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ABOUT THE INSTITUTE
About the Institute

The physical infrastructure of surface transportation (highways, bridges, pavements, signs and signals, intermodal facilities, etc.), comprises 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. But 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 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, 2007 and August 31, 2008, its first 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.
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.
Center Staff

ITI is an interdepartmental center within Northwestern’s McCormick School of Engineering and Applied Science, and as such, its Director, Dr. Joseph L. Schofer, was appointed by and reports to the Dean of the McCormick School.

Director Schofer is responsible for the day-to-day management and administration of the activities of the Institute, including but not limited to developing, implementing and monitoring the Institute’s annual budget, interacting with federal officials responsible for administering the Institute’s grant funding, overseeing the Institute’s program of research and development projects, managing the technology transfer process, and establishing and leading the public information program for the Institute. He is also actively engaged in outreach to and through professional organizations, civic interest groups, and local and national public agencies.

In addition to the Director, the Institute employs three administrative staff members to support its operational activities: Assistant Director Elizabeth Brasher; Business Manager Colleen Hull, and Creative Coordinator Melissa Mattenson. The administrative staff is pictured in the top row of Figure 1.

The Institute also employs a four-person research team with experience in non-destructive evaluation and remote monitoring of transportation infrastructure. The Research Engineering Group (REG), pictured in the bottom row of Figure 1, includes Chief Research Engineer Daniel Marron and three Research Engineers: Daniel Hogan, David Kosnik, and Mathew Kotowsky. Project-related research funding supports all faculty, research staff, and graduate students engaged in Institute-supported research projects.

The ITI Research Engineering Group

REG professionals possess exceptional skills and experience in the 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:

- In partnership with infrastructure owners and operators across the nation, conduct the REG’s own research on development and deployment of innovative instrumentation and monitoring techniques to solve real and current infrastructure problems
- Support ITI-funded researchers and their students with instrumentation, communications, and deployment expertise
- Support other ITI technical program functions as necessary, including teaching, conference communications, and outreach

The REG provides core support services across the ITI program, ensuring that state-of-the-art monitoring and communication technologies are available for and deployed in ITI research applications.

Building the Research Program & Community

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 comprised of senior Northwestern faculty and administrators. This group provides occasional strategic advice to the Director. Members during Year 1 were:

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

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

**Professor Surendra P. 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 1 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

**Professor Donn Hancher**
Department of Civil Engineering, University of Kentucky
SUCCESS IN EDUCATION
Education

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.

Figure 2: Infrastructure Facilities and Systems class field trip to the $15 billion O'Hare Airport Modernization Program site
Support for the MPM Program

A key programmatic element to achieve ITI’s educational objective is support for the multi-disciplinary Transportation Infrastructure Management (TIM) specialization in the Master of Project Management (MPM) program offered through Northwestern University’s Department of Civil and Environmental Engineering. The MPM program prepares professionals for careers in civil engineering project management. The TIM component has evolved as an extension of the more generalized Infrastructure Management specialization within the MPM program. ITI-affiliated faculty frequently serve on M.S. committees to review the projects required of all MPM students.

ITI’s investment in the MPM program also benefits undergraduate and graduate students in the Department of Civil and Environmental Engineering as well as graduate students in other engineering departments, the Transportation Center, the Kellogg Graduate School of Management, and the Medill School of Journalism, who take some of the courses and attend seminars and field trips sponsored by the MPM program.

Infrastructure Courses

ITI created and supports the Infrastructure Facilities and Systems course in the Department of Civil and Environmental Engineering, taught by ITI Director Professor Joseph L. Schofer, to introduce engineers and other students to the functions, importance, and complexity of civil infrastructure systems, with an emphasis on surface transportation systems. This course now serves as a senior capstone civil engineering design course in the Department, providing the context in which senior students apply and demonstrate the full spectrum of analysis and design skills acquired through their undergraduate engineering studies.

This unique course mixes classroom and team working sessions with weekly field trips to major infrastructure facilities around Chicago, some of which are shown in Figures 2-5. Students get a first hand understanding of the construction and operation of large infrastructure facilities as they meet their site hosts who are usually project managers or designers who provide technical and managerial insights as well as conveying excitement about their field well beyond what can be experienced in the classroom.

Web site: mpm.northwestern.edu
The field trips in this course in 2008 included:

- O’Hare Airport Modernization Program – a $15 billion project
- Bovis Lend Lease construction management firm and tour of Trump Tower construction site
- Illinois State Toll Highway Authority I-294 expansion – precast concrete bridge construction, slip-form paving operations
- City of Evanston potable water treatment plant
- Belt Railroad of Chicago Clearing classification and intermodal yard
- Testa Produce Warehouse – designing a green building on a brownfield site

In 2008, the fourteen students in this course worked in two teams to design a utility building for a local park district on top of a capped landfill; the site is shown in Figure 5. This project presented a host of design challenges, including roadway access for large trucks, traffic management, structural and aesthetic design, foundation challenges of landfill construction, and capture and utilization of methane gas emissions from the landfill. Throughout the project, students applied the variety of engineering, project development, and management skills they learned at Northwestern.

Some non-engineers were again included in the class to bring a diversity of perspectives to an infrastructure engineering project and to demonstrate the value of interdisciplinary collaboration. Student projects were presented to and well-received by professional engineers and infrastructure specialists who serve advisory functions for ITI and the Department of Civil and Environmental Engineering.

During the past year ITI continued to invest in the professional components of civil engineering education to prepare people for careers in transportation and other infrastructure fields. A key element of this program is the computer-aided drafting (CAD) course based on AutoCAD software. Utilizing the newly established CAD laboratory, shown in Figure 6, which is furnished with 21 workstations donated by General Motors and Autodesk design software furnished by ITI, Research Engineer Daniel Hogan and Adjunct Professor Wayne Bielski once again offered a two-quarter course sequence in engineering graphics and computer aided design to 20 undergraduate engineering students. Responding to student feedback after last year’s course, a new feature of this year’s course was more in-depth education in the fundamentals of engineering graphics.
K-12 Outreach

As a part of its effort to restructure K-12 educational outreach, the Institute began a collaboration with a Northwestern engineering alumnus who works with Chicago Cares, a city-wide volunteer agency, to develop an outreach enrichment program for 5th and 6th grade students at an inner city public school. ITI would organize and support field trips to infrastructure engineering sites for the children and provide advice to Chicago Cares volunteers.

