# About the Institute

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Director &amp; Staff</td>
<td>6</td>
</tr>
<tr>
<td>Building the Research Program &amp; Community: Executive Board, Research Advisory Panel</td>
<td>8</td>
</tr>
<tr>
<td>Education</td>
<td>9</td>
</tr>
<tr>
<td>Research</td>
<td>10</td>
</tr>
<tr>
<td>Technology Transfer</td>
<td>11</td>
</tr>
<tr>
<td>Policy &amp; Management</td>
<td>12</td>
</tr>
</tbody>
</table>

# Vision of the Institute

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success in Education</td>
<td>16</td>
</tr>
<tr>
<td>Success in Research</td>
<td>20</td>
</tr>
<tr>
<td>Success in Technology Transfer</td>
<td>30</td>
</tr>
<tr>
<td>Success in Management &amp; Policy</td>
<td>44</td>
</tr>
<tr>
<td>Center of Excellence</td>
<td>54</td>
</tr>
<tr>
<td>In Memoriam: David F. Schulz</td>
<td>58</td>
</tr>
<tr>
<td>Appendix 1: Funding Sources and Expenditures</td>
<td>60</td>
</tr>
</tbody>
</table>

## Success in Technology Transfer

- 71 Successful Technology Deployments in 21 States and DC 44
- Infrastructure Technology Institute Web Site 44
- Further Commercialization of NUCu (ASTM A710 Grade B) Steel 46
- Acoustic Emission in Material Science 47
- Structural Crack Monitoring of an Historic Church 48
- The Midwest Bridge Working Group 50

## Success in Management & Policy

### Center of Excellence

### In Memoriam: David F. Schulz

### Appendices

- Appendix 1: Funding Sources and Expenditures 64
- Appendix 2: Research Projects 65
- Appendix 3: Publications by Project 66
- Appendix 4: Directory of Key Personnel 68
ABOUT THE INSTITUTE
Infrastructure is the connective tissue of our economy and society. The extent and capacity of U.S. transportation infrastructure are characteristics we take for granted until something goes wrong. The tragic collapse of the I-35W bridge in Minneapolis was a wake-up call about the importance of and risks to that infrastructure. While the emerging evidence on I-35W suggests that the failure may have been designed in from the start, the consequences of the loss of this structure, both immediate and long term, remind us of our dependence on such connective tissue.

Northwestern University’s Infrastructure Technology Institute (ITI) is committed to ensuring our nation’s surface transportation infrastructure against failure. 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.

This report describes the activities and achievements of the ITI team during its 8th year of funding under the Transportation Equity Act for the 21st Century (TEA-21). It goes beyond our technology advances to describe our educational achievements and support of policy analysis and the infrastructure policy debate.

Founded in 1992 under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), ITI is a University Transportation Center funded under the Transportation Equity Act for the 21st Century. This report documents activities between September 1st, 2006 and August 31st, 2007, the Institute’s TEA-21 Year Eight.

The theme of the Infrastructure Technology Institute is improving the technology and expertise available to address the problems of the nation’s transportation infrastructure.
Construction of a new bridge in Lake Villa, Illinois fabricated with NUCu Steel developed at Northwestern University
Center Director & Staff

ITI is an interdepartmental center within Northwestern University's McCormick School of Engineering and Applied Science. The Director of the Institute, David F. Schulz, was appointed by and reports to the Dean of the McCormick School. The Director is responsible for the day-to-day management of the Institute, including, but not limited to developing, implementing, and monitoring the annual budget, interacting with federal officials responsible for administering the Institute's grant funding, and carrying out all other aspects of the Institute's program. The Director is 100% funded by the Institute.

In addition to the Director, the Institute employs three other staff members to support its educational and administrative activities: Assistant Director Elizabeth Brasher, Business Manager Colleen Hull, and Creative Coordinator Melissa Mattenson.

The ITI Research Engineering Group

The Institute employs an in-house engineering staff, the Research Engineering Group (REG) consisting of Chief Research Engineer Daniel Marron and three Research Engineers: Daniel Hogan, David Kosnik, and Mathew Kotowsky. REG personnel possess exceptional skills and experience in field deployment of advanced instrumentation techniques for monitoring civil infrastructure facilities. Their experience is applied to the three-fold mission of the ITI REG:

- Support ITI-funded researchers and their students with instrumentation and communications expertise
- Conduct the REG’s own deployment research into innovative instrumentation and monitoring techniques
- Support other ITI technical program functions as necessary

The REG provides core support services across the ITI program, ensuring that state of the art monitoring and communications technologies are available for and deployed in ITI research applications. The REG also provides information technology support to the Institute and its administrative staff and is closely involved with the educational activities of the Institute.

The Institute does not directly employ faculty, but project-related, proposal-based research funding supports faculty, research staff outside of the REG, and graduate students working on Institute-supported projects.
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 an advisory committee that meets to review, discuss, and recommend proposals for the upcoming funding period. The Director weights the recommendations of the advisory committee against the Institute’s strategic plan and available funding. As a 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, and others).

At these meetings, members of the research teams present a brief update 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 8 were:

**Professor Joseph T. Walsh Jr., Chair**
Senior Associate Dean, McCormick School of Engineering and Applied Science

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

**Professor Surendra P. Shah**
Director, Center for Advanced Cement-Based Materials

**Professor Joseph L. Schofer**
Associate Dean, McCormick School of Engineering and Applied Science

Research Advisory Panel

A Research Advisory Panel 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 8 were:

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

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

**Professor Donn Hancher**
Department of Civil Engineering
University of Kentucky
**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. A key programmatic element to achieve that 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 TIM program has evolved as a specialized extension of the more generalized Infrastructure Management specialization within the MPM program (mpm.northwestern.edu). 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. This extended impact is achieved by support for courses, seminars and symposia, field trips, and technical short courses.

ITI created and supports the Department of Civil and Environmental Engineering course Infrastructure Facilities and Systems, taught jointly by ITI Director David Schulz and Professor Joseph L. Schofer. This unique course introduces engineers and other students to the functions, importance, and complexity of civil infrastructure systems, with an emphasis on surface transportation systems. Figure 10a shows these students touring the Trump Tower construction site in downtown Chicago, Illinois.

