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# Infraestructure Technology Institute
Northwestern University

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US Secretary of Transportation Ray LaHood meets the press at the 2011 Lipisnski Symposium.
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.

ITI research engineer David Kosnik prepares a steel column for sensor installation.
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 challenging engineering situations 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, 2010 and August 31, 2011, its fourth 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.
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 five-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

**Principal Administrative Staff**

**Joseph L. Schofer**  
Director

**Elizabeth M. Brasher**  
Assistant Director

**Melissa Mattenson**  
Manager of Publications & Communications

**Stacy Hester**  
Accounting Assistant

**ITI Research Engineering Group**

**Daniel Marron**  
Chief Research Engineer

**David Corr**  
Clinical Associate Professor of Structural Engineering

**David Kosnik**  
Research Engineer

**Matthew Kotowsky**  
Research Engineer

**Brian Quezada**  
Research Engineer
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.

Executive Board

In addition to the Director, the governance structure of ITI includes an Executive Board composed of senior Northwestern faculty and administrators. This group provides occasional strategic advice to the Director. Members during Year 4 of SAFETEA-LU were:

Professor Richard Lueptow, Chair
Senior Associate Dean, McCormick School of Engineering and Applied Science and Professor of Mechanical Engineering

Professor Raymond Krizek
Director, Master of Project Management Program, and Pepper Professor Civil and Environmental Engineering

Professor Surendra Shah
Director, Center for Advanced Cement-Based Materials and Walter P. Murphy Professor of Civil and Environmental Engineering

Research Advisory Committee

A Research Advisory Committee made up of senior engineers and researchers not otherwise affiliated with Northwestern University, provides advice to the Director on the selection of research projects. Members of this panel during Year 4 of SAFETEA-LU were:

Dr. Kurt Bauer
Executive Director Emeritus, Southeastern Wisconsin Regional Planning Commission

Ms. Sheila R. Duwadi
Bridge Safety, Reliability, and Security Team Leader, Federal Highway Administration

Mr. Bernard J. Ford
Executive Vice President, McDonough Engineering

Dr. Edwin C. Rossow
Emeritus Professor of Civil and Environmental Engineering, Northwestern University
SUCCESS IN EDUCATION AND TECHNOLOGY TRANSFER
ITI continued to work closely with its deployment partners during the past year, including:

- University of Kentucky Research Foundation
- Kentucky Transportation Cabinet
- Illinois Department of Transportation
- 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
- AASHTO TSP2 Program hosted at Michigan State University
- GeoTDR, Inc.

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

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.
Researchers, Politicians And Industry Professionals Discuss High Speed Rail At Recent Lipinski Symposium

“How fast? How soon? How much?” were key questions debated by participants at the 5th annual William O. Lipinski Symposium on Transportation Policy, which focused on the future of high speed rail (HSR) transportation in America. Named in honor of former U.S. Representative William O. Lipinski, this year’s event brought together supporters and skeptics to consider the challenges and opportunities of HSR.

Secretary of Transportation Ray LaHood began the day with a strong advocacy statement: “Very soon, you’re going to be riding on a train from Chicago to St. Louis that’s going to be a state of the art train on state of the art tracks because of the investments that we have made in high speed rail in Illinois. For whatever critics there are here of high speed rail today, for the people, this is an alternative form of transportation that currently does not exist in Illinois. This will get cars off the road, get people out of congestion and from one point to another in an efficient, cost-effective way. This is what the American people want.”

In a panel discussion moderated by Bruce Dold of the Chicago Tribune, LaHood’s view was shared by Joseph Szabo, U.S. Federal Railroad Administrator; former Minnesota Congressman James Oberstar; and Howard Learner, Executive Director of the Environmental Law and Policy Center. Speaking in opposition were Samuel Skinner, former White House Chief of Staff and U.S. Transportation Secretary; Congressman William Shuster from Pennsylvania; and Robert Poole, Director of Transportation Policy at the Reason Foundation.

Arguing in favor of balanced federal investment in transportation, Mr. Oberstar said, “We have invested very heavily in highways and air travel and not enough in train travel -- $1.4 trillion in highway spending, $485 billion in air travel since 1975, and $38 billion in rail…passenger service needs to be more dependable and faster than the car.”

“How can we afford it?” queried Mr. Learner about public investments in railroads, air and highway services, “this decision is a ‘both/and,’ not an ‘either/or.’ In many metro areas ridership is going up, which tells us that there is need and desire from the public for all services.”

Rep. Shuster argued that, “…there is a place for high speed rail in this country, but not in the way the president has laid out. The northeast corridor is the most congested part of the US – this is where we should focus and the administration has missed
this...we ought to be focusing the dollars where the connections make sense.”

