. US Representative Daniel Lipinski reported that it has been difficult to get the message of the value of CREATE across to the public, but the social, economic, and environmental benefits of the project will be significant. Six projects are already underway under the CREATE umbrella, and the Illinois State Capital Bill promises another $300 million for the project. Rep. Lipinski reminded participants that it is important to build support for CREATE at all levels.

Railroad consultant Norman Carlson emphasized the need to educate the public and policy makers about the importance of freight to the economy of the nation and the region, and to use that as a basis for growing support for CREATE.

Several speakers addressed the need for a national transportation policy to guide planning, investments, and the development of a financing strategy. Professor Hani Mahmassani, Director of Northwestern’s Transportation Center, pointed out that the European Union is ahead of the United States in this respect. There, the priority is to move more traffic by rail, reducing truck dominance to achieve social and environmental benefits.

A national plan would provide the basis for coordination and collaboration across federal transportation agencies, the 50 states, and the private sector to deliver a more integrated and sustainable freight system that ensures our economic competitiveness. Administrator Szabo reported that the Federal Railroad Administration is currently developing such a plan, which integrates passenger, freight, and intermodal rail transportation, and connects to the safety, livability, competitiveness, and sustainability initiatives of the federal government.

Speakers on the concluding panel addressed the national balance between truck and rail. Both James LaBelle of the civic interest group Chicago Metropolis 2020 and Paul Nowicki, vice president of the BNSF Railroad, discussed the introduction of road pricing as a source of much needed funding for the highway network, as well as to provide incentives to shift more long-haul freight to rail. Beyond the environmental and energy benefits, such a shift would reduce the burden on aging highway infrastructure.

As they focused on freight, speakers and the 250 participants at the Lipinski Symposium addressed the needs of both private and public freight transportation infrastructure – the CREATE project to relieve both rail and road bottlenecks, rail network integration through mergers and acquisitions, and the importance of maintaining and renewing aging freight infrastructure to protect capacity and reliability of services, ensuring the economic vitality of the region and the nation.
THE DAVID F. SCHULZ AWARD FOR OUTSTANDING PUBLIC SERVICE IN TRANSPORTATION AND INFRASTRUCTURE

The David F. Schulz Award for Outstanding Public Service in Transportation and Infrastructure is presented annually at the William O. Lipinski Symposium on Transportation Policy. This award commemorates the lifelong commitment of David F. Schulz (1949-2007) to transportation infrastructure. The founding Executive Director of Northwestern University’s Infrastructure Technology Institute, Schulz was an articulate spokesman and advocate for transportation throughout his career as a public servant, elected official, university leader, and teacher.

The Schulz Award honors individuals or groups for technical or policy innovations of transportation or infrastructure, or for public policy leadership in calling attention to problems in transportation or infrastructure.

The 2009 award was presented to key collaborators from five different agencies who worked to create the new I-35W St. Anthony Falls bridge in downtown Minneapolis. This bridge replaces the structure which collapsed on August 1, 2007. The winning agencies were: Figg Engineering, the Minnesota Department of Transportation, the Federal Highway Administration, the City of Minneapolis, and Flatiron-Manson.

This infrastructure disaster took 13 lives, and caused over 140 injuries. Destruction of this key link—carrying over 140,000 vehicles each day—was a major disruption for the city, region, and state, imposing traffic delays and congestion affecting both passenger travel and the logistics operations in the upper Midwest. With incremental transportation costs estimated to be at least $400,000 per day, quick restoration of this major Mississippi River crossing was a priority, but rebuilding a bridge of this scale in the middle of a major city is a long and complex task.

The new St. Anthony Falls Bridge opened to traffic only 414 days after the old bridge was lost. The new bridge is spectacular—a work of art and technology designed to last 100 years. It features a segmental concrete box girder design that facilitated rapid and high quality construction and that benefits from high performance concrete.

The bridge was built under a design-build contract in which Minnesota DOT implemented extraordinary measures to facilitate efficient communication between the owner, the stakeholders, the regulatory agencies, and the design-build team.

Despite the speed of the effort, aesthetics were a key part of the proposal evaluation process, and that is apparent from the result.

Incentive payments tied to the cost of diverted traffic to reward timely, and early, completion were offered—and earned.