ITI extends the reach of its educational programs by bringing infrastructure knowledge to pre-collegiate students. These outreach programs are designed to develop and test methods to teach secondary school students about the characteristics, functions, design and operation of transportation and other civil infrastructure systems. Though less technical than their collegiate counterparts, these courses offer younger students educational opportunities that wouldn’t otherwise be available to them before college. Figure 10b shows high school students touring the Evanston Water Treatment Plant as part of the ITI Summer Infrastructure Camp.
Research

The Institute’s research program has focused upon 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 infrastructure materials that are better suited for their tasks. Specific work during Year 8 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 communications devices that awaken and transmit when significant events occur

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

• Analysis of critical infrastructure failures and development of safer codes and standards for the design of concrete structures

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

Technology Transfer

A key to ITI's achievements in SHM has been our ability to work in partnership with infrastructure agencies and owners to develop and deploy innovative technologies while helping solve the real problems of those partners. 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

Our 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.

Policy and Management

The Institute Director continued to work with local and national news media to provide expertise on key transportation and infrastructure issues. The Director and other faculty affiliated with the Institute were active contributors to the discussion in the aftermath of the I-35W bridge disaster in Minneapolis. In addition, Director Schulz and Professor Schofer contributed to the public dialog on transit funding for northeastern Illinois through a variety of media contacts. A partial listing of ITI media citations is available on the Institute’s website: www.iti.northwestern.edu/policy.
VISION OF THE INSTITUTE
Our Vision

"Establish ITI as a premier academic center for the development, application, and implementation of technologies, tools, and materials for monitoring, managing, and building surface transportation infrastructure facilities and systems."

In ITI’s TEA-21 Strategic Plan, the Institute established an ambitious vision for the six-year period and set specific goals. Below is a statement of these goals and their achievement.

| Our Goal: | Develop a transportation infrastructure engineering educational program at the Master’s level while enriching the undergraduate civil engineering curriculum at Northwestern and providing significant professional development opportunities to transportation infrastructure practitioners. |
| How it was Achieved: | ITI’s Public Infrastructure Management and Infrastructure Facilities and Systems courses have become mainstays in the Master of Project Management program. With a total enrollment of 16 students over the 2006-2007 school year, these courses have attracted graduate and undergraduate students from many different departments across Northwestern University. |

| Our Goal: | Continue its successful transportation infrastructure research programs in continuous remote monitoring and nondestructive testing and evaluation of transportation infrastructure and materials. |
| How it was Achieved: | By successfully completing 71 total deployments nationwide, ITI has established a reputation for responsiveness, excellence, and efficiency in structural health monitoring. During Year 8 of TEA-21, ITI continued its successful SHM program by adding six new deployments and maintaining eight existing operational deployments. |

<p>| Our Goal: | Build on its success in moving into practice the innovative transportation infrastructure technologies it develops. |
| How it was Achieved: | ITI has transferred several former research projects into standard practices for engineers both in and out of the transportation industry. These include applications of innovative technologies such as automated inclinometers, automated total stations, autonomous Internet-based cameras, custom-designed autonomous crack monitoring systems, and new construction materials. Institute research techniques have found their way into the standard practices of several consulting firms and state departments of transportation. |</p>
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<tr>
<th>Our Goal:</th>
<th>Contribute to advances in transportation infrastructure policy and management, particularly the vexing problem of the increasing paralysis of the transportation infrastructure industry in pursuing large and complex projects.</th>
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<td>How it was Achieved:</td>
<td>ITI's continuous remote monitoring projects have provided engineers and policy makers with the data gathering techniques and data needed to assess infrastructure condition and provide a basis for making investment and reinvestment decisions.</td>
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<th>Our Goal:</th>
<th>Grow the number of public and private sector transportation infrastructure industry partners with whom ITI works on technology issues.</th>
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<td>How it was Achieved:</td>
<td>ITI continued to partner with both private entities and public agencies to fulfill its research objectives. In the geotechnical engineering field we have worked with consulting firms, construction contractors, and aggregate mining companies. Civil Data Systems, a private spinoff company that has commercialized some of ITI's most successful research products, has brought ITI-developed data management and construction recording techniques to the private sector.</td>
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<th>Our Goal:</th>
<th>Establish public and private sector partnerships with the goal of influencing public policy and management based on Institute research.</th>
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</thead>
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<td>How it was Achieved:</td>
<td>ITI has worked closely with private contractors and public agencies on a large development in downtown Chicago involving substantial underground construction including construction of a new subway station. The policy issue is assessing – and controlling – the effect of construction on critical underground utility infrastructure elements. We have also worked with limestone aggregate mining companies in Florida to distinguish the impacts of blasting from other factors causing damage to houses. This work helps to assure the availability of aggregates that are essential for constructing surface transportation infrastructure facilities.</td>
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<th>Our Goal:</th>
<th>Generally enhance its position as the recognized center of excellence in transportation infrastructure technology.</th>
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<tr>
<td>How it was Achieved:</td>
<td>The recognition brought to ITI by engagement of our leadership in media discussions of infrastructure needs and policies, the participation of ITI staff in trade shows and transportation conferences, and the ITI web site have allowed infrastructure professionals to seek out partnerships with ITI. Continued involvement with the Kentucky Transportation Cabinet, the Midwest Bridge Working Group, and several consulting firms have kept ITI fresh in the minds of practicing engineers when considering continuous remote monitoring of infrastructure facilities.</td>
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SUCCESS IN EDUCATION
Public Infrastructure Management Course

The Institute’s ground-breaking Public Infrastructure Management course attracted both undergraduate and graduate students during Year 8 of TEA-21. This course introduces students to infrastructure systems and their functions, planning, management, and finance. Students learn an original process model for public infrastructure management that is carried through the course. They analyze case studies of infrastructure management successes and failures, and each student prepares a research paper on a public infrastructure management problem in the context of the process model.