ITI has also begun to forge a new partnership with Northwestern’s chapter of the National Society of Black Engineers (NSBE) to assist this group in establishing and supporting a junior NSBE chapter at Evanston Township High School. ITI will provide matched financial support for field trips, lecturers, and mentoring. Together these will be cost-effective ways to attract and inform minority high school students about public infrastructure systems, problems, and career opportunities.
Student Awards

ITI-affiliated students at Northwestern University have recently won a variety of prestigious awards during SAFETEA-LU Year 1. These undergraduate and graduate students work closely with ITI-affiliated faculty in their coursework, research, and extracurricular projects.

Zitao Zhang, a second-year Civil Engineering graduate student in transportation, won the American Society of Civil Engineers (ASCE) Illinois Section Transportation Engineering Scholarship. Mr. Zhang, pictured in Figure 9, is a graduate of Tsinghua University in Beijing and was the first undergraduate president of the ASCE Student Chapter in mainland China. In the summer of 2008, Mr. Zhang served as an intern with Northwest Airlines. He works with ITI researcher Professor Pablo Durango-Cohen.

Mark Ahasic was selected for an Eno Leadership Conference Fellowship Award. The Eno Leadership Conference selects a group of top transportation graduate students to come to Washington, D.C. to learn about the United States’ transportation policy process by meeting with key government, association, and industry leaders. Mr. Ahasic, a former JetBlue employee, is a student in Northwestern University’s Kellogg School of Management and a graduate of Northwestern University’s Industrial Engineering program. He is also currently serving as the Chair of the Northwestern University Transportation Club.

Pattharin Sarutipand, a Civil and Environmental Engineering Ph.D. candidate working with ITI researcher Professor Pablo Durango-Cohen, won an International Road Federation Executive Leadership Fellowship. This award brings together outstanding international students to foster the importance of leadership while developing a better understanding of the transportation industry in the United States as well as the benefits and merits of the International Road Federation. Executive Fellows are nominated by their professors and must demonstrate great educational accomplishments as well as a strong desire to use their education in their home countries. Ms. Sarutipand is pictured in Figure 8.

Emily Kushto, a first-year Civil Engineering graduate student in transportation, won a scholarship from the Illinois Section of the Institute of Transportation Engineers. Ms. Kushto, pictured in Figure 7, is a graduate of Bucknell University and a registered professional engineer. She previously held the position of Senior Engineer at Edwards and Kelcey in New York.

Mackenzie Nicholson, a senior Civil Engineering student, and Laura Riegel, a senior Industrial Engineering student, received scholarships from the Women’s Transportation Seminar. Ms. Nicholson has worked for Kittelson Associates in Portland as well as for a consulting firm in Australia. Ms. Riegel completed an undergraduate research study examining the carbon footprint of logistics operations at Philips Electronics. Ms. Nicholson and Ms. Riegel are pictured in Figure 8.
Figure 9: Civil Engineering graduate student Zitao Zhang, ITI Director Joseph Schofer, Civil Engineering undergraduate student Jeff Meissner, and ITI Research Engineer Daniel Hogan at the ASCE Illinois Section awards dinner.
SUCCESS IN RESEARCH
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.

Figure 10: ITI Chief Research Engineer Daniel Marron installs acoustic emission transducers on a steel bridge.
Specific research work during Year 1 included:

- Development and deployment of tools and methods for structural health monitoring (SHM) of transportation infrastructure, including applications to fracture-critical bridges

- Development of tools and methods for monitoring the impact of transportation construction and resource extraction activities on nearby facilities, including autonomous measurement of site deformation and construction vibrations

- Development of advanced wireless data acquisition systems that can be field-deployed for extended periods while recording significant random events

- Development of innovative materials for transportation infrastructure, including continued evolution of weldable high strength steels for bridges and new concrete mixtures optimized for slip-form paving

- Analysis of critical infrastructure failures as the basis for developing safer codes and standards for design of concrete structures

Institute researchers have deployed advanced continuous remote monitoring technologies on transportation infrastructure facilities around the nation. In collaboration with deployment partners, have used elements of the nation's infrastructure as our field laboratory to develop, deploy, and test advanced SHM technologies, and 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.
CONTINUOUS MONITORING OF LIVE STRAINS IN AN INTERSTATE BRIDGE RETROFIT

Principal Investigator: Daniel Marron
DOT Priorities: Safety; Security, Preparedness, and Response; Infrastructure Renewal

Figure 12: The I-65 John F. Kennedy Memorial Bridge (center) crosses the Ohio River between Louisville, Kentucky and Jeffersonville, Indiana.
The John F. Kennedy Memorial Bridge, shown in Figure 12, carries Interstate 65 over the Ohio River between Louisville, Kentucky and Jeffersonville, Indiana. Four bearings on the large through-truss structure are designed to resist substantial upward forces that might otherwise lift the bridge off its supports. In a 2006 inspection, one of the four anchor bolts restraining one of these bearings was found to have fractured. Beginning in the summer of 2007, the Kentucky Transportation Cabinet (KYTC) engaged ITI’s Research Engineering Group (ITI-REG) to help investigate the anchor bolt failure as part of a multi-party effort. This work was described in ITI’s annual report for Year 8 of the TEA-21 grant cycle (2006-2007). Under Year 1 of SAFETEA-LU, during the summer of 2008, the ITI team – including several undergraduate engineering students – developed a data acquisition and communication hardware suite to monitor continuously the strains and displacements in critical parts of the bearing assembly, including those installed during a retrofit to repair the failed bolt. Assembly of the hardware suite in the ITI laboratory is shown in Figure 13.