“It’s certainly nice to have travel choices, and we have a number of choices already, but the real question is who is paying for them?” asked Robert Poole. “High speed rail is not a business, all over the world it is a subsidized mode and we only know of two systems that have actually recovered their capital costs. Others have received significant capital subsidies and others have received operating subsidies.”

The panel debate was followed by a discussion of the challenge of forecasting the market demand for high speed rail services. Dr. Steven Polzin, Director of Mobility Policy Research at the University of South Florida’s Center for Urban Transportation Research, said that “The level of understanding we have of travel behavior is really better than its ever been – we’ve been watching and collecting data for a number of years, but clearly uncertainty still remains.”

Polzin noted that travel trends are hard to predict due to competing services, uncertainties in local and regional land use development, connectivity to other modes of transit, and the challenging environment that accompanies the introduction of a service that is new to this country.

Frank Koppelman, professor emeritus of Northwestern University and Kimon Prossaloglu of Cambridge Systematics, Inc., outlined the critical importance, and the challenges of, forecasting ridership and revenue on a new system, particularly one for which that has been no prior U.S. experience on which to basis forecasting models. This makes it difficult to anticipate traveler responses. The problem is compounded by limitations in available, timely intercity passenger travel data. Data gaps in rail and auto travel are particularly important.

Koppelman, who chairs the peer review panel for the travel forecasting component of the California High Speed Rail Program, cited the importance of peer reviews in such contexts to make assumptions and models transparent and the guard againsted biased estimation.

A third panel addressed the other major challenge to implementing HSR in America, finance. William Testa, Vice President of the Economic Research Department at the Federal Reserve Bank of Chicago, focusing on the Chicago region, spoke about the potential economic development benefits from HSR. “Benefits in economic development hold great promise,” he said, “but they are quite uncertain and would likely require public subsidy.” He then posed the
question, “What is the public’s appetite for risk (and possible failure)?”

Thomas Lanctot, Principal at William Blair & Company, described the need for and the value of public-private partnerships. “Private sector engagement is going to be of critical importance if high speed rail is going to succeed. The traditional methods of infrastructure finance, either federal grants or borrowing money, are just not going to be enough to make this thing go.”

Lanctot reviewed the recently-released business plan for the California HSR and observed that, “While the California High Speed Rail Business Plan reflects improved and more conservative analysis, many assumptions remain optimistic and speculative.”

Raymond Ellis, Managing Director of AECOM, Inc. expressed doubt that “…there are any US true high speed rail projects which will throw off sufficient cash from operations to 100% finance their capital costs.” He also saw it as unlikely that any (private) concessionaires would accept the ridership and revenue risk associated with monetizing (franchising) a HSR project. Furthermore, he felt that funding a true HSR program on their own is beyond the capacity of any of the 50 states.

If HSR rail is to proceed, Dr. Ellis felt these requirements have to be met:

HSR programs should be implemented incrementally and the increments should have independent utility. The Federal government must be a reliable partner to the states, Amtrak, and the private sector in implementing HSR programs. This may include grants as well as credit support through the RRIF and TIFIA program. States must also be meaningful partners with the Federal government. States as well as multi state entities need the authority to enter into public private partnerships, through which availability payments would be the mechanism for supporting implementation and operation of HSR programs. Joint development programs should be pursued at stations – with a particular emphasis on funding/financing those stations and related facilities.

In the closing panel, earlier speakers and panel participants joined in a final question and answer session, moderated by ITI Director Joseph Schofer. The panel synthesized the knowledge shared throughout the day and shared their conclusions.

One participant asked a particularly interesting question: “A lot of the discussion today recapitulates the
discussions held in the 50’s about how to fund the Interstate highway system...There was never any prediction that the highway system would be a business – it would be a public transportation system. Is there any reason we can't look at passenger rail the same way?"

William Lipinski responded, “Eisenhower was the main proponent of the Interstate highway system, and he pushed for it to move forward because he wanted the highway system for military purposes. This is an element that does not really exist today with high speed rail.”

Mr. Lipinski closed the forum with this statement: “We have heard many interesting facts today, and I have big doubts about true high speed rail in this country... I don't see any possibility of true high speed rail coming to pass. We don't have any money to finance an aviation bill or the highway trust fund right now, and I don't see how we can take on true high speed rail at this time. We can, however, upgrade our existing railways.”

During luncheon, Former Rep. Lipinski presented the David F. Schulz Award for Outstanding Public Service in Transportation and Infrastructure to U.S. Senator Richard J. Durbin, for his contributions to securing resources for major transportation investments in Illinois.
ITI Supports The National Bridge Management, Inspection, And Preservation Conference

The ITI Research Engineering Group supported the Federal Highway Administration (FHWA) 2011 National Bridge Management, Inspection, and Preservation Conference by recording and webcasting breakout sessions on bridge inspection. Building upon the success of the 2007 FHWA National Bridge Preservation Workshop – also recorded and webcast by ITI – the 2011 conference featured expanded management, inspection, and preservation tracks in addition to plenary technical sessions.