A key element of this course is an all-day charrette: a design exercise in which student teams work on a realistic quick-response infrastructure management challenge. Throughout the course students are trained and required to use professional quality presentation tools and styles. In the fall of 2006, this class had an enrollment of eight students.

Infrastructure Facilities and Systems Course

The Infrastructure Facilities and Systems course, first offered in the spring of 2005, now also serves as the senior capstone civil engineering design course in the department of Civil and Environmental Engineering, 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 continues to mix classroom and team working sessions with weekly field trips to major infrastructure facilities around Chicago. Students get a first hand understanding of the construction and operation of large infrastructure facilities as they meet their site visit hosts who are usually project managers or designers that can provide technical and managerial insights as well as excitement about their field that is beyond what can be experienced in the classroom. The field trips in this course in the spring of 2007 included:

- Bovis Lend Lease construction management firm and tour of Trump Tower construction site
• Illinois State Toll Highway Authority I-355 extension: high level precast concrete bridge and slipform paving operation

• Wadsworth Prairie wetland restoration project

• Belt Railroad of Chicago Clearing Classification Yard and repair shops

• Chicago Transit Authority Brown Line reconstruction project

In 2007, the eight students in this course worked in small teams to design temporary residences suitable for facilitating large-scale, transient displacement of families. Motivated by the events of Hurricane Katrina, the project included design of housing, water and energy utilities, and transportation for materials and components. The students applied the variety of engineering, project development, and management skills they learned as undergraduate engineers at Northwestern University.

Because of the campus-wide appeal of this course, non-engineers were included, bringing a diversity of perspective to an infrastructure engineering project to demonstrate the value of the 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.

ITI Engagement in the MPM Program

ITI has continued to engage in the educational activities of Northwestern University’s Master of Project Management Program which prepares professionals for careers in civil engineering project management. ITI has brought a Transportation Infrastructure Management specialty to the MPM program by supporting the addition of new courses: Public Infrastructure Management and Infrastructure Facilities and Systems. ITI Director David Schulz created and taught the first course, and Professor Schulz and Professor Joseph Schofer shared the second.

The ITI director and other ITI-affiliated faculty frequently serve on M.S. committees to review the projects required of all MPM students. Through the mentoring these professors provide, MPM students are given the opportunity and the tools to complete meaningful projects that prepare them for careers in transportation infrastructure management. The courses offered by ITI attract both undergraduate and graduate students, extending the impact of ITI and promoting interest in and knowledge of transportation infrastructure systems management.

21a. Professor Joseph Schofer teaches a graduate level class in infrastructure systems.
Summer High School Infrastructure Camp

Building on the successful experience of the summer of 2006, ITI once again hosted its Summer Infrastructure Camp as part of Northwestern University's National High School Institute (NHSI). The camp is a residential program in which students receive a preview of the collegiate living experience and engage in an intensive mix of classroom learning, field trips, and team project work. In 2007, campers looked at the critical infrastructure issue of sustainability. Director Schulz assigned students the task of designing a sustainable town, including examination of housing, employment, education, commerce and institutional infrastructure such as hospitals, police and fire stations, libraries, parks, and other governmental and private institutions. Figure 22a shows camp participants enthusiastically working in groups to create their design project. A series of infrastructure field trips complemented the campers' experience. The 2007 camp included trips to two new locations, the Wadsworth Prairie Wetlands Preservation Project and the Evanston Water Treatment Plant (shown in Figure 22b), in addition to the Illinois Railway Museum and exploring Chicago architecture and infrastructure along the Chicago River. For more information about the summer camp, visit the ITI Summer Infrastructure Camp web site: www.itisummercamp.org.
Student of the Year

ITI selected Nathan Tregger, Ph.D. student in Northwestern University’s Department of Civil and Environmental Engineering, as its UTC Outstanding Student of the Year. Mr. Tregger works with ITI researcher Professor Surendra Shah on the development of advanced self-compacting concretes. His research focuses on developing a basic understanding of the mechanisms that dictate the balance between flowability and shape-stability of freshly placed concrete. Processing during and immediately after mixing and placing has become an important focus of the study of concrete. Tregger brings a cross-disciplinary approach to his research, incorporating techniques from civil engineering, chemistry, materials science, and applied mathematics. Utilizing his analytical and experimental skills and his attention to detail, he has achieved important results that he has shared in award-winning presentations at concrete and ceramics conferences both in the US and abroad.

In addition to his research, he has served as a teaching assistant for several classes and supervises undergraduate students conducting research. Mr. Tregger also serves on the Civil Engineering Graduate Student Board, which is responsible for organizing extracurricular activities.
Engaging Undergraduate Engineering Students

In an effort to promote public awareness of the impact and importance of urban infrastructure systems, ITI Director Professor David Schulz and ITI researcher Professor Charles Dowding collaborated in a project to create a self-guided walking tour of the infrastructure facilities around downtown Chicago's recently reconstructed Wacker Drive shown in Figure 24a. Figure 24c shows a map of the area covered in the tour. After completing a proof-of-concept version in 2005, the project was assigned to a team in Northwestern University's freshman Engineering Design and Communication (EDC) course in which students work in teams to design solutions to meet the needs of real clients. ITI acted as the client in this initiative in the spring of 2007 and an EDC team comprised of four undergraduates created a product to fulfill ITI's need for the self-guided infrastructure tour.

The EDC team created audio tracks to form an eleven-stop guided tour. These files, as well as the previous year's four-stop tour, are available on a web site created and hosted by the Institute: www.iti.northwestern.edu/wackerdrive. Figure 24b shows the web site as it would appear on an end-user's computer. Designed for use with an Apple iPod but compatible with any device capable of playing an MP3-encoded audio file, a user visits the project's web site, prints the map, places the audio tracks on a music player, and enjoys the tour. The map and audio files provide a fully immersive experience of the infrastructure during a walk on Wacker Drive along the Chicago River from Navy Pier to Wolf Point.
Welding Workshop

In May of 2007, ITI sponsored a workshop to introduce engineering students to the types of welding techniques commonly used to build civil infrastructure projects. ITI hired Jim Koutsoures, the welding instructor from nearby Evanston Township High School, who supplied five wire welding machines and a plasma cutter for the students' use. Mr. Koutsoures and ITI Research Engineer Dan Hogan spent a Saturday assembling the welding stations and teaching a day-long class. Eleven undergraduate students learned plasma cutting and welding techniques using MIG welders and shielded metal arc welding (stick welding).