The continuous monitoring installation was deployed on the bridge in August of 2008, as shown in Figure 14. It consists of a computer-controlled data acquisition system, cellular communication hardware, an industrial computer system, and several power supplies in a traffic signal controller-type enclosure. Strain gauges measure axial, bending, and torsional strain at various locations on the anchor bolts, while displacement transducers and a triaxial accelerometer measure the overall motion of the bearing assembly. Finally, load cell washers allow comparison of the loads borne by the anchor bolts to those borne by additional restrainers installed as part of the retrofit. Sensor-based monitoring is particularly useful because the live strain data needed to monitor the performance of the bearing assembly retrofit cannot be obtained by visual inspection. Because the bearing is inaccessible without a scaffold or lift bucket, the use of continuous remote monitoring in addition to field visits by an instrumentation technician allows acquisition of more data under a more representative variety of traffic and environmental conditions without incurring additional access costs.

Data from the continuous monitoring system are delivered to ITI via cellular modem. The data are then made available to KYTC engineers via secure Internet display technology previously developed at ITI. This permits both KYTC and ITI engineers to track quantitative performance indications from this important bridge detail, including the new retrofit in near-real time. The ability to respond to emergent conditions indicated by remote sensing data will help to safeguard the serviceability of the bridge and protect the traveling public.
NEW APPROACH FACILITATES ACOUSTIC EMISSION TESTING OF STEEL BRIDGE DETAILS

Principal Investigator: Daniel Marron
DOT Priorities: Safety; Infrastructure Renewal

Figure 15: ITI engineers move into position to deploy acoustic emission transducers on the top chord of the JFK Bridge.
Acoustic emission (AE) testing is an established non-destructive evaluation method for pressure vessels and other industrial facilities. ITI is a leader in innovative applications of AE testing to large civil structures. In particular, AE is useful for locating and characterizing cracks in structural steel members. However, the effectiveness of past AE testing on bridge elements has been contingent on relatively favorable conditions on site, including fair weather or availability of some shelter for the equipment and operators, availability of electricity, and relatively easy access to the detail of interest. Since these favorable conditions tend to be the exception rather than the rule on highway bridges, a new approach was needed to take full advantage of AE testing.

To meet this challenge, the ITI Research Engineering Group (ITI-REG) developed a customized weatherproof enclosure that can be installed on a bridge component by a person working from a lift bucket, as shown in Figure 15. The enclosure contains the AE hardware, a rugged laptop computer, and a battery-backed power supply. The enclosure can be clamped to the bridge near the area of interest, minimizing the instrument cable length, and therefore the vulnerability to electrical noise. Power and communications are provided by a low-cost umbilical made from materials available at home improvement stores. The test operator is able to control the AE acquisition hardware from a more convenient location using readily available remote access software.

The new approach developed at ITI was deployed on the John F. Kennedy Memorial Bridge (the AE work is unrelated to the monitoring of the uplift bearing anchor bolts described previously). When inspections revealed a five-inch full-depth transverse crack in a fracture critical member on the top chord of the bridge, the Kentucky Transportation Cabinet mobilized a variety of non-destructive evaluation techniques, including AE, to characterize the crack. The crack was near a peak of the continuous cantilever through truss, high above the roadway and accessible only by lift bucket during limited lane closure windows. Using the new weatherproof enclosure, members of the ITI-REG were able to deploy the AE instrument array (shown in Figure 16) quickly and run tests under live traffic loads without requiring rush hour lane closures. Since live traffic loading provides the excitation for this type of AE monitoring, it is helpful to run tests lasting up to several hours. This would have been impossible without the new enclosure. Figure 17 shows ITI engineers remotely starting an AE test from the bridge deck as the lift bucket is prepared to clear the bridge.

The tests revealed no evidence that the crack was propagating into regions of concern on the truss element. Furthermore, the AE tests found indications of another defect in a weld near the crack. The presence of that defect, which is believed to be a slag inclusion, was confirmed by radiography. This is an example of the value of corroboration by multiple non-destructive evaluation techniques for validating the use of AE on highway bridges.
NEW ACM INSTRUMENTATION HELPS ADDRESS POTENTIAL SHORTAGES OF ROAD AGGREGATE

Principal Investigator: Charles Dowding
DOT Priorities: Environmental Stewardship; Infrastructure Renewal

Figure 18: Road aggregate must often be quarried by blasting before it can be processed and used in infrastructure projects.
Autonomous Crack Monitoring (ACM) technology developed with ITI support may provide a means to address potential shortages of raw materials for transportation infrastructure construction and maintenance. Suburban sprawl and an increasingly litigious climate are important barriers to the production of essential mined materials, such as road aggregate, shown in Figure 18. A 2007 report commissioned by the Florida Department of Transportation points out that if current regulatory trends continue, it may become necessary to import aggregate from as far away as the Yucatán Peninsula in Mexico, drastically and unnecessarily increasing the cost of infrastructure construction in Florida; similar trends can be observed throughout the nation.

During the summer of 2007, ITI engineers installed a computer-controlled ACM system in a residence adjacent to a road aggregate quarry in Naples, Florida; an elevation view of the house is shown in Figure 20. This system employed special sensors to measure the change in width of cracks in the house walls as they respond to changes in temperature and humidity as well as dynamic effects induced by ground motion and everyday household activities, such as slamming doors. This work was described in ITI’s annual report for Year 8 of the TEA-21 grant cycle (2006-2007).

Early in Year 1 of the SAFETEA-LU grant, Professor Dowding’s team analyzed data from over six months of continuous measurement of crack response to seasonal, frontal, and daily environmental changes, as well as dynamic events. The data clearly showed that crack response to environmental and household stimuli was at least one order of magnitude greater than crack response to blast-induced ground motion. Dowding included these data in a report to the board of commissions of Collier County, Florida, to provide a quantitative basis for their ongoing regulation of aggregate quarry operations.