The 2011 conference, held November 1-2 in St. Louis and subtitled “Managing the Nation’s Bridges: Beyond the Short Term”, attracted nearly twice the number of attendees as the 2007 workshop. Technical presentations illustrated a wide array of strategies and methods to ensure the safety and performance of the nation’s highway bridges. In the plenary sessions, speakers emphasized that bridge preservation is the most sustainable strategy to ensure the long-term serviceability of the nation’s highway bridges and discussed how performance metrics can be used to move away from the “worst-first” practice of addressing only bridges in poor condition and instead adopting preservation strategies to keep good bridges in good condition.

Technical sessions in the bridge inspection track recorded by the ITI REG included an introduction to bridge inspections using the new AASHTO element-level inspection manual, quality control and quality assurance of bridge inspection data, and discussion of the future of the FHWA National Bridge Inventory. Other talks in the inspection track made direct ties to the bridge preservation theme: for example, using inspection data to identify preservation needs, and development of procedures beyond inspection reports for timely identification and corrective action for specific maintenance needs before they reach critical levels.

Conference attendees gave the event high marks and called for another conference in two years. In the meantime, they asked for continued promotion of bridge preservation, increased research into effective preservation strategies and they called for increased sharing of best practices among the states.
ITI was well represented at the 91st Annual Meeting of the Transportation Research Board in January of 2012. Research Engineer David Kosnik co-hosted a half day workshop titled “Practical Health Monitoring for Transportation Structures.” The workshop focused on practical health-monitoring technologies for bridges and ancillary highway structures, providing state-of-the-practice information for bridge owners regarding implementable health-monitoring strategies that can be applied to ensure safety and effectively manage aging transportation structures. Topics included instrumentation, systems, software durability, and successful case studies of technology applications.

ITI Director Joseph Schofer received the Roy W. Crum Distinguished Service Award from TRB in recognition of his outstanding achievement in transportation research.
The Midwest Bridge Working Group (MBWG), a technology transfer forum sponsored by ITI and operated by the University of Kentucky, held its spring meeting in June, 2011. The meeting was hosted by the Missouri Department of Transportation at the Crowne Plaza Hotel in downtown St. Louis, Missouri.

This one-and-a-half-day meeting attracted 110 attendees: 30 state and local department of transportation personnel representing twelve states, four representatives of the Federal Highway Administration, 10 researchers representing three universities, and 66 representing industry, vendors, and consultants. In the two months after the meeting, 14 people viewed it on the MBWG’s Web site: www.midwest-bridge.org.

A full day of 16 presentations on inspection, maintenance, safety, construction, and rehabilitation topics, made up the first full day of the meeting. Presentation topics included innovative technology for monitoring the condition and performances of bridges, new products to aid in bridge inspection and construction, proposals of new best practices for bridge maintenance and inspection, experiences with fire damage to bridges, and even US efforts to construct bridges in Afghanistan.

68 conference participants spent a half-day taking field trips to the 137-year-old Eads Bridge and the not-yet-completed Interstate 70 Bridge, both of which connect Illinois to Missouri across the Mississippi River at St. Louis. Field trip participants first heard presentations by Missouri DOT engineers, who reviewed the extensive I-70 bridge construction project, and engineers from Transystems, who reviewed the recently completed rehabilitation project on the Eads Bridge. Participants then boarded busses to tour the two bridges.
ITI Researchers work with Metro North engineers to install equipment.

SUCCESS IN RESEARCH
No Data? Big Problem.

by Mortimer Downey, Joseph Schofer, and Johanna Zmud

Joseph Schofer is a professor at Northwestern University. Johanna Zmud is director of the transportation, space and technology program at the RAND Corporation. Mortimer Downey served as Deputy Secretary of Transportation during the Clinton administration.

Bridges are falling down, or being built to nowhere. Highways are getting more congested, airports more crowded, and transit systems struggle to cover costs and keep up with growing demand. How can we address the problems of passenger and freight mobility with limited resources?

Saving money at the expense of informed transportation decisions is pennywise and pound foolish.

In hard economic times, America’s leaders are looking for every opportunity to spend less and get more bang for the taxpayer’s buck. It’s a time for smarter decisions – especially transportation investment and policy choices based on independent and objective information. We must understand where and what the needs are, what works and doesn’t, and where the payoffs are greatest. That takes data – and good data are hard to find.

Yet in passing the long-overdue two-year, $109 billion highway finance reauthorization bill, the Senate dropped a modest provision to assure timely travel data needed to make the smart choices that will keep people and freight moving safely and efficiently.