Following this one day workshop, Mr. Hogan worked with student members of Northwestern University's solar race car team who wanted to extend their welding knowledge from steel to aluminum. Mr. Hogan provided instruction in gas tungsten arc welding with aluminum. As a result of this training, these undergraduate students successfully designed and welded the entire frame for the solar race car, shown in Figure 25a.

Computer-Aided Drafting Classes

In 2004, ITI supported a student-led initiative to offer formal classes in computer-aided drafting (CAD) using AutoCAD software. The program was an immediate success and helped many undergraduates in civil engineering to obtain summer internships with civil engineering firms. During Year 8 of TEA-21, Northwestern University’s McCormick School of Engineering and Applied Science received fifty-five refurbished Hewlett-Packard workstations through a grant from General Motors. Twenty-one of these machines were used to create a dedicated classroom, shown in Figure 25b, for the sole purpose of teaching CAD. ITI purchased a software package that includes AutoCAD and several other engineering and solid modeling applications. Utilizing these new resources, ITI Research Engineer Dan Hogan and Adjunct Professor Wayne Bielski once again offered a two-quarter course sequence in engineering graphics and computer aided design to twenty undergraduate engineering students.

During TEA-21 Year 8, a survey of the students in the class indicated that they were interested in more in-depth education in the fundamentals of engineering graphics. To meet this need, the CAD instructors collaborated with engineering faculty to design a new course that contains more fundamental graphics instruction; this revised course will be offered during the 2007-2008 academic year.
ASCE Tour of San Francisco Infrastructure

In the fall of 2006, Northwestern University's student chapter of the American Society of Civil Engineers (ASCE), pictured in Figure 27a, began planning an educational alternative spring break 2007 trip for undergraduates in the Department of Civil and Environmental Engineering. After surveying the membership and vetting several promising options, the executive board decided on a trip to the San Francisco Bay Area to tour the construction of the new portion of the San Francisco-Oakland Bay Bridge. The students took advantage of ITI's long-standing relationship with engineers at the California Department of Transportation to arrange a tour of the construction site. The students paid their own air fares and the Illinois Section of ASCE contributed funds to pay for the students' ground transportation. Several members of the faculty and staff served as guides on the trip.

The four-hour tour of the massive Bay Bridge construction site, shown in Figure 26a, was the focal point of the trip. Students also toured the nearby project to replace the obsolete Carquinez Bridge, a through-truss bridge built in 1927. The new bridge, shown alongside the old bridge in Figure 26b, is a concrete segmental box-girder suspension bridge. A tour of the Army
Corps of Engineers San Francisco Bay Hydrology Model and the San Francisco Cable Car museum rounded out the rest of the trip.

At the conclusion of the trip, students made a presentation on their experiences to the Illinois Chapter of ASCE’s executive board as well as to graduate students and faculty of Northwestern’s Masters of Project Management program. This presentation is available on the ITI web site at www.iti.northwestern.edu/sf2007. The report on the trip was very well received by students, faculty, and members of the Illinois ASCE executive board and future alternative spring break trips may become a new part of the chapter’s outreach and education program.

Daniel Hogan Receives Practitioner Advisor Award

ITI Research Engineer Daniel Hogan, pictured in Figure 27b, was selected to receive the 2007 Region 3 Practitioner Advisor of the Year Award from the American Society of Civil Engineers (ASCE). Mr. Hogan was nominated for this award by the officers of Northwestern University’s Student Chapter of ASCE, and he was selected by the ASCE Committee on Student Activities to receive the honor based on his outstanding work and dedication as practitioner advisor to the Student Chapter.

As the primary advisor to the Student Chapter, Mr. Hogan works with the Chapter’s executive board to establish educational workshops, organize on-campus recruitment activities, plan field trips, interact with other Northwestern faculty and staff, and provide educational enrichment opportunities to undergraduates in the Department of Civil and Environmental Engineering. Mr. Hogan’s dedication to these students has allowed the Student Chapter to flourish during his three year tenure as advisor.
SUCCESS IN RESEARCH
Modernizing Design Codes and Practices for Concrete Structures

Principal Investigator: Professor Zdeněk Bažant

Structural engineering design differs fundamentally from other forms of engineering design in that the full-scale test of a structure, such as a bridge or a tunnel, is impossible because the product is far too large to test in a laboratory. For this reason, structural engineers rely heavily on standard, industry-accepted practices and regulatory codes that have been derived through extensive study of the theory of structural and material mechanics. These codes are intended for a wide audience of practicing engineers and thus are kept simple and not necessarily at the cutting edge of research.

ITI researcher Professor Zdeněk Bažant, an expert in the material science of concrete, has conducted extensive research into the trend that structures composed of very large concrete beams tend to fail more frequently than structures composed of smaller beams. Professor Bažant has shown through his research that this phenomenon, known as the size effect, is caused by energy release and stress redistribution due to quasibrittle fracture growth. Further testing of this theory has shown that for an increase of beam thickness from 0.25 meters to 1 meter, the failure probability increases by a factor of one thousand. This calculation has been verified by analysis of recent statistics on infrastructure disasters worldwide.

During Year 8 of TEA-21, Professor Bažant continued his work to modernize these design codes and practices using new models developed through his Institute-sponsored research. During this time, the American Concrete Institute (ACI) Committee 209, Creep and Shrinkage, approved for publication a report that includes the modern model of creep and shrinkage developed by Professor Bažant at Northwestern University. Additionally, his group published a paper proposing a revision to ACI Standard 318 which would introduce modern models into the standard design codes. These publications represent significant technical and political advancements in the design of large concrete structures worldwide.