Later in Year 1 of SAFETEA-LU, ITI engineers installed an additional sensing suite in the instrumented house, nearly doubling the number of sensors. The new installation, a small part of which is shown in Figure 19, included a more advanced computer-controlled data acquisition system and was added to the house in parallel to the old installation, which continues to gather data. The new installation includes sensors to measure crack response on two axes at a wall joint, as well as an array of transducers to measure the response of a ceiling joist and an entire wall to dynamic phenomena. These data will be compared to a variety of input factors, including wind gusts and thunder, household activity, and ground motion and air overpressure from blasting. These data are autonomously reported on a web site for review and analysis.

It is expected that this research will promote a more thorough public understanding of relative impact of blasting on cracking in homes through more sophisticated sensor suites and the immediate Internet-availability of the data as a public relations tool. This transparency and information flow may help assuage quarry neighbors’ fears of structural damage and allow production of essential raw materials to continue.
As advances in technology allow for smaller and smaller sensors and communication equipment, wireless sensor networks have become attractive, cost-effective alternatives to traditional wired sensing systems for structural health monitoring. They have the potential to lower the overall cost of monitoring dramatically by reducing labor-intensive installation procedures, and they have proven to be far less intrusive to the occupants of a monitored structure than their wired counterparts. Wireless sensor networks have been shown to be very effective for long-term periodic sensing - that is, at making measurements at pre-determined intervals for months or years at a time. This is made possible by keeping the sensing hardware in a low-power, non-sensing “sleep” state during the vast majority of the deployment; the hardware briefly returns to full-power mode at pre-selected times to take a measurement before returning to the sleep state. However, many events that warrant monitoring are random: construction activities, blasting, accidental impacts, to name a few. To respond to random events, sensors must be continuously powered-on, negating the power-saving measures that practical wireless sensing requires. The ITI team, in cooperation with Northwestern’s Department of Electrical Engineering and Computer Science, developed a hardware solution to this problem.

The new technology, dubbed Shake ‘n Wake, is a circuit board which snaps into an off-the-shelf wireless sensor platform. Using a low-power analog comparator, the Shake ‘n Wake device monitors an input channel; when the event threshold is exceeded, the board awakens the high-power areas of the wireless sensor to enable data acquisition. This represents a strategy by which a wireless sensor network for monitoring of transportation infrastructure can detect random events without sacrificing battery life. Figure 21 shows the Shake ‘n Wake circuit board along with two different vibration sensors that may be used to trigger it.

During Year 1 of SAFETEA-LU, ITI engineers conducted experimental verification of Shake ‘n Wake. Through testing in the laboratory and the field, the performance of the new device was evaluated in terms of its power consumption and its ability to detect and respond to events of interest. The Shake ‘n Wake proved to be extremely efficient, consuming very little additional energy when compared to the rest of the wireless sensor network. When combined with appropriate vibration sensors, the Shake ‘n Wake is capable of detecting extremely small vibrations, thus allowing the development of future wireless sensing systems for the purposes of monitoring construction vibrations, crack propagation in steel bridges, and intrusion detection.
The manufacture of portland cement is a highly energy-intensive process with a significant carbon footprint, and there is a growing consensus that strategies to develop “greener” concrete need to be pursued more actively. One proven method of doing this is to replace some of the portland cement with industrial byproduct materials such as fly ash and blast furnace slag to create so-called blended cements. In the presence of portland cement, these materials react with water and can actually improve the strength and other engineering properties of the concrete. Thus their use has the potential to generate both environmental and engineering benefits. However, a key drawback to their use is that they react more slowly than portland cement, so the early strength development of the resulting concrete during the first few days after mixing is slower. This slows construction schedules and makes the concrete more prone to early age cracking if it is not protected from drying. For these reasons, these byproduct materials are underutilized, particularly in the United States.

During Year 1 of SAFETEA-LU, Professors Jeffrey Thomas and Hamlin Jennings used insights gained from their research into the basic chemical reactions that occur in portland cement to develop a new strategy for increasing the early hydration process of alternative cements. Prior to SAFETEA-LU Year 1, these researchers had shown that the addition of a relatively small amount of laboratory-prepared calcium-silicate-hydrate to portland cement, a substance similar to the primary naturally-formed hydration product, significantly increases the rate of reaction during the first few days. This is a seeding effect, whereby the added material provides a multitude of new locations where hydration products can easily form. Such an effect is used in a wide variety of scientific and practical applications where an energy barrier to nucleation limits the rate of forward reaction, e.g., the seeding of clouds to form rain. During SAFETEA-LU Year 1, the researchers successfully applied a similar approach to stimulate the early hydration of an alternative cement system made from pure ground blast furnace slag, a byproduct of iron manufacturing. The hydration rate of this alternative cement system is compared to that of traditional cement in Figure 22. This exciting result opens the door to the greater utilization of byproduct materials in a wide variety of infrastructure applications and thus to reduced carbon emissions from the concrete industry.
Infrastructure performance models are mathematical expressions that relate infrastructure condition measures to a set of explanatory variables such as design characteristics, traffic loading, environmental factors, and history of maintenance activities. The idea is to relate condition to the variety of causal factors to provide a basis for forecasting future condition based on service life/time-to-failure distributions and scheduled maintenance and rehabilitation activities, and thus to guide maintenance and operating policies. Particularly in the last 10-15 years, developments in sensors, statistics, and computing have led to a wide variety of new models of infrastructure performance. Unfortunately, these efforts have been disconnected from each other, and as a result there is a lack of standards and criteria for the development, utilization, evaluation, and selection of performance models. In response, Professor Durango-Cohen and his team have developed an online platform/repository/testbed system to facilitate the exchange of data and information related to infrastructure performance models. The result is the Pavement Analysis Comparison (PAC) web site, launched in late 2007 and hosted by ITI. A screen capture of the PAC site is shown in Figure 23.