The federal government allocates about $50 billion each year from motor fuel tax dollars to assure that we have the passenger and freight mobility to keep society productive and the economy ticking. State and local governments spend even more for the same purposes. Making the best use of such funds – for highways, transit systems, passenger rail services, airports, ports — is especially important when costs are outstripping tax revenues and needs are continuing to grow.

Smarter transportation decisions require comprehensive, accurate and timely data about infrastructure condition, travel time reliability, crashes and their causes. These data can inform decision makers about what really works – how best to relieve congestion and improve supply-chain connectivity to make freight transportation – and hence the U.S. economy – more competitive. Good data can enable people and businesses to use the transportation system more efficiently and ensure universal mobility.

The National Travel Data Program, defined in a study conducted by the Transportation Research Board (TRB), part of the National Research Council, would have directed the Secretary of Transportation “…to collect essential national passenger and freight travel data to guide transportation operations, policy, and investment decisions for Federal, State, and local governments and the private sector.” This program would have integrated, enhanced, and sustained existing federal transportation data programs to serve as an anchor for efforts now conducted by state and local governments and the private sector. The result would be a powerful decision-support infrastructure to preserve and improve America’s transportation system and keep the country competitive in the years to come.

Critics, of course, figure they already know where and how to spend the money, so information-based decision making is superfluous. But there are all too many examples of transportation investments – or non-investments – that have not made good use of America’s limited resources. Bridges are load-restricted, closed, or falling down from lack of maintenance; transit systems endure unending cycles of maintenance interruptions; congestion wastes our time and impedes logistics. We have bridges to nowhere and other misplaced investments: good data can embarrass bad projects as well as promote good ones. There is plenty that decision makers can learn from good data thoughtfully used.

Some say that the private sector will collect all the data we need. True, entrepreneurs are far down the road collecting and disseminating real-time congestion data useful to drivers and decision makers. But the private sector isn’t interested in monitoring public infrastructure or providing data to support transportation policies that guide economic development or equity. The data problem we face will be solved only through effective public-private collaborations – just the sort the National Transportation Data Program would support.

The Senate may have passed up the National Travel Data Program to save money. But saving money at the expense of informed transportation decisions is pennywise and pound foolish. The National Travel Data Program could help us pick smart solutions to mobility problems at a cost of about nine cents a
year for the average driver. Not a bad investment to make transportation decisions better and smarter.

This column was also signed by fellow members of the Transportation Research Board Policy Committee on Strategies for Improved Passenger and Freight Travel Data: Joseph G.B. Bryan; Anne Canby, president of the Surface Transportation Policy Project; Anand Desai, professor at The Ohio State University; Lance R. Grenzeback, senior vice president of Cambridge Systematics Inc.; Hermann Habermann; Timothy A. Henkel; James M. Lepkowski, Institute for Social Research, University of Michigan; Daniel Murray, vice president of the American Transportation Research Institute (ATRI); Alan Pisarksi, transportation consultant; and Steven Polzin, University of South Florida. The views expressed are the authors’ and not necessarily those of TRB or the National Research Council.
In early 2012, the ITI REG and several civil engineering students took part in a collaborative research project with Metro North Railroad (MNR) near New York City. MNR, the second-largest commuter railroad in the nation, carries over 270,000 passengers every weekday from five surrounding counties and Connecticut to Grand Central Terminal in Manhattan. Operating six rail lines over 765 track-miles with 121 stations and over a thousand rail cars, the amount of critical infrastructure for which MNR is responsible is staggering.\(^1\)

In addition to the tracks, embankments, stations, tunnels, cars, communication systems, power systems, and railroad bridges that one might expect such a large railroad operator to maintain, MNR is also responsible for several bridges that carry local automobile and pedestrian traffic over its tracks. One such bridge, the one carrying Fulton Avenue over the MNR New Haven line in Mount Vernon, New York, is over a century old and requires special attention from MNR forces to ensure its safe operation.

The Fulton Avenue Bridge, a steel eye-bar through-truss structure with an asphalt-overlaid wooden deck, carries two lanes of traffic, two sidewalks, and several local utility lines over four active tracks and a power substation. The bridge also provides access to two staircases to the platforms of the Mount Vernon East rail station. Routine inspections of the bridge by MNR’s engineers have resulted in several repairs and improvements, including re-decking and installation of steel cables to bolster critical tension members supporting the deck, that have allowed the bridge to continue operating for the past hundred-plus years.

To supplement its inspection and engineering analysis activities and to gain more insight into the performance of the retrofits, MNR enlisted the ITI REG to design and install an autonomous remote
structural health monitoring system on the bridge. The system, comprising a high-speed data logger, nineteen strain gages, five accelerometers, two thermocouples, an ambient environmental condition sensor, two high-definition cameras, an encrypted cellular uplink, and support electronics, monitors and records the condition of the bridge at all times, automatically publishing this data to a password-protected Web every night. Should a large vehicle cross the bridge (in violation of the posted three-ton load restriction), the system will automatically record high-frequency data from all of the sensors along with digital images of the vehicle as it crosses. It will then alert MNR engineers so they can evaluate the structural effect of the illegal crossing.