In addition to technical research, Professor Bažant has continued his campaign to understand and analyze the tragic failures of large concrete structures such as the 1959 collapse of the Malpasset Dam in France and the 1996 collapse of the Koror-Babeldaob Bridge in Palau. In conjunction with the American Society of Civil Engineers (ASCE), the National Academy of Engineering (NAE) and 27 leading structural engineering professors from universities worldwide, Professor Bažant has been working to secure the release of structural data taken in the wake of disasters from political and legal constraints so that these data can be used to improve structural safety around the world.
Autonomous Crack Monitoring as a Public Relations Tool

Principal Investigator: Professor Charles Dowding

Autonomous Crack Monitoring (ACM) technology developed with ITI support is an integral part of ongoing efforts to ensure the availability of aggregates for infrastructure construction in the face of disputes between quarry operators and their neighbors over ground motion from blasting. Throughout the country, and especially in the fast-growing and limestone-rich south Florida region, legal proceedings threaten to curtail the production of limestone aggregate essential for construction and maintenance of roads, bridges, and other transportation infrastructure. The continued production of reasonably-priced aggregate is of grave concern to the Florida Department of Transportation, as described in the Strategic Aggregate Study published by that agency in March 2007.

To distinguish structural damage due to quarry blasting from other causes, ITI engineers installed an ACM system in a residence adjacent to a road aggregate quarry in Naples, Florida. The house, shown in Figure 31a, was purchased specifically so that research equipment could be installed. Special sensors measure the change in the width of cosmetic cracks in the house 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. Every day, the computer-controlled data acquisition system and advanced communication technology automatically transmit data to the ITI laboratory for analysis and reporting on a web site. Test structures such as this are showing that crack response due to blast-induced ground motion is much smaller than response to daily, frontal, and seasonal changes in temperature and humidity.

New Internet display techniques are being employed to combine data acquired from the ITI research instruments with data obtained from a commercial vibration monitoring system used to ensure compliance with local blasting regulations. This combined web site is designed to serve for both research purposes and to communicate with and educate quarry neighbors and the general public regarding compliance with blasting regulations as well as the miniscule nature of blast vibration effects on cracks.

Data acquired by the ACM system is being used to prepare a report to the board of commissioners of Collier County, Florida, in whose jurisdiction the aggregate quarry operates. The ACM data will help provide a quantitative basis for their decisions, rather than relying on the qualitative damage claims reported by nearby residents. Furthermore, the ACM web site will help to assuage the residents’ fears of damage by demonstrating that crack response to blasting at the quarry is insignificant compared to environmental effects and household activities.

One of the biggest barriers to the economical and efficient deployment of any structural sensing system is the necessity to run wiring throughout a structure to reach sensors placed on all elements of interest. This barrier can be eliminated with the use of newly developed wireless sensor networks. Many commercially-available wireless sensor networks exist, but they all have one major flaw when compared with their more expensive wired counterparts: A typical commercial wireless system dependent on standard AA batteries can be expected to run only a few days unless sensing is suspended for the vast majority of the time that the sensors are deployed.

The suspension of sensing is an acceptable solution for a monitoring scenario in which the phenomenon to be measured does not undergo unexpected changes. A significant problem arises, though, when it is important to detect random physical events while still only sensing periodically. In the current state of commercially-available wireless sensor networks, there is no immediate solution to this problem. One must sacrifice battery life for constant awareness of the physical state of the structure being monitored.

ITI-sponsored Civil Engineering researcher Dr. Charles Dowding, Electrical Engineering and Computer Science (EECS) Department faculty Dr. Peter Dinda and Dr. Robert Dick, EECS graduate student Sasha Jevtic, and ITI Research Engineer Mathew Kotowsky worked together in an interdepartmental effort to invent a hardware solution that would allow a wireless sensor network to respond to a random physical event while suspending active sensing for the majority of the time. The technique, called Lucid Dreaming, and the hardware implementation itself, called Shake ‘n Wake (shown in Figure 32a), were published in the proceedings of the IPSN/SPOTS 2007 conference at the Massachusetts Institute of Technology in April, 2007. The full sensing system, pictured in Figure 32b and Figure 32c, has been successfully deployed in a vibration-monitoring setting in a residential structure near the Northwestern University campus. Utilizing Lucid Dreaming, this system runs autonomously for over six months using two AA batteries at each sensor location. This project opens up vast possibilities for the use of wireless sensor networks in transportation-related monitoring and sensing.

Improved Slip-form Concrete

Principal Investigator: Professor Surendra Shah

Concrete used in road construction is a highly complex material that requires the use of a wide variety of techniques and tools to ensure the most durable highways possible. During Year 8 of TEA-21, ITI researcher Professor Surendra Shah, an expert in the science of concrete and director of Northwestern University's Center for Advanced Cement-Based Materials (ACBM), collaborated with researchers at Iowa State University to engineer superior cementitious materials that can reduce construction time and increase reliability and durability of concrete roads.

Typical concrete construction requires complex formwork, vibration, consolidation, or extrusion to attain the necessary shape and strength to perform as designed. Figure 33a shows one efficient method of concrete road construction, slip-form paving, which typically requires extensive internal vibration to be used during the paving process to ensure that the concrete will attain the proper strength and shape. The new concrete, termed Slip-Form-Self-Consolidating Concrete (SF-SCC), allows the use of the slip-form paving technique. Its high flowability eliminates the need for the use of vibrating rollers which have been shown to cause long-term durability issues, but it is shape-stable enough after placement to reduce expensive and time-consuming formwork installation.

Prior to TEA-21 Year 8, Professor Shah's research had already yielded a significant increase in the fundamental understanding of aggregation mechanisms influencing flowability and shape-stability in freshly placed concrete in a laboratory setting. Conventional rheometer testing is impractical outside of a laboratory and the industry accepted slump-flow test was not designed for measuring SF-SCC's critical parameters. Professor Shah's research during Year 8 of TEA-21 focused on developing field-friendly quality control methods to determine whether or not the proper SF-SCC composition has been achieved. A combination of advanced rheological (flowability) testing, and computational fluid dynamics computer programs was employed to qualify the slump-flow test as a practical yet accurate predictor of behavior of an SF-SCC mix at the installation site.