This web site contributes to the theory and practice of performance modeling by serving as an authoritative repository of modeling information and providing online access to a testbed that allows analysts to evaluate the capabilities of their own models against well-established benchmarks. Specifically, the site provides a high-level description of the objectives and experimental design of the AASHO (1962) Road Test, data from which remains in widespread use despite their age, and describes the various state-of-the-art performance models available in current literature. The online tools allow analysts to upload their own performance models and compare them to the variety of benchmarks available in the database.

Visit the PAC web site: modelingpavements.iti.northwestern.edu
CLARIFICATION OF THE BRIDGE DISASTER IN PALAU:
A SPRINGBOARD FOR FUTURE PROGRESS IN PRESTRESSED
BRIDGE DESIGN

Principal Investigator: Zdeněk Bažant
DOT Priorities: Safety; Global Connectivity; Infrastructure Renewal; Advanced Transportation Research

Since it is impractical to conduct full-scale laboratory tests of large civil structures, and because major structural failures of transportation infrastructure are relatively rare, it is essential that engineers learn from structural failures when they do occur. With this in mind, during Year 1 of SAFETEA-LU, Professor Bažant and his group have continued their campaign to gain access to and analyze data from prominent failures of concrete structures.

One important example is the Koror-Babeldaob Bridge, which connected two islands in the Republic of Palau; part of the archipelago is shown in Figure 24. When completed in 1977, the bridge held the world span length record for a prestressed box girder; however, the bridge collapsed following a retrofit in 1996, killing two and injuring many more. When court experts were unable to explain the cause, a condition of the final settlement with the government of Palau was that all technical data pertaining to the collapse be sealed in perpetuity. It should be noted that in other transportation fields – particularly commercial aviation – technical data from any failure must be released to the public per United States law and international treaties. In November 2007, Bažant, as the plenary speaker at the 3rd Structural Engineers World Congress, proposed a resolution to declare the withholding of technical data from major disasters to be a violation of engineering ethics and an obstacle to progress. The Congress passed the resolution and conveyed it to the government of Palau and to the law firms that had arranged the sealing of the data.

In January 2008, the attorney general of Palau agreed to release the data for analysis by Bažant and a forensic engineering firm, opening the door for serious scientific study. After nine months of work, Bažant and his team were able to identify the cause of the excessive deflections that preceded the collapse. He presented the results in a special plenary lecture at the 8th International Conference on Creep, Shrinkage, and Durability of Concrete Structures (CONCREEP-8) at Ise-Shima, Japan. The following discussion revealed that there are over one hundred bridges similar to the failed Koror-Babeldaob Bridge in Japan alone, and dozens of them showed similar, unexplained, excessive deflections.

Significantly, the newly available data from Palau also showed an analytic model developed by Bažant’s team with ITI support is fully consistent with observations from the failure. This analysis, which could not have been performed without data from the Palau bridge collapse, provides important new evidence with which Professor Bažant continues to urge the American Concrete Institute to revise its design codes to protect the safety of the traveling public.
CONDITION MONITORING OF URBAN INFRASTRUCTURE

Principal Investigator: Richard Finno
DOT Priorities: Safety; Environmental Stewardship; Infrastructure Renewal; Advanced Transportation Research

Figure 25: Construction of a new wing at the Museum of Fine Arts building in Boston. The large excavation is immediately adjacent to the existing building.
ITI has a strong record of research and field instrumentation deployments involving methods to monitor soil deformations and structural responses adjacent to deep excavations made in congested urban areas, including excavations for transportation facilities and buildings near transportation facilities. Results of these efforts, documented in annual reports under the TEA-21 grant, have shown that ITI has developed, evaluated and verified new techniques for acquiring and displaying in real time data from a variety of devices. This real time sensing, when coupled with newly developed numerical tools, facilitates nearly-continuous, updated predictions of ground and structural responses to nearby excavations. With this unprecedented flow of information, adjustments to construction procedures to prevent or limit structural damage can be implemented in a timely fashion before damage is done to nearby structures or utilities.

During SAFETEA-LU Year 1, ITI engineers deployed deformation monitoring equipment at the site of construction of an addition to the Museum of Fine Arts in Boston, shown in Figures 25 and 26. The excavation was made between two existing wings of the museum, with the support walls within several feet of the existing foundations, similar to excavation that might be made for a new subway tunnel in a dense urban area. Movements at the wall were limited by construction permit to one inch, a very tight criterion for excavations made in medium-stiff clays. An autonomous robotic survey station measured lateral movement and settlement at a number of points around the site, while a web camera installed next to the survey station allowed remote monitoring of construction progress. Figure 27 shows the survey station and web camera as they were mounted to the wall of the existing Museum of Fine Arts building. Survey data and web camera images were made available to contractors, engineers, and other stakeholders on a secure project web site in near-real time. Professor Finno and his team also employed inverse analysis, an analysis process in which near-real time data from the field site is used to refine key soil parameters in numerical models of the excavation while the excavation is ongoing. This was particularly challenging because the effects of nearby buildings had to be considered. Finno’s team also collected block samples of the clay at the site for a detailed laboratory evaluation of the constitutive response of the material.