The system was installed during Northwestern’s spring break in March by ITI REG staff members and two undergraduate students who traded a more traditional collegiate spring break experience for a week of working long hours on the railroad – sometimes in the very early morning, the only time some portions of the tracks could be taken out of service to allow for access to certain bridge components. Using the automated Web display, MNR engineers will be able to track any changes in performance of the bridge between inspections, providing more information to guide the choice between repairing and replacing the structure.

1. MNR statistics available at http://www.mta.info/mta/network.htm
Advances In Bridge Monitoring Against Scour

Principal Investigator: Daniel Marron

Scour, the process by which moving water removes soil and rock from the bed of a waterway around the foundations for bridge piers and abutments, is by far the leading cause of bridge failures in the United States. Because it is a serious and widespread problem, much research has been devoted to methodologies and devices for monitoring scour along bridge foundations and abutments, with varied degrees of success.

In the late 1990s and early 2000s, the Northwestern University Infrastructure Technology Institute (NU-ITI) developed a method for measuring structural response to scour based upon tilt measurements. Rather than attempt to measure the scour holes themselves, the NU-ITI system uses a network of electronic tilt meters to indirectly measure scour by measuring the long-term tilt of the bridge piers. During high water, the tilt sensors are read at least once an hour — typically more often — and the data are examined by state highway engineers at regular intervals. Before electronic monitoring, an engineer was typically stationed at the bridge 24 hours a day to watch for signs of distress. Should distress occur — for example, a noticeable bend in the bridge railing — the bridge would be closed immediately. With electronic monitoring, the same level of diligence in observation can be attained without personnel on site. The tilt-based scour measurement technique was subsequently adopted by the California Department of Transportation (Caltrans) for scour-critical bridges statewide. Currently, at least six bridges on the California highway system are monitored in this way; several others were monitored for years before the bridges were replaced as programmed.
One major barrier to wider application of tilt-based scour monitoring is the cost of wiring power and communication links to sensor nodes on the bridge. Wireless sensor networks provide an attractive alternative since they eliminate the need to run power and communication cables; this is especially important on long spans that may exceed one-quarter mile in length or on spans where access is difficult. In response, NU-ITI is developing and evaluating two wireless sensor network systems for tilt-based scour monitoring of highway bridges. Following laboratory evaluation, both systems were deployed for field trials on a bridge in California in September 2011.

The first system is a commercial off-the-shelf wireless sensor network paired with the same tilt sensors used in previous bridge monitoring projects. The second system was developed in-house from wireless components based on the ZigBee standard. The wireless data acquisition devices are paired with a small, low-power electrolytic tilt sensor. Both systems are scalable to many wireless nodes. Repeater nodes may be deployed as necessary to extend the range of the system.

Both systems send data to a base station located on a nearby utility pole. The base station aggregates the data from the two wireless sensor systems and transmits it to NU-ITI over a cellular modem. From there, the data are presented on a password-protected Web site for interpretation.

ITI engineers returned to the field site in summer 2012 to make adjustments to the systems according to field performance lessons learned thus far. It is expected that these field trials will lead to development of a practical low-cost wireless sensor network for scour that could be deployed on bridges nationwide.
Weathering of A710 Grade B Steel in Lake Villa Bridge, IL

Principal Investigators:
Semyon Vaynman, Morris E. Fine, Y-W. Chung

“Weathering steels” are steels that exhibit enhanced resistance to atmospheric corrosion due to the formation of a protective oxide/hydroxide layer on the steel surface exposed to the ambient atmosphere. These steels are used in buildings, bridges, and other structures and can provide significant cost savings and environmental benefits when used unpainted. For example, for bridge construction without painting, one can realize an initial cost saving of more than 10 percent, with the additional benefit of easier installation and handling during assembly. The life cycle cost savings are more than 30 percent because weathering steels require less maintenance and are more durable than common construction steels. Since painting is not required, there are no volatile organic compounds (VOC’s) from paints to deal with, and there is no need for the removal or disposal of contaminated blast debris over the life span of the structure. Because of these cost and environmental benefits, the use of weathering steels specifically for the construction of highway bridges has increased over the years. However, the available weathering steels (A709 HPS70W and A588) require a very long time to form a protective rust layer and in many geographic locations the rust on these steels looks very uninform. A710B steel was developed at Northwestern University. This is a strong, very tough at low temperatures, easily weldable steel that is highly weatherable. In accelerated tests performed at Bethlehem Steel Company (now ArcelorMittal) A710B significantly outperformed the best weathering steels presently used for bridge construction (A588 and A709 HPS70W).