The results showed that the outcome of a standard slump-flow test correlated well with the yield stress of the mixture, while the time it took for the slump-flow test to reach the final diameter was correlated with the ratio of the viscosity and yield stress. The research has shown that a simple mini-slump test on cement paste can be used to determine the most important material properties of newly placed concrete while at a field construction site.
Integrated Condition Monitoring of Downtown Chicago Urban Excavation

Principal Investigators: Professor Charles Dowding and Professor Richard Finno

ITI has a long history of research and field instrumentation deployments involving methods to monitor soil deformations and structural responses adjacent to deep excavations in congested urban areas, including excavations for transportation facilities and for buildings near transportation facilities. ITI has completed successful deployments in downtown Chicago, on the Northwestern University campus in Evanston, Illinois and at a high-rise building in Seattle, Washington. These efforts have developed, evaluated and verified new techniques for acquiring and displaying real time data from a variety of devices, including tiltmeters, inclinometers and automated motorized total stations. This real time sensing, when coupled with newly developed numerical analysis tools, allows continuously updated predictions of ground and structural responses due to nearby excavations. Using this unprecedented flow of information, adjustments to construction procedures can be implemented before any severe damage is done to nearby structures or utilities.

During TEA-21 Year 8, Institute researchers Professors Charles Dowding and Richard Finno collaborated on the
monitoring and evaluation of the Block 37 development in downtown Chicago and its effect on nearby infrastructure. The project involves a major development combining both private and public investment. The public portion of the work is supported by the Chicago Transit Authority (CTA), which is constructing a new subway station with connections to both Chicago airports.

The proximity of important utilities to the excavation support system imposed strict limits on ground movement caused by construction of the deep excavations and tunnel connections. In addition to the usual near-surface utilities, the Blue and Red Line subways in Chicago straddle the 50-foot-deep excavation which covers most of a city block in the center of the Loop, Chicago’s central business district. These active subway lines will be connected through the completed excavation to a common station contained within the commercial development. Of great concern to city regulators is the freight tunnel located within 8 feet of the limits of the project at a depth of 50 feet below the street. Figure 34a shows this 80-year-old freight tunnel that now carries the majority of the fiber optic communication cables for buildings in the Loop. Because of the sensitivity of these cables to damage, the excavation must not adversely affect the tunnel structure. Figures 34b and 34c show the instrumentation layout at the construction site.

The excavation is being made with “top-down” construction methods that allow the high rise commercial development to proceed upward at the same time as the excavation proceeds downward. In this scenario, the excavation will take several years since it does not need to be completed before construction begins on the building’s above-ground components. The extended excavation period of this project provides an unusually rigorous test for the automated monitoring systems with respect to the long-term reliability of their custom-designed electronic control systems in a harsh construction environment. The analysis of possible sensor drift over time is also a major concern for many of these instruments, particularly those based on microelectromechanical systems (MEMS) technology.

ITI has deployed a commercial MEMS-based in-place inclinometer, shown in Figure 35a which autonomously reports the magnitudes of lateral movements that occur from the ground surface down to a depth of 90 ft at a location between the support wall of the excavation and the sensitive freight tunnel. One important finding of this portion of the research is that the MEMS-based sensors in the inclinometer are not stable over long periods of time. Even in the relatively constant temperature ground environment, the commercial system’s sensors indicate lateral movements occurring when no construction activities took place near its location, and in fact none were measured by conventional, manually read inclinometers. Temperature compensation did not correct the problem and thus this type of sensor is not suitable as an in-place inclinometer for long duration measurement applications.

To monitor the effects of the excavation on the tunnel itself, members of the ITI Research Engineering Group installed a network of 17 displacement sensors across the construction joints in the tunnel liner. Figure 35b shows one of these sensors...
success in research spanning a typical construction joint. The sensors are monitored by a custom-designed data acquisition system, shown in Figure 36b which transmits data back to the ITI laboratory each night. If these data show a significant change in the width of the construction joints, the construction can be stopped immediately to avoid damaging the sensitive communication infrastructure in the tunnel.

The main excavation, which began in the fall of 2006, is about 50% complete. ITI, in conjunction with spinoff company Civil Data Systems, LLC, has developed a password-protected website that serves as a repository for all field performance data collected at the site, both autonomously and by conventional manual methods employed by on-site engineers. In addition to sensor readings, this secure, web-based system contains all records of significant construction events at the site so that they may be correlated with any potential anomalies in system readings. Documentation of construction events, recorded manually by field engineers, are transmitted electronically to Civil Data Systems where they are integrated into the autonomously collected data in the web-based archive. This system has been in operation for 1½ years and is used extensively by the City of Chicago engineers to track the progress of the excavation and the ground movements it causes.

As the excavation bottoms out, the effects on the freight tunnel will become apparent and predicted performance will be evaluated. The excavation to date has had no apparent effect on the freight tunnel or the two subway tunnels.
Automation of a Commercial In-Place Inclinometer

Principal Investigator: Professor Richard Finno

During the course of any excavation, it is expected that some amount of deformation of the surrounding soil will occur. When an excavation occurs in a dense urban setting, contractors must work under strict conditions to avoid causing excessive movement in the surrounding soil. The current industry-standard technique of determining whether or not excavation activity has moved soil uses manually operated inclinometers. These devices require personnel to be present at the construction site, and the resultant data can be inconsistent and slow to arrive due to personnel scheduling issues and varying methods of operating the equipment.

The geotechnical monitoring industry has put forth a solution to this problem by the introduction of a new type of inclinometer known as an in-place inclinometer (IPI). An IPI is permanently grouted into a drilled shaft and is designed to permit an engineer to use a laptop computer to gather perfectly consistent digital data while on the construction site. This technique solves the problem of data inconsistency, but does not address the requirement for an engineer to be on-site to take the data and transmit it back to interested parties.