The excavation was completed successfully with movements that were less than the maximum specified values, and without damage to the adjacent Museum of Fine Arts building. Data from the robotic survey station played a key role in showing that the support system performed as designed. The numerical analyses also indicated limitations with the current state of the art for predicting performance of the support system when movements are very small at the early stages of construction.\(^3\)

\(^3\) These findings were presented in the MS thesis of Mr. Izzat Katkhuda, “Automated Monitoring and Performance Evaluation of the MFA Excavation in Boston, MA.”
ITI RESEARCHERS PRESENT ADVANCES IN GEOTEchnICAL INSTRUMENTATION

Principal Investigators: Richard Finno and Charles Dowding
DOT Priorities: Safety; Environmental Stewardship; Infrastructure Renewal; Advanced Transportation Research

Figure 28: ITI Research Engineers David Kosnik (second from right) and Mathew Kotowsky (far right) discuss ITI’s field instrumentation experience with other attendees at the 7th International Symposium on Field Measurements in Geomechanics.
ITI-sponsored research was prominently featured in the program of the 7th International Symposium on Field Measurements in Geomechanics (FMGM), a technical conference presented by the Geo-Institute of the American Society of Civil Engineers (ASCE), held September 24-27, 2007, in Boston, Massachusetts. ITI researchers contributed six technical papers, authored by Professors Charles Dowding and Richard Finno and research engineers David Kosnik and Mathew Kotowsky. Professor Finno, pictured in Figure 29, presented an invited theme lecture and Professor Dowding served as vice chair of the conference organizing committee.

Professor Finno’s invited theme lecture, “Use of Remote, Real-Time Monitoring Data for Supported Excavations,” summarized advances in the theory and practice of design and performance evaluation of supported excavations. The technique, called “inverse analysis,” uses intelligent updating with real-time data to improve the ability of numerical models to predict soil deformation around an excavation. Improved performance models will help anticipate and prevent disruptions to transportation infrastructure facilities, such as roads, railroads, and pipelines, due to nearby excavations. Finno also presented a technical paper, “Real Time Monitoring at the Olive 8 Excavation,” which described the use of an automated survey instrument to measure the performance of a deep excavation with an unusual support system.

Professor Dowding presented “Response of Historic Structure to Long-term Environmental and Construction Vibration Effects” and “Multi-Hop Wireless Crack Measurement for Control of Construction Vibrations.” These, respectively, described wired and wireless approaches to measuring the effect of construction vibrations on adjacent structures.

ITI research engineer David Kosnik, pictured in Figure 30, presented “Internet-Enabled Geotechnical Data Exchange” and “Case Studies in Integrated Autonomous Remote Monitoring,” which described ITI’s techniques and experience in data acquisition, communication, and autonomous data archiving and display over a wide range of infrastructure instrumentation projects. Mr. Kosnik emphasized the importance of robust communication systems and the value of autonomous Internet-enabled data display techniques, such as those developed at ITI.

When not presenting papers or attending sessions, ITI research engineers David Kosnik, Mathew Kotowsky, and Daniel Hogan staffed an information booth in the exhibit area, as shown in Figure 28, showcasing ITI’s work and soliciting new external deployment partners for ITI research.
In late 2007, a new project was undertaken as a joint effort between ITI and a five-year NSF-funded program on Partnerships for International Research and Education (PIRE). The project focuses on intelligent structural health management (ISHM) of civil infrastructure. The PIRE-ISHM program is led by Northwestern University in partnership with universities and industry from China, India, Korea 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.

In the first year, the program has secured memoranda of understanding with Hong Kong Polytechnic University and China’s Dalian University of Science and Technology and Harbin Institute of Technology for cooperative research on ISHM of civil structures. This alliance will facilitate the future exchange of researchers between Northwestern and these partner organizations.

The program has also made several advances in its technical agenda during its first year, including the acquisition of ultrasonic and thermal imaging systems for nondestructive diagnostics which enable large area imaging of structures for detection of potentially dangerous flaws. The use of infrared cameras as a highway and bridge inspection tool has grown in recent years, especially in the area of quality control of asphalt paving operations, evaluation of existing pavements, and inspection of concrete bridge structures.

The PIRE program will explore the use of infrared cameras as a diagnostic tool for evaluating bridge structures, such as those shown in Figures 31 and 32. In particular, the program will monitor a bridge during its service loading to investigate the effect of service vibration on existing internal flaws within beams or columns by taking advantage of frictional heat generation that occurs when vibration causes material elements to rub together in a way that may eventually weaken them.
Figure 32: An open-spandrel concrete deck arch bridge
SUCCESS IN TECHNOLOGY TRANSFER
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 while helping to solve the real problems of those partners.

Figure 33: View of the excavation for the Chicago Spire. The contractor employed ITI-developed Internet-enabled camera techniques for project management.
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 website, 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.

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

• Kentucky Transportation Cabinet

• Wisconsin Department of Transportation

• California Department of Transportation

• Illinois Department of Transportation

• Chicago Department of Transportation

• The Indiana Rail Road Company

• Schnabel Foundation Company, Southborough, Massachusetts

• Jones Mining Company, Naples, Florida

• GeoSonics Inc., Warrendale, Pennsylvania

• Vulcan Materials Company, Franklin, Wisconsin

• Union Tank Car Company, Chicago, Illinois

• Lafarge North America, Herndon, Virginia

• Coachella Valley Water District, Coachella, California

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 tank cars and bridges.

Additional technology transfer activities are shown in Figures 33 and 34.
NEW 50-60 KSI STEEL FOR BRIDGES

Principal Investigators: Professors Morris Fine and Semyon Vaynman
DOT Priorities: Infrastructure Renewal; Advanced Transportation Research

Figure 35: A new highway bridge constructed by the Illinois Department of Transportation with innovative weathering steel developed with ITI support
Under the TEA-21 grant, Professors Morris Fine and Semyon Vaynman developed a 70 ksi yield strength, high performance steel (ASTM A710 Grade B) with good fracture toughness at low temperatures, excellent weldability without pre-heat or post-heat, and corrosion resistance superior to all other weathering steels. In 2006, the bridge shown in Figures 35-37 was built in Lake Villa, Illinois using this steel. The bridge was not painted, resulting in initial savings of $300,000.

The Illinois Department of Transportation (IDOT) expressed the need for a less expensive and lower strength (50 ksi yield strength) steel than A710 Grade B. Together with Christopher Hahin of IDOT, Fine and Vaynman designed a steel composition with lower concentration of costly elements (copper and nickel) and increased concentration of manganese, an inexpensive element. A 40 lb. laboratory heat was cast, hot rolled, and tested. The yield strength was 61 ksi, and the ultimate tensile strength was 75 ksi with excellent ductility.