A710B steel was used unpainted to construct a new bridge in Lake Villa, IL in 2006. The monitoring and analysis of the bridge over the last six years revealed that the steel weathers very uniformly on vertical and horizontal surfaces of the girders. Over the last few years the color progressively changed from bright red-brown when the bridge was assembled (Figure A) to dark black-brown now (Figure B). The rust is compact, very hard and well adhered to the steel surface giving the steel good protection against further corrosion. X-ray diffraction analysis of the rust shows changes of the rust from mostly amorphous state when the bridge was just erected to a fine-grained crystalline state now. This progression is typically observed in advanced weathering steels during 10-15 years after erection. A709B steel achieved this look in just few years.
Inexpensive Wireless Structural Health Monitoring System for Tracking Expansion and Contraction of Cracks

Adobe house used for research project in Albuquerque, New Mexico.

**Principal Investigator:**
Charles Dowding

**Autonomous Crack Monitoring (ACM) Goes Southwestern**

In conjunction with the New Mexico Department of Transportation (NMDOT) and Almone-Martin Associates (AMA), ITI is assisting with the analysis of the response of adobe and historic structures to nearby construction activities. Often it is necessary to repair or build adjacent to existing atypical structures such as those built of adobe or structures of unusual historical significance. In these circumstances it is necessary to establish standoff distances for vibration producing activities such as vibratory roller compaction, pile driving, and/or blasting. ACM has been helpful in providing information concerning the necessary level of conservatism when concerns are raised about vibratory sensitivity of these structures. ACM provides a comparison of crack response to vibratory and climatological events, as a means of determining the comparative sensitivity. In this study as in many others ACM is being enhanced with measurements of structural response in order to calculate the general strain level produced by vibratory activities. To date two structures have been monitored, a historic building on the Campus of New Mexico State University and the adobe structure in Albuquerque shown in the photograph. Plans are being made to instrument a church in a native pueblo following pipeline construction and subsequent.

The adobe Albuquerque structure was found to have responded less to the vibratory rolling than to typical daily, solar induced heating and cooling. This was true for vibratory roller induced ground motions that exceeded 0.5 inches per second. Other structures that have been instrumented with ACM and structural response instruments. This is the second structure whose responses to high vibratory roller excitation were significantly smaller than those to climatological factors. The first was a wood frame, ranch style house in Las Vegas.
ITI Assesses Response of Urban Structures to High Frequency Blast Vibrations

Close in blasting for multi-billion dollar rapid transit transportation projects in dense, urban areas require unusual methods to control vibratory excitation because of the unusual geometry of the blasting, unusually high excitation frequencies, and multiple story, atypical building shapes. Structures of concern may be located on rock directly above or directly adjacent to the blast and as such they typically experience excitation frequencies that can be 5 to 10 times higher than typical blast induced ground motions. These blasts often involve small charge weights per hole and thus produce low energy but high particle velocities. Because of these considerations, additional methods of monitoring/measuring the excitation motions as well as analyzing the responses are required.

ITI is developing new methods of modeling the response of the atypically shaped buildings. These new methods involve use of three dimensional models like that in the illustration. Measurements were obtained of building responses and in-ground (rock) excitation motions generated by immediately adjacent blasting. The three dimensional model can be excited at multiple locations along the base to replicate a traveling, high frequency wave of excitation. The model response can then be compared to the measured response to determine the best modeling procedures.

So far, the measurements and modeling have shown that the 4 to 5 story urban buildings amplify the excitation motions less than typical 1 or 2 story residential structures. This non- or reduced amplification is a result of the mismatch of the excitation and natural building response frequencies in this case. In addition the models have been successful in calculating responses that are equal to those that were measured at the top of the buildings.
Nanomaterial-based sensing devices

Principal Investigator: Sridhar Krishnaswamy

Humidity sensors are in large demand in industrial, environmental, and structural monitoring fields. One of the most frequent causes of structural and civil infrastructure failure is corrosion. A large number of structures degrade and fail due to inefficient humidity monitoring. To prevent catastrophic failures of large structures due to corrosion, it is imperative to monitor environmental conditions such as humidity accurately. In recent years, a lot of research has been focused on using carbon-based nanomaterials such as graphene and carbon nanotubes to fabricate sensors, which have high sensitivity and selectivity.

Prof. Sridhar Krishnaswamy and his graduate student Gautam Naik at the Center for Quality Engineering have demonstrated using nanomaterials such as graphene and graphene oxide for humidity sensing. Graphene, a two-dimensional monolayer of carbon atoms, has been demonstrated as a promising sensing material, because of its unique and outstanding mechanical, thermal, and electrical, properties. The group uses the chemical method for synthesis of graphene oxide, since it is the cheapest and the best possible method for large scale production. Humidity sensing devices, such as those shown in the figure, are fabricated by vacuum filtration of a graphene oxide suspension in water.