To solve this problem, members of the ITI Research Engineering Group developed and installed a remotely-operable hardware system, shown in Figure 37a and Figure 37b, to take readings automatically from a commercially available IPI that was installed near the excavation for a new subway station in downtown Chicago to monitor the Block 37 development project. Figure 35a shows members of the ITI Research Engineering Group (REG) installing the IPI. The location that required monitoring was isolated in a remote section of an active construction site, away from power and communications connections. Additionally, this system had to be protected from the various pieces of construction equipment and staged materials that would cross over it daily. The battery-operated system transmitted readings from the IPI three times per day via a cellular connection back to the ITI lab in Evanston for a period of 3-4 months before a battery replacement was required. This technique led to a steady stream of consistent data that could be instantly viewed in any web browser.
The John F. Kennedy Bridge carries Interstate 65 over the Ohio River at Louisville, Kentucky. The large through-truss structure has four uplift bearings, two each on the north and south banks of the river. In a 2006 inspection, one of the four anchor bolts restraining the northwest uplift bearing was found to have fractured. The washer on the anchor bolt opposite the failed bolt was observed to be loose, indicating that the bolt was bearing considerably less load than its counterparts. The bearing assembly was also subject to visible vibrations (up to one-half inch amplitude) due to traffic loads. The remaining bolts showed over 20% section loss, and ponding of water was observed at the bases of the anchor bolts, indicating that corrosion and stress corrosion fatigue were likely causes of the bolt failure.

During the summer and fall of 2007, the Kentucky Transportation Cabinet engaged ITI to help characterize the behavior and state of stress of the bearing assemblies under live traffic. ITI engineers applied strain gauges and deployed displacement transducers and accelerometers on all four uplift bearings to compare the behavior of bearings with intact bolts to the bearing with the fractured bolt. Each site was monitored under live traffic for several hours during both daytime and evening. The data revealed that the live strains in the two anchor bolts restraining the northwest bearing were approximately ten times greater than the live strains in the anchor bolts on the other bearings.

In late October of 2007, a replacement anchor bolt was instrumented with strain gages by ITI engineers, as shown in Figure 39a. Live strains in the replacement bolt and three original bolts were measured as the replacement bolt was installed and tensioned. Additional data were recorded for twelve hours overnight after the replacement bolt was tightened. The data showed that the replacement bolt and the three original bolts were bearing more appropriate loads. ITI is scheduled to deploy a system for continuous remote monitoring of live strains in the
anchor bolts in early 2008. This system will help characterize the long-term behavior of the anchor bolt and aid in evaluation of the retrofit.

The REG undertook this instrumentation effort as part of its mission to promote the use of non-destructive evaluation and continuous monitoring as tools in the decision making process of infrastructure owners. Our data from the initial monitoring influenced the retrofit choice made by the Kentucky Transportation Cabinet and readings taken during the installation of the new anchor bolt confirmed that it was functioning as designed. The permanent continuous remote monitoring system will increase confidence in the repair and provide an additional measure of safety unattainable by conventional periodic bridge inspection.
During TEA-21 Year 8, members of the ITI Research Engineering Group (REG) traveled around the country to participate in various meetings of transportation professionals, including meetings of the Midwest Bridge Working Group (MBWG) in December of 2006 in Memphis, Tennessee, and in May of 2007 in Milwaukee, Wisconsin, and the Federal Highway Administration’s (FHWA) National Bridge Preservation Workshop in St. Louis, Missouri, in April of 2007.

Due to the enormous growth of interest in the MBWG in past years, the ITI REG developed and deployed a web conferencing mechanism that allowed transportation professionals to attend these meetings from anywhere with web access. Live video of the presenters and their digital presentations was broadcast over the Internet in real-time to dozens of participants who were not able to travel to the meeting venue. Remote participants could call in by telephone or submit e-mail questions to the REG staff and have questions answered by the current presenter or by any other meeting participant.

Following the success of the Memphis MBWG meeting, organizers of the FHWA National Bridge Preservation Workshop (NBPW) enlisted the ITI REG to provide Internet broadcasting for their St. Louis meeting. This event took place over two days and included not only the standard presenter and slideshow format but two sets of three concurrent breakout panel sessions to be broadcast simultaneously while also allowing remote users to participate in the discussions via a live web-based chat room. The web-based system connected transportation professionals from across the country to the live meetings in St. Louis.
Continuous Remote Monitoring Project
Web Sites

Principal Investigator: Daniel Marron

Over the course of TEA-21, ITI engineers have developed, deployed, and verified techniques for continuous remote monitoring of a variety of structures. Every continuous remote monitoring project has an associated web site that is designed and maintained by the ITI staff in concert with Civil Data Systems, the private spinoff company that has commercialized ITI-developed web-based data display and management technologies. Each of these web sites thoroughly documents the project and makes all collected data available in near real time. ITI’s strategy of automated data collection and display provides project managers easy access to information about the health of a structure and quick warnings at the first signs of trouble with a structure or monitoring system. Project web sites that were deployed or maintained during Year 8 of TEA-21 are listed below.

**Fully Public Web Sites**

**TDR slope monitoring of SR-66 over the Little Blue River**
Suflur, Indiana
Monitored August, 2001 through November, 2005
http://data.itl.northwestern.edu/tdr/sulphur/

**Crack monitoring of a house near an underground aggregate mine**
Frankfort, Kentucky
Monitored January 14 - June 2, 2005
http://data.itl.northwestern.edu/acm/kentucky/

**Crack monitoring of historic Blair House during Pennsylvania Avenue reconstruction**
Washington, District of Columbia
Monitored July 19 - October 7, 2004
http://data.itl.northwestern.edu/acm/house/

**Crack monitoring of a house adjacent to road construction**
Las Vegas, Nevada
Monitored June 17 - September 24, 2002
http://data.itl.northwestern.edu/acm/vegas/

**TDR subsidence monitoring of I-70 over abandoned coal mine**
Cambridge, Ohio
Ongoing monitoring since August, 2001
http://data.itl.northwestern.edu/tdr/cambridge/

**Password-Protected Web sites**

The following sites are password-protected by request of our deployment partners.