Every step was compressed; work progressed day and night, quality control was stepped up, and a landmark collaboration among all parties delivered a landmark bridge, pulling off an amazing infrastructure success.

This project is a model for rapid infrastructure restoration that recognizes the high costs of infrastructure disruption and responds with creativity, commitment and coordination. It is a model of what can be done when the right resources are brought together. ITI Director Joseph Schofer presented the award to the team, and Jo Ann and Bobby Schulz (David Schulz’s widow and son) attended the presentation.


Bottom: (from left to right) Jon Chiglo, Minnesota Department of Transportation; Joseph Schofer, ITI; Linda Figg, Figg Engineering; Bobby Schulz; Jo Ann Schulz; Peter Sanderson, Flatiron-Manson; Romeo Garcia, Federal Highway Administration; and former U.S. Rep. William O. Lipinski.
The 52nd Meeting of the Acoustic Emission Working Group

The Infrastructure Technology Institute hosted the 52nd meeting of the Acoustic Emission Working Group (AEWG) October 19-21, 2009, in Sturgeon Bay, Wisconsin. AEWG is an international organization dedicated to advancement of the theory and practice of acoustic emission (AE) testing. AE is the phenomenon by which materials under stress emit noises – sometimes audible, as with the “tin cry” known to metalworkers, but more often inaudible ultrasonic frequencies – and to the non-destructive evaluation (NDE) technique based upon analysis of these noises. ITI is a leader in the application of AE techniques to large civil structures, especially steel bridges. While a wide variety of AE applications were featured at the 2009 meeting, civil infrastructure was a special area of focus. Sturgeon Bay was selected as the meeting site in part because it allowed participants to tour steel bridges on which AE had been performed.

The first day of the meeting consisted of a series of hour-long primer sessions intended to introduce novices to basic AE concepts while refreshing and expanding the knowledge of veteran AE workers. The morning featured lectures on AE instrumentation and basic analysis as well as feature-based analysis. The afternoon was dedicated to civil infrastructure applications. ITI research engineers David Kosnik and Daniel Marron presented a summary of ITI’s work on AE localization and characterization of cracks in steel highway bridges. Kosnik and Marron also discussed AE for localization of mechanical noise sources on large movable structures.

The second and third days of the meeting were filled with technical presentations and lively discussion. Presentations ranged from AE sensor design and data analysis techniques to practical applications ranging from materials science to medicine, civil structures, and aerospace. Immediately following a tour of one of the iconic bascule bridges in downtown Sturgeon Bay, ITI research engineers David Kosnik and Daniel Marron presented their recent work on AE for localization of the source of unsettling “banging” noises observed on a bascule bridge. Because sound travels about 17 times faster in steel than in air, it is nearly impossible to locate the source of such noises by ear. AE source location techniques can provide unambiguous results; once the noise source is identified, it is possible to determine the cause.

On Tuesday evening, an awards dinner was held during a boat tour of Sturgeon Bay. Attendees were treated to up-close views of the three bridges over the bay and adjoining ship canal. Masayasu Ohtsu of Kumamoto University was awarded the AEWG Gold Medal for his work on AE analysis of concrete, including investigation of rebar corrosion and corrosion-induced cracking.
Developing a Research Agenda for Transportation Infrastructure Preservation and Renewal

Research is one of the keys to solving the crisis in America’s infrastructure. This was the focus of the fourth annual Spotlight Conference sponsored by the Research and Innovative Technology Administration (RITA) of the U.S. Department of Transportation and organized by the Transportation Research Board (TRB) of the National Academies. Held November 12-13, 2009 in Washington DC, the conference brought public and private infrastructure owners and managers together with researchers to discuss infrastructure preservation problems and needs and to define a research agenda for the future. The planning committee was chaired by ITI Director Joseph Schofer. TRB management was provided by Thomas Palmerlee, Associate Director of the Technical Activities Division.

“Many elements of the nation’s surface transportation infrastructure are deteriorating as a consequence of aging and growing stresses,” Schofer said to conference participants. “Under these circumstances, it is particularly important to develop and deploy the best methods and technologies to support effective management of transportation infrastructure … The roadmap we develop together should serve as a guide for both research investors and producers in the deployment of resources and talent to assure the condition, performance, safety and security of the nation’s transportation system in the years ahead.”