The humidity sensors work on the principle of change in resistance on exposure to humidity. As seen in the figure, the sensing device is enclosed in a sealed chamber with a mini-humidifier and a commercial humidity monitor. On exposure to humidity, the conductivity of the device increases due to water molecules getting adsorbed on the surface of the device. Since this change in conductivity is different for varying humidity levels, it can be used to measure the humidity level in the chamber. Experiments were conducted for various humidity levels, and interesting results were observed.

Surprisingly, the sensing devices showed different behavior at low (<50%) and high (>50%) humidity levels. Numerous cyclic experiments were conducted to confirm this, and a humidity sensing mechanism was proposed. The fabricated sensors had a fast response time, 10 times faster than the commercial humidity monitor. Thus, a promising application of using graphene oxide as large-area room-temperature humidity sensors was experimentally demonstrated. Detailed experimental results were presented at the ASME 2012 International Mechanical Engineering Congress, and the paper is also under review for publication in a journal.
Design and application of high-volume fly ash self-consolidating concrete with the incorporation of nanoparticles

Principal Investigator: David Corr

The overall aim of the work was to improve the constructability and sustainability of concrete by manipulating its fresh-state and mechanical performance. The approach was to alter its material design to incorporate high replacement of cement with fly ash. Fly ash is a coal combustion byproduct, so essentially waste. Therefore its use in concrete can reduce its carbon footprint by reducing cement content, as well as help to alleviate the storage of fly ash slurry, both of which make the infrastructural material more environmentally friendly. However, fly ash poses issues that negatively impact constructability. It contributes to the high formwork pressure exhibited by self-consolidating concrete (SCC, a highly flowable concrete), which raises cost by necessitating increased formwork. Also, fly ash severely retards hydration and early-age strength gain, which slows construction. The application of nanotechnology to enhance the properties of cement-based materials is a growing area in cement and concrete research. In this work, the use of nanoparticles to offset the negative effects of fly ash and improve the material’s constructability was investigated.

Previous studies have demonstrated the potential of nano-sized attapulgite clays in reducing the lateral pressure of SCC exerted on formwork during casting. The formwork pressure response of SCC hinges on the material’s rheological properties, specifically cohesion strength and thixotropic structural rebuilding. The influence of the attapulgite clays on these two properties were evaluated using novel rheological methods. It was demonstrated that the clays significantly increase cohesion and accelerate thixotropic structural recovery of cementitious systems. The results also provided insight into how the mineral admixture can be incorporated into the mix design of SCC to control its formwork pressure response.

The potential of CaCO$_3$ nanoparticles in offsetting the negative effects of fly ash on the early-age, hardened properties of cementitious systems was investigated. The focus was on obtaining a well-dispersed, stable CaCO$_3$ aqueous suspension to enhance the effect of the nanoparticle, as well as limit the addition level necessary to reduce cost. Through proper processing techniques, CaCO$_3$ nanoparticles at additions as low as 1% by mass of binder led to improvements in the early-age mechanical properties of fly ash-cement systems.
Condition Monitoring of Urban Infrastructure: Effects of Ground Movements on Adjacent Structures

Principal investigator: Richard Finno

The proximity of important infrastructure to the excavation support system imposes strict movement limits associated with the construction of the deep basement. When evaluating damage potential in buildings affected by ground movements, the main two sources of uncertainties in the analysis are the structural evaluation of the affected building and the movement prediction. A key issue in the structural evaluation is to define the level of ground movements that will prevent or minimize damage to the adjacent structures. This depends on the type of building that is being impacted by the operations, resulting in a wide range of possible allowable movements. In many projects, the allowable movements are set arbitrarily, and without consideration of the details of either the structures to be protected or the ground conditions.

With the help of ITI research engineers and our research partner, Hayward Baker, Inc., we monitored the ground movements caused by the excavation for the William Jones High School in Chicago and evaluated the effects of these deformations on two adjacent structures founded on shallow foundations. To provide the detailed data needed to define the deformations where damage was initiated, we installed an automated monitoring system consisting of a robotic total station to measure deformation prisms mounted on the two buildings on the east side of the excavation and tilt meters on the exterior walls the buildings to measure tilt of the walls at several footing locations. We also obtained lateral soil deformations throughout the soil profile behind the sheet pile wall from inclinometers. We were able to relate the ground movements and building deformations to construction activities at the site and were able to identify the conditions whereupon minor cracks were initiated on the buildings. The damage was cosmetic and occurred only in the architectural details and manifested itself at a building distortion of 1/1000. This observation can be used to help set rational criteria for allowable movements for excavations in urban areas. This work has been a focus of the doctoral thesis of Kristi Kern.
Remote sensing technologies have been widely applied to provide reliable information on real-time performance of transportation infrastructures. Agencies that have adopted these technologies need rigorous and efficient methods to process their nascent output to a form that is useful to address management needs. As the scope of monitoring grows, it is pivotal to synthesize data from multiple simultaneous measurement streams with various physical properties into succinct and reliable results that maximize decision-making utilities. Professor Durango-Cohen and his graduate students Yikai Chen and Weizeng Zhang are developing a data processing framework that analyzes and synthesizes important information on infrastructure performances of the US Highway 2 bridge in Hurley, Wisconsin.