The Charpy fracture energy of this steel is remarkable – higher than 264 ft-lbs, the limit of the testing apparatus. Specimens did not fracture in Charpy machine down to -40°F. This performance vastly exceeds the ASTM specification for bridge steels of this strength. No commercially available steel has such high fracture energies at low temperatures. Mr. Hahin is planning to specify the newly developed high fracture energy steel for a bridge in Illinois in the near future.
THE MIDWEST BRIDGE WORKING GROUP

Principal Investigator: Theodore Hopwood, University of Kentucky
DOT Priorities: Safety; Reduce Congestion; Infrastructure Renewal; Environmental Stewardship; Security, Preparedness, and Response

Figure 37: Theodore Hopwood welcomes attendees to the Spring 2008 meeting of the Midwest Bridge Working Group held in Evanston, Illinois, and hosted by ITI.
The Midwest Bridge Working Group (MBWG) is a forum for exchanging information about bridges – problems, best practices, research results, etc. – among participating state highway agencies. Created in 1996 and sponsored by ITI through a subcontract with the Kentucky Transportation Center at the University of Kentucky, the MBWG focuses on issues of inspection and maintenance of bridges. Group membership has grown well beyond the Midwest, and now includes bridge specialists from California, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, Ohio, Tennessee, Texas, Virginia, Wisconsin, and West Virginia.

One meeting was held in Year 1 of SAFETEA-LU in June, 2008 in Evanston, Illinois, as shown in Figures 37-39. The meeting attracted 114 on-site attendees, including 64 state highway agency employees representing 20 states. This meeting was broadcast live over the Internet by the ITI Research Engineering Group, allowing participation in the meeting by those who were not able to travel to be there in person.

Meeting attendance has increased progressively year to year, proving the practitioners and researchers highly value the opportunity to communicate with each other in a face-to-face setting. The meetings are a source of the latest information coming from both peer experience and research findings.

ITI also hosted a special half day Regional Bridge Preservation & Maintenance Meeting after the conclusion of the regular MBWG agenda. Its purpose was to align national bridge preservation efforts with the regional bridge working groups, state DOTs, UTCs, FHWA, AASHTO, and the TSP2 program. The twenty four participants in attendance were a diverse mix of transportation professionals from these groups. Each regional bridge working group made a presentation detailing their current status and what they perceived was needed to build a strong, unified, identifiable bridge preservation community. ITI and the University of Kentucky have been assisting other regional groups for years by sharing our experience with the MBWG. At this meeting, ITI committed to continue this and also to consider requests from regional groups for more direct support during the next year in order to “jump start” the program until the AASHTO TSP2 Bridge Center has been selected

For additional information see: www.midwestbridge.org
Commercialization of Institute Sponsored Research

Civil Data Systems, LLC is an independent company created for the express purpose of commercializing a number of technologies developed at ITI. Since its incorporation in August of 2003, Civil Data Systems (CDS) has successfully transferred several ITI technologies from the arena of academic research into the private sector. In particular, CDS works to commercialize technologies for Internet display of data from sensor-based remote monitoring of civil infrastructure as well as the use of Internet-enabled cameras for management of construction projects. Recent CDS clients include STS Consultants, Hayward Baker, and Charleston, South Carolina-based 4SE Inc. Through a continuing partnership, CDS brings ITI technology into the private sector while ITI is able to participate in new research opportunities with commercial partners.

In the fall of 2007, CDS was engaged by Hayward Baker to provide construction surveillance cameras on two worksites in downtown Chicago: an office building on Wacker Drive, and the Chicago Spire, a lakefront condominium development by architect-engineer Santiago Calatrava, which would become the tallest building in North America when complete. These installations represent the adoption of methods developed by ITI-sponsored researchers Professors Charles Dowding and Roberta Massabò.

In 2003, Dowding and Massabò proposed to use an Internet-connected camera overlooking a construction site as a teaching tool for students of transportation engineering, structural engineering, and project management. Once the camera was installed on the roof of a high-rise building overlooking the construction of the 11th Street pedestrian bridge in downtown Chicago, however, it became apparent that the technology would be just as useful to practicing engineers and project managers as a mechanism for keeping a visual record of construction activity and staging.

For the two Chicago worksites, Civil Data Systems built a customized bracket and enclosure to mount the camera and communication equipment on the roof of an adjacent building, as shown in Figure 40. The brackets attach to the parapet wall of the existing building to support the camera safely in all weather conditions without damage or any modification to the parapet or roof. Civil Data Systems’ unique ability to utilize a wide array of robust wireless Internet connections allows real-time remote control of the pan-tilt-zoom cameras, while on-site computer control captures a time-lapse photographic record of construction progress at each area of interest on the site. The use of flexible and robust wireless communication hardware, installation of the equipment without any modification to host structure, and customized integration of off-the-shelf components, keeps the costs far lower than those to install and maintain their traditional wired counterparts.

As construction projects become more complex and schedules tighten, demand for this innovative project management tool is expected to increase.

For more information, visit www.civildata.com
72 Successful Technology Deployments in 21 states and DC

The impact of ITI-supported research and deployment activities is spread across 21 states at 72 different sites, as shown on the map in Figure 41. ITI’s reputation as a center of excellence for non-destructive remote infrastructure monitoring has grown through successful applications, publications, and its often-visited web site, such that project and site managers with significant concerns about the condition of their facilities frequently contact ITI for advice, support, and technology applications. During Year 1 of SAFETEA-LU, the ITI team established one new field deployment and upgraded three existing deployments.

Newly Re-Designed Web Site

At the end of TEA-21 Year 8, ITI came to the realization that its web presence greatly needed an overhaul. Although the web site was receiving 1.2 million total page views per year and an average of 731 unique visitors a day, the organization of the site was less than ideal, and it was often difficult to find important documents and information.