US Secretary of Transportation Ray LaHood kicked off the two-day conference by saying that the Obama administration is committed to revitalizing the nation’s infrastructure. To accomplish this, forward-looking, innovative transportation ideas and policies are necessary. “It’s a new day at DOT,” LaHood said, emphasizing the importance of maintaining assets and making them safe, efficient, and sustainable. Keynote presentations were given by three infrastructure owner-managers. Michael Miles, Deputy Director for Maintenance and Operations at the California Department of Transportation (Caltrans) spoke about spending funds wisely so that all needs, not just some, can be fulfilled. He also explained that Caltrans is moving towards preventative maintenance to extend the life of structures at significantly less cost.

Robert Prince, Vice President of AECOM Transportation and former General Manager of the Massachusetts Bay Transportation Authority, stressed the need to build support for transportation infrastructure preservation. “We are all in the same boat, and
we need to tell our story better because the public doesn’t understand. We need to help them understand,” he said.

The last speaker of the morning, David Connell, Vice President of Union Pacific Railroad, emphasized the importance of research in driving further safety and efficiency improvements, as it would “set our future.”

Conference participants then worked in four breakout sessions to define a comprehensive research agenda for infrastructure preservation and renewal. The focal areas were Inventory and Condition Assessment, Innovative Materials for Preservation, Restoration, and Reconstruction, Strategies for Rapid Repair and Rehabilitation, and Methods to Support Infrastructure Preservation and Renewal. A key resource for this process was more than thirty poster presentations describing research activities and achievements. ITI and Northwestern University were well-represented at the poster session. The ITI Research Engineering Group (REG) – David Kosnik, Daniel Marron, Mathew Kotowsky, and David Corr – presented five posters, and Civil Engineering graduate students Nathan Tregger and Zoi Metaxa presented their research with ITI researcher Professor Surendra Shah. The REG posters were co-authored by ITI researchers Professors Charles Dowding, Richard Finno, and Pablo Durango-Cohen.

The conference ended with presentations from each of the discussion groups and the development of research priorities by all participants. In addition to the lengthy research agenda, a series of six crosscutting themes was discussed throughout the conference. TRB prepared and issued the infrastructure preservation and renewal research agenda at the end of December. It was widely distributed at the 89th Annual Meeting of the Transportation Research Board in January, 2010, and Schofer and other members of the planning committee are working with TRB and RITA to distribute the agenda even more broadly.

In the breakout sessions the REG presented several significant case studies of recent projects, including acoustic emission monitoring of two steel bridges, continuous remote monitoring of in-service historic utility tunnels, continuous remote monitoring of uplift bearings on a large truss bridge, and the use of wireless sensor networks to monitor crack growth on bridges.

Since the conference ended, Schofer and other members of the planning committee have been working with TRB and RITA to distribute the agenda even more broadly at other meetings, and through publication of the recommendations in the ASCE Journal of Infrastructure Systems.
The Midwest Bridge Working Group, an ITI-sponsored forum for information exchange among bridge maintenance, inspection, and preservation professionals, met twice during the 2009-2010 grant year. The December, 2009 meeting was held in conjunction with the kickoff meeting of the new Southeast Bridge Working Group in Baton Rouge, Louisiana. Among the 95 attendees were federal and state department of transportation personnel, consultants, and researchers. A total of 20 state departments of transportation were represented. Presentations — five by consultants, four by state DOT officials, two by university researchers, and one by an FHWA official — covered a wide variety of topics of interest to the bridge maintenance, inspection, and preservation community.

Among the formal presentations was “Getting Data Back from Your Bridge”, a talk by ITI research engineer Mathew Kotowsky on best practices for communication and control hardware and software for remote monitoring of structures. The experience of the ITI Research Engineering Group has shown that the success of a remote structural health monitoring project often hinges on the effectiveness and robustness of the communication and control processes. All presentations were recorded and broadcast over the Internet by the Louisiana Department of Transportation & Development and Louisiana State University, which hosted the event. The meeting concluded with an hour-long informal roundtable discussion on bridge preservation and maintenance. The following morning, the group visited a newly-rehabilitated movable bridge over Bayou Grosse Tete, a small but busy waterway near Baton Rouge. The bridge opened several times during the field trip, allowing the attendees to see it in action.