The Hurley bridge is subject to heavy loads from daily truck traffic, many of which are believed to be overweight logging trucks travelling from Michigan into Wisconsin. The Wisconsin Department of Transportation is concerned about that the observed traffic will cause premature degradation of the structure due to fatigue and overstress conditions. The ITI Research Engineering Group have collaborated with WisDOT and installed an array of displacement transducers, strain gauges, thermal couples and a weigh-in-motion system on the bridge to monitor its real-time performances. The data processing framework is developed to help manage the bridge by:

1. Providing real-time, reliable alerts when potential damage or risk of structural change in the facilities is detected, and
2. Determining the nature and physical meanings of these detected changes. In particular, by adopting multivariate statistical techniques, the framework lends its capability to monitoring multiple measurements on the bridge simultaneously so as to:
   - Reduce the complexity of data to enable efficient computation, illustration and management
   - Assure reliable structural inferences by capturing inherent correlations among facility properties and rigorously controlling the overall false alarm rate.

The data processing system has already yielded several points of information. As an example, over the first week of February 2011, the system detected a transitory outlier on the bridge. A deeper analysis identified two major components that drove the outlier: 1) a northbound shift in the bearing and 2) a break of structural consistency between a symmetric pair of strains on the girder which supports the right lane of traffic. This is believed to be caused by overweight trucks. Such a top-down approach not only improves the overall processing efficiency, but also reveals rigorous results that are not detectable through disaggregated monitoring processes.

While unusual in occurrence, none of the detected changes represent an immediate threat to the safety or serviceability of the bridge. Instead, they demonstrate the ability of the data processing system to efficiently and reliably detect out-of-the ordinary events as well as subtle long-term changes. Future work will enable similar data processing systems to provide alerts of structural performance changes in near-real time.
Nondestructive Evaluation of ASR Damage in Concrete

Principal Investigator: Jianmin Qu

Alkali-silica reaction (ASR) in concrete is a deleterious chemical reaction between the alkalis in pore solution of cement paste and the reactive silica of concrete structure aggregates. The main reaction product of this process is ASR gel, located mainly in the interface zone between the aggregate and surrounding cement paste. As ASR damage progresses, more gel is produced, which induces significant interface pressure, causing cracking, in concrete. The cracking produced by ASR can significantly undermine the durability of concrete structures and may result in reduced service life. Developing methodologies to nondestructively assess the degree of ASR damage, and building models to predict the structure response of damaged structures fits our National Strategy for Surface Transportation Research.

The most common way to evaluate ASR damage is to measure the volumetric change (expansion) of standard mortar samples. However, such change occurs primarily during microcrack initiation and crack growth, i.e., the later stages of ASR damage development. Therefore, such method is not effective in detecting early ASR damage. More importantly, it cannot be used to actual structures in service. An alternative technique is using nonlinear ultrasonic methods to detect ASR damage. Prior to this year, our experimental data have already demonstrated that damage induced by Alkali-silica reaction in concrete, even in its very early stage, can cause changes in acoustic nonlinearity parameter. However, there is currently no model that explains the relationship between the acoustic nonlinearity parameter and ASR damage.

This year we have developed a micromechanics-based chemo-mechanical model that relates the acoustic nonlinearity parameter to ASR damage. The mechanical part is developed based on a modified version of the generalized self-consistent theory. The chemical part of the model accounts for two opposing diffusion processes. One is the diffusion of alkali ions in the pore solution into aggregates, and the other is the permeation of ASR gel from the aggregate surface into the surrounding porous cement matrix. Furthermore, a facture model is used to simulate crack initiation and growth, so that the crack density and total expansion can be obtained. Finally, the acoustic nonlinearity parameter is determined as a function of exposure time by accounting for the gel pressure and the crack density.

The results of numerical prediction and experimental measurements are in good agreement. Although more experiments on aggregates with different activities are needed to further validate this model, the present work has shown that the proposed model has a very good potential to quantitatively predict the acoustic nonlinearity variation during ASR damage. The combination of numerical prediction and experimental measurements can monitor the structure health and may help predict the service life of concrete structures.
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