ITI Director Joseph Schofer tasked Creative Coordinator Melissa Mattenson and the ITI information technology staff with revamping the web site at the beginning of SAFETEA-LU Year 1. A new design was planned to focus on usability and accessibility of project data as well as compliance with Northwestern University McCormick School requirements and RITA reporting requirements.

Since the launch of the new site in June, 2008, it has been well received. The web site currently houses many research publications, presentations, articles, and talks, as well as seminar and symposium information, a staff and Principal Investigator directory, and all important required reporting documentation.

Visit the ITI website at www.iti.northwestern.edu

Figure 41: A current map of active and completed ITI projects
SUCCESS IN MANAGEMENT & POLICY
ITI has made major contributions to inform the regional and national debate on transportation infrastructure policy and management. In October, 2007, ITI co-sponsored the inaugural William O. Lipinski Symposium on Transportation Policy, shown in Figures 42 and 43.
The symposium addressed regional congestion with the theme “Focusing on Moving the [Chicago] Region in a New Direction.” The symposium brought together regional and national decision-makers and transportation experts to explore actions and policies for our region. The second Lipinski Symposium will be held in November, 2008.

Director Schofer has continued to work actively with local and national media to keep infrastructure condition and performance in the news, as well as commenting on the effect of petroleum prices on travel and transportation, transit funding, and other matters.

He is actively engaged in transportation planning and policy activities through the Transportation Research Board, where he serves on several conference planning committees, the SHRP2 Capacity Technical Coordinating Committee, as well as standing committees of TRB. He successfully proposed the topic for the 2009 RITA-TRB Spotlight Conference to focus on infrastructure preservation and rehabilitation issues.

The Lipinski Symposium on Transportation Policy, subtitled “Focusing on Moving the [Chicago] Region in a New Direction,” explored planning, management and finance of transportation in Chicago for the 21st century. Held in Chicago in, October, 2007, the Symposium was co-sponsored by the Metropolitan Planning Council, the most prominent and oldest regional civic interest group in the Chicago area. The first in a continuing series, this event was attended by over 250 people including political leaders, technical professionals, scholars, and members of the media. U.S. Representative James Oberstar (D-MN) was keynote speaker.

The day-long event began with discussion of some of the important accessibility and mobility issues affecting the vitality and prosperity of the Chicago region and the nation. A second panel described some best practices for managing and financing transportation systems, including success stories from around the world. Rep. Oberstar gave the keynote address, calling for action from all levels of government to attend to deteriorating transportation infrastructure. The afternoon panel discussed cutting edge policy and technical tools to improve the performance of regional transportation systems. In the final panel, regional political leaders discussed ideas that are likely to work in this region. The program ended with an active discussion among panelists and attendees.
CENTER OF EXCELLENCE
Center of Excellence

The first year of SAFETEA-LU has been a time for expanding and advancing ITI’s contributions to transportation infrastructure monitoring, management, and policy.
We are particularly proud of our achievements this year in three important areas:

- Innovations in infrastructure measurement methods and applications, materials, and design principles
- Dissemination of results and innovations, achieved through numerous conference presentations, outreach activities, the Midwest Bridge Working Group, and our web site
- Education of the next generation of infrastructure experts, through classroom experiences supported by ITI, engagement of undergraduate and graduate students in fabrication of testing equipment, as well as hands-on experience in field deployments

Our faculty has achieved important breakthroughs in the development of new and safer design codes for large concrete bridges. Other members of the ITI team are developing new concrete materials which promise important construction and performance advantages for transportation infrastructure. Our work on new steels was directed at more cost-effective materials for bridges, and we are collaborating with Illinois DOT and others to identify opportunities for field applications.

We performed multiple technology applications on the critical John F. Kennedy Bridge, providing timely information to protect a vulnerable facility. In each of these applications the ITI REG was able to advance the state of the art in field measurement methods for infrastructure systems.

The new Shake ‘n’ Wake wireless system is opening new long-term wireless infrastructure monitoring opportunities.

During this year we initiated collaboration with a major private transportation infrastructure owner, the Indiana Railroad. There is a vast amount of private transportation infrastructure, much of it in railroads. The public interest here is large, because of the potential for rail/truck tradeoffs and the implications for energy, congestion, and infrastructure deterioration.

ITI faculty and staff have been particularly active in participation at national and local conferences, and the Lipinski Symposium brought new ideas to Chicago’s transportation community. Our students are excited about their engagement with ITI, their numbers are growing, and our graduates are finding strong acceptance in the job market.
APPENDICES
APPENDIX 1: FUNDING SOURCES AND EXPENDITURES

Funding Sources: $6,933,697

- Federal Grant: 53%
- University: 43%
- Other (Research Partner): 4%

Total Expenditures: $5,383,810

- Research: 84%
- Education: 7%
- Administration: 5%
- Other (Research Partner/Faculty Effort): 4%
APPENDIX 2: PUBLICATIONS BY PROJECT

A221: Improved Condition Monitoring for Bridge Management

PI: Daniel Marron


A222: Size Effect, Failure Risk, and Creep-Shrinkage Damage: Progress in Concrete Design Codes and Practice

PI: Zdeňek Bažant


A223: ACM / Commercialization of Measurement Technologies

PI: Charles Dowding


A224: MEMS / Commercialization of Measurement Technologies

PI: Charles Dowding


A225: A Knowledge Management Platform for Infrastructure Performance Modeling

PI: Pablo Durango-Cohen

A227: Condition Monitoring of Urban Infrastructure

**PI: Richard Finno**


A228: Strategies for Improving Low CO² Cements

**PI: Hamlin Jennings**


A229: Design and Application of Low Compaction Energy Concrete for Use in Slip-Form Concrete Paving

**PI: Surendra Shah**


A232: Patterson Professorship

**PI: Hani Mahmassani**