The May, 2010 meeting was hosted by the Illinois Department of Transportation at their District 1 headquarters in Schaumburg. Thirteen formal
presentations were made during the first day of the meeting: three by state DOT officials, one by an FHWA official, three by consultants, two by trade associations, and four by vendors. All presentations were recorded by ITI personnel and posted on the Midwest Bridge Working Group's Web site, www.midwestbridge.org, for viewing by persons unable to attend the meeting.

Two roundtable discussions comprised the next morning's meeting. The first covered a wide range of bridge inspection and maintenance issues suggested from the floor by state DOT personnel. The second discussion concentrated on sharing of successes and best practices among agencies, particularly in the fields of bridge inspection, protective treatments for bridge decks, mitigation of rebar corrosion, and experiences with asset management software. 97 people attended the May meeting, including 45 state DOT personnel representing 16 states. Also represented were one county highway department, three universities/research institutions, consultants, vendors, and FHWA.
ITI’s Internet-Enabled Monitoring Technology Helps Ohio DOT Safeguard Interstate 70

Principal Investigator: Charles Dowding

The Ohio Department of Transportation (DOT) has deployed an Internet-enabled monitoring system based on ITI technology on a section of Interstate 70 in Muskingum County which is threatened by subsidence of abandoned coal mines beneath the highway. This installation, done in cooperation with Geotechnical Consultants, Inc., of Westerville, Ohio, is the continuation of work in two areas pioneered by ITI researchers: geotechnical applications of time-domain reflectometry (TDR), and autonomous Internet-enabled remote monitoring of transportation infrastructure.

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 the Muskingum County deployment, eight TDR cables were installed in horizontal boreholes: one each beneath the travel and passing lanes of both east- and westbound I-70 in two sections, totaling 3600 centerline-feet of monitored highway. Since the susceptibility of the abandoned mines to subsidence or collapse is related to the level of the ground water table in the mine, a piezometer in a vertical borehole measures the water table as well - engineers know to be especially vigilant if the water table drops suddenly.

Since the system came online in the summer of 2010, each TDR cable has been automatically interrogated every six hours. Piezometer data and equipment diagnostic data such as temperature and battery voltage are recorded at the same interval. Every night, ITI’s remote monitoring server connects to the I-70 datalogger to download the latest readings. The data are then entered into a relational database and displayed on a password-protected Web site. This method of data collection and distribution frees engineers from the tedious task of manual data acquisition and archiving, and facilitates sharing of data among many parties: state engineers and geologists in various offices across the state, consultants, academics, and others.

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 surface. Thus, TDR data may be used both to provide early warning of sub-surface failures and to evaluate the performance of mitigation efforts. ITI’s Internet-enabled TDR display technology brings those data to the attention of interested parties quickly and easily.
ITI researchers were actively involved in the 89th Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, this past January. ITI researchers and principal investigators attended the event and presented the results of several projects.

Professor Joseph Schofer reported the outcomes of the recent UTC Spotlight Conference Developing a Research Agenda for Transportation Infrastructure Preservation and Renewal. In November, 2009, the Spotlight Conference drew public and private infrastructure owners and managers together with researchers to discuss infrastructure preservation problems and needs and to define a research agenda for the future. Schofer chaired the planning committee of the spotlight conference, in close collaboration with Thomas Palmerlee, TRB Associate Director of the Technical Activities Division.

Four members of the planning committee reported on the recommended research agenda that was borne out of the 2009 conference, and senior managers from the California Department of Transportation and the Massachusetts Bay Transportation Authority commented on the relationships between the recommendations and their agency needs. This was the beginning of a larger effort to advance the research agenda by disseminating it widely to a variety of audiences.

Professor Pablo Durango-Cohen gave a tutorial on application of time-series methods to transportation research. These methods filter through a data set that may contain many daily, seasonal, or annual cycle elements. Because of the number of factors in the data, relevant trends are often obscured. Advanced statistical tools make it possible to smooth out these external factors to reveal an underlying trend. It is then possible to create a deterioration model that can be useful for management decision-making.

Durango-Cohen presented several case studies of time-series analysis for infrastructure data, including analysis of the 1958-1960 AASHO road test and deterioration of a highway bridge element monitored by ITI. The AASHO road test was a comprehensive full-scale accelerated test of flexible and rigid pavements under a variety of designs and loadings. Since pavement performance is affected by seasonal changes, Durango-Cohen uses statistical tools to find the true deterioration trend within the seasonal elements of the data set. In the case of the bridge element, a bolt which fractured under repeated loading and corrosion damage, Durango-Cohen used advanced statistical methods to search for a trend in the data recorded before fracture that could provide early warning of future failures.

ITI research engineer David Kosnik presented a paper entitled “Autonomous Condition Monitoring of an In-Service Historic Utility Tunnel.” This paper discussed a unique monitoring project in which ITI instrumented a section of century-old freight tunnels in downtown Chicago. These tunnels once connected many of the buildings in Chicago’s central business district for freight delivery and refuse collection but now carry electrical and communication cables throughout the area, including to financial markets. The presence of these critical utilities in the tunnels immediately adjacent to a deep excavation for a new building prompted the Chicago Department of Transportation (CDOT), which is the organization responsible for oversight of the tunnels, to enlist the help of several organizations, including ITI, to install sensor systems to monitor the effects of the excavation on the tunnels.

ITI engineers installed a network of displacement sensors at fourteen locations along the city block-long length of tunnel adjacent to the excavation. A field computer with custom software written at ITI recorded sensor data hourly and automatically uploaded it nightly to ITI servers, where it was published on a password-protected web site for review and analysis by CDOT and others. CDOT personnel brought the latest data from the web site to daily construction meetings at which they had authority to halt work if excessive displacements were measured. The ITI monitoring system operated continuously for over two years, by which time the excavation was complete. Ultimately, little movement was measured at the tested locations; nonetheless, all parties benefited from the near real-time availability of displacement data from ITI’s sensing network in the tunnel throughout the project.
Success in Research
The Institute’s research program focuses on ensuring the viability of transportation infrastructure systems through the development and application of innovative measurement, monitoring, and communications technologies to gather critical data on the structural health of infrastructure systems. ITI has also invested in the development of new and improved infrastructure materials.

Institute researchers have deployed advanced continuous remote structural health monitoring (SHM) technologies on transportation infrastructure facilities around the nation. In collaboration with deployment partners, we have used elements of the nation’s infrastructure as our field laboratory to develop, deploy, and test advanced SHM technologies. In the process we have helped agencies to identify and understand significant problems with their transportation infrastructure. These partnerships have provided unique and challenging settings for research and invaluable learning opportunities for our students.
ITI Research Embraced in High Rise Construction

**Principal Investigator:**

**Richard Finno**

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 is a prime example of 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.

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 during the innovative “top-down” construction process in which the concrete slabs of the basement levels are constructed as the excavation progresses rather than after excavation is complete. Just before each slab of concrete is poured, engineers attach these gages to the reinforcing steel and immediately begin to take readings. 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.

In December 2009, the Chicago Department of Transportation and owners of the largely completed building requested that ITI continue its investigation into the effects of the construction method on surrounding infrastructure with the goal of developing design recommendations for future use of this innovative construction technique. Keeping the sensing system in place for a longer period of time makes more data available to engineers about the long-term performance of top-down construction as it affects the surrounding soil and infrastructure.

Though the building’s basement levels were part of an active construction site at the time of the installation of the equipment, these levels are now the garage where the building’s new occupants will park their cars. As with any long-term structural health monitoring system, especially those that exist in an area to which the public has access, great care must be taken by engineers to protect the equipment from accidental damage and to minimize inconvenience to the building’s occupants. The efforts of the ITI engineering team to leave the building’s residents with a functional yet inconspicuous monitoring system not only ensure the safety and continued successful operation of the equipment, but also provide a stage on which to showcase the advancements in structural and geotechnical health monitoring pioneered by ITI.

Top: The One Museum Park West high-rise construction progressed simultaneously with the fifty foot deep excavation for the parking garage below.

Bottom: The final configuration of the data logger in the basement parking garage.
The Chicago Transit Authority (CTA) operates approximately 36 miles of elevated rapid transit passenger rail service in and around the city of Chicago. A significant portion of this service operates over century-old structures built by a now-defunct predecessor to the CTA. Several of these reinforced concrete structures show signs of deterioration caused by corrosion of their reinforcing steel and subsequent spalling of their concrete columns. To address these issues immediately, the CTA has installed steel shoring to secure some of these bridges. The steel shoring is designed to pick up any share of the load that the deteriorating concrete columns cannot support.

In late 2009, the CTA enlisted the help of ITI to design a prototype continuous autonomous remote structural health monitoring system for one of these bridges. The goal of the research project is to evaluate the load bearing performance of the shoring and to provide additional data to assist in managing the allocation of limited resources for bridge replacement.

The monitoring system consists of several types of strain gages that can be used to determine the loads carried in both the vertical steel elements and in horizontal reinforcing bars in newly-poured concrete footings supporting the shoring. Should the concrete columns deteriorate further, loads from the structure, roadbed, and trains will be transferred to the shoring, and strain gages will reflect the increased loading on the steel components. Strain gage measurements are monitored in real-time over the Internet by ITI and CTA engineers, who can assess trends in performance of the structural system.

After approximately one year, ITI and CTA engineers will identify which of several different experimental strain gage configurations most clearly measures deterioration of the bridge. That configuration will be applied to shoring on deteriorating bridges of similar design throughout the CTA network, allowing CTA to make informed decisions about priorities for bridge replacement throughout its rail system.
Long Term Structural Health Monitoring Begins in Hurley, Wisconsin

**Principal Investigators:**
Daniel Marron & David Corr

There are over 597,000 publicly owned bridges in the United States, but resources available to maintain them are limited. University Transportation Center researchers can provide a better understanding of how structures respond to real world conditions by applying structural health monitoring techniques to selected in-service bridges. Engineers and policy makers can then use this additional information to make more cost effective choices, benefiting the entire transportation system.

In July of 2009 the ITI Research Engineering Group began a multi-year cooperative research project in partnership with the Wisconsin Department of Transportation (WisDOT) to deploy and evaluate advanced structural health monitoring techniques on a typical highway bridge. The target of the study is a five-girder continuous-span steel bridge with a concrete deck which carries US Highway 2 over the Montreal River between Hurley, Wisconsin, and Ironwood, Michigan. The bridge design is typical of many small river crossings throughout the country. However, this bridge is of special interest because it is regularly subjected to truck loads well in excess of its posted 40 ton limit due to nearby logging operations.

WisDOT contracted with a commercial supplier to install a state of the art real time weigh-in-motion system adjacent to the bridge to measure vehicle loads and as a supplement to enforcement efforts. This presented a unique opportunity for research collaboration, since the actual vehicle loads on instrumented structures are rarely available for comparison with strain and other measurements.

During the second half of 2009, REG engineers, along with Northwestern graduate and undergraduate students, designed, constructed, and installed a comprehensive automated, structural health monitoring system on the Hurley bridge. The system consists of 14 strain gages, four accelerometers, two displacement transducers, and six environmental sensors applied at critical locations on the structure. The sensors feed data into a logger located in an enclosure at the end of the bridge, along with supporting communications and electronic equipment. Real time data, including weigh-in-motion data, are automatically transmitted back to ITI servers, where they are processed and made available in near real time on a password-protected project Web site. In addition...
Top: Electronic hardware inside the instrument cabinet for the Hurley structural health monitoring system.

Right: ITI Research Engineer David Kosnik and undergraduate student Ken Fuller test the ultrasonic river stage sensor under the bridge.

Bottom: Undergraduate students Jeff Meissner and Olivia Nelson prepare to install instrument cables in a trench between the bridge and the instrument cabinet.

to making data available to WisDOT and Michigan Department of Transportation personnel, ITI researchers and Northwestern students are analyzing bridge performance using time series statistical models and comparing measured strain values with those predicted by finite element models. The comprehensive set of load-response measurements gathered during this multi-year project will be a unique resource for bridge engineering studies.
Under the TEA-21 grant, a 70 ksi yield strength, high performance steel (ASTM A710 Grade B) was designed and developed at Northwestern University. This steel achieved good fracture toughness at low temperatures, exhibited weldability without pre-heat or post-heat, and showed corrosion resistance superior to all other weathering infrastructure steels. A bridge was built in Lake Villa, Illinois using this steel in 2006.

However, most new bridges designed in the United States call for 50 ksi yield strength steel. To develop a 50 ksi yield strength steel that would be less costly than A710 steel but would also have its outstanding fracture toughness and corrosion resistance, the ITI-supported researchers adjusted the composition of A710 Grade B steel to contain less copper and nickel.

This new steel was first produced and tested in the laboratory, where it was found that the mechanical and fracture properties of the steel significantly exceeded bridge steel requirements. The researchers made additional adjustments to the steel's composition to facilitate commercial production. Steel Dynamics, Inc. of Fort Wayne, Indiana, then produced I-beams suitable for bridge construction. The mechanical properties — including fracture toughness — of the commercially-produced steel still exceed the values required by bridge codes.

Now, the Illinois Department of Transportation is building a new bridge carrying Dixie Highway over Butterfield Creek in Flossmoor, Illinois, using this recently developed steel.

This bridge uses hot-rolled and air-cooled wide flange I-beams. The use of I-beams greatly reduced the number of welds needed to fabricate the bridge, thus further reducing the construction cost. The bridge is scheduled to be completed in October, 2010.
The ITI-sponsored project on Intelligent Structural Health Management (ISHM) of Civil Infrastructure is being conducted in conjunction with a five-year NSF-funded program on Partnerships for International Research and Education (PIRE): US-Asia Network of Centers for ISHM of Safety-Critical Structures. The PIRE-ISHM program is led by Northwestern University and partners with universities and industry from China, India, and the United States. The aim of the program is to develop new diagnostic and prognostic methods to ensure structural reliability, and to exchange researchers with the other partner organizations to foster a cross-disciplinary research program.

As part of the ITI-sponsored research in ISHM of civil infrastructure, Professor Sridhar Krishnaswamy and his team have been working on development of probabilistic fatigue damage prognostics and advanced fiber optic sensors for structural health monitoring.

**FATIGUE CRACK GROWTH OF STEEL**

Probabilistic considerations play a dominant role in the four stages of the diagnostics and prognostics of fatigue damage in metals. Considerable attention has been given to the evolution and detection of pre-crack fatigue damage and the probabilistic aspects of subsequent macrocrack formation. For macrocrack growth and detection, the well-known Paris law for crack growth under cyclic loading conditions can be useful, particularly if it is placed in a probabilistic context, and if the constants in the law are represented by probability distributions.

By introducing the probability of detection concept, various probabilities related to the existence of a crack larger than a critical size after a given number of load cycles can be determined. Graduate student Moshe Cohen is working with Professor Jan Achenbach to develop such probabilistic models. Achenbach made a major presentation on this work at the International Workshop on Structural Health Monitoring, held at Stanford University in September, 2009.

When considering the health of a structure, two types of cracks must be considered: one is a crack which is undesirable, and the other is a crack which causes the structure to become unsafe or to fail. The probability of the existence of a crack larger than the "undesirable" size but smaller than the "failure" size becomes an important metric for SHM: it is the probability of the existence of a crack which does not pose an immediate hazard but should be repaired before it causes catastrophic failure.

The mechanical properties that influence the growth of a fatigue crack in a material are not well known. However, they can be characterized by probability distributions. Use of these distributions allows more accurate prediction of the probability of the existence of a crack of length greater than the "undesirable" size. Data collected by the ISHM team in India during the summer of 2009, along with a data set from the literature, were processed to yield useful probability distributions of crack growth parameters.

**FIBER OPTIC SENSOR DEVELOPMENT**

Krishnaswamy and his team have also worked to develop various types of optical fiber sensors with high sensitivity, selectivity, and responsivity suitable for structural health monitoring. The technology takes advantage of long-period gratings (LPGs) in photonic crystal fibers (PCFs) with innovative coatings. These devices are attractive for SHM applications due to their small size, immunity from electromagnetic interference, geometric versatility, multiplexing capability, and resistance to corrosive and hazardous environments.

Recent research has shown that LPGs written on standard optical fibers could be used as a powerful sensing platform for structural health monitoring. However, LPGs have some limitations in sensitivity, selectivity, and response time. Krishnaswamy’s team has developed two new coatings for LPGs to mitigate these limitations and enhance the sensitivity of the devices. This promises new developments in sensors for SHM of transportation structures.

**Above: Mode field intensity distributions in a solid-core PCF at wavelength of 1550 nm.**
Funding Sources and Expenditures

**Funding Sources:** $6,398,000

- **Federal Grant:** 42%
- **University:** 50%
- **Other (Research Partner):** 8%

**Total Expenditures:** $6,642,414

- **Research:** 18%
- **Education:** 5%
- **Administration:** 7%
- **Other (Research Partner):** 70%