**Urban excavation monitoring of Block 37 Redevelopment**
Chicago, Illinois
Ongoing monitoring since November, 2006
http://data.itl.northwestern.edu/block37/

**Crack monitoring of a house near a limestone quarry**
Naples, Florida
Ongoing monitoring since June, 2007
http://iti.jones.civildata.com/

**Wireless crack monitoring test house**
(Featured at IPSN/SPOTS Conference, 2007)
Evanston, Illinois
Monitored February - October, 2006
http://data.itl.northwestern.edu/acm/orrington/

**Urban excavation monitoring at Olive8 Development**
Seattle, Washington
Monitored May 19 - September 11, 2006
http://data.itl.northwestern.edu/adm/seattle/

**Crack monitoring of a house near a limestone quarry**
Milwaukee, Wisconsin
Test house for a variety of instrumentation schemes since 2000; latest tests February, 2004 - August, 2006
http://data.itl.northwestern.edu/acm/milwaukee/

**TDR subsidence monitoring of SR-66**
Sebring, Florida
Monitored April, 2001 through April, 2005
http://data.itl.northwestern.edu/tdr/florida/

**Michigan Street lift bridge life extension**
Sturgeon Bay, Wisconsin
Monitored with various instrumentation schemes since 1995; latest configuration used from July, 2004 through August, 2006
http://data.itl.northwestern.edu/sturgeon_bay/
SUCCESS IN TECHNOLOGY TRANSFER
71 Successful Technology Deployments in 21 States and DC

The impact of ITI-supported research and deployment activities is spread across 71 sites in 21 states and DC, as shown on the map in Figure 44a. 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 the project and site managers with significant concerns about the condition of their facilities frequently contact ITI for advice, support, and technology applications. During Year 8 of TEA-21, the Institute added six new technology deployments while maintaining eight existing deployments.

Infrastructure Technology Institute Web Site

The ITI web site (located at www.iti.northwestern.edu) serves as the clearinghouse for all Institute-related research publications, presentations, articles, talks, seminars and contact information. The web site is also the main avenue by which members of other educational institutions, private enterprise, departments of transportation, and interested individuals are able to benefit from the work of ITI. Analysis of the public's use of the web site, therefore, is important in understanding the impact of the Institute on the world. To that end, the ITI Information Technology staff keeps detailed statistics regarding the usage patterns of the web site.

During TEA-21 Year 8, the ITI web site received 1.2 million total page views with an average of 731 unique visitors per day. Figure 45a shows that daily traffic to the web site spiked during August of 2007, which coincides with the time of the collapse of the I-35W bridge in Minneapolis.

An examination of the top entry pages, shown in Figure 45b, indicates that views of the institute's page on bridge disasters (www.iti.northwestern.edu/resources/bridges/disasters.html) draws many users to the site. As in past years, bridge disasters tops the list of search engine terms that brings visitors to the ITI web site, having nearly double the number of searches as “time domain reflectometry,” the second-most sought topic.
45a. Traffic to the ITI website increased dramatically in the wake of the collapse of I-35W in Minneapolis.

45b. "Bridge disasters" still tops the list of search engine terms that bring visitors to the ITI website.
Further Commercialization of NUCu (ASTM A710 Grade B) Steel

**Principal Investigators: Professor Emeritus Morris E. Fine and Research Professor Semyon Vaynman**

The various types of steel that are commonly used for bridges throughout the United States have physical properties that require extra cost in fabrication and construction. Traditional high strength steels require tempering and quenching in the manufacturing (rolling) process to acquire sufficient yield strength (usually 70 ksi). Welding such steels also requires both preheating and post heating to prevent cracking at the joint. They must also be painted periodically throughout their lifetime for protection against corrosion.

Realizing the potential cost savings that could be brought about by eliminating these requirements, ITI researchers Professors Morris E. Fine and Semyon Vaynman designed and developed a new type of steel that is engineered to avoid these extra costs of manufacturing, fabrication, installation, and maintenance associated with conventional steels. Dubbed NUCu steel, Northwestern’s new material possesses superior strength and toughness of equal to or greater than standard steels, but simpler and less expensive manufacturing and fabrication requirements. It is less costly to manufacture than other steels because it does not require quenching and tempering or thermomechanically-controlled processing to achieve its strength, which means that it can be made by any steel mill in the US. This increases competition and lowers cost. It can be welded without heat treatment, which means less cost for assembly. It has weathering characteristics that eliminate the need for painting. Significant progress was made during 2006-2007 in further commercialization of ASTM A710 B steel:

- The Illinois Department of Transportation completed a study on the machinability of steels used in bridge construction; NUCu Steel was found to outperform traditional bridge steels such as ASTM A36 and ASTM A709 HPS70W.

- NUCu Steel was included in the Next-Generation Rail Tank Car Project, an innovative joint initiative of Dow Chemical, Union Pacific Corporation and Union Tank Car Company, focused on the design and implementation of a new tank car with enhanced ability to transport hazardous chemicals safely. The steel plates that remained from the bridge construction were purchased by Union Tank Car Company for use in this new project. In the initial testing phase, NUCu steel exhibited the highest fracture toughness at low temperatures among all representative steels included in the program. Professors Fine and Vaynman presented the results in a joint paper with representatives of Union Tank Car Company at a tank car symposium in September of 2007.

Additional information about this steel can be found at [www.nucu-steel.org](http://www.nucu-steel.org).

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Acoustic Emission in Material Science

Principal Investigator: Daniel Marron

ITI engineers possess specialized equipment and expertise in the application of acoustic emission (AE) for non-destructive testing which have applications beyond testing of structures. When not in use in the field, the REG has regularly loaned its equipment to Northwestern University’s Department of Materials Science and Engineering for use in transportation related basic research. During Year 8 the REG provided technical assistance to graduate students characterizing novel metal foam materials as part of Professor David Dunard’s research.

Metal foams are a newly emerging class of lightweight cellular engineering materials. They possess a very low mass density, controlled porosity, and a closed-cell structure making them ideal for use as lightweight stiffeners in automobiles, energy absorbers in crash events, ballistic protection, mine blast mitigation, vibration damping, and acoustic insulation. Other researchers are currently studying their applications as structural members of locomotives and crash energy absorbing materials for passenger cars. Aluminum foams in particular are well suited for reducing equipment weight, strengthening collision posts, increasing fire resistance, and enhancing overall passenger safety and comfort.

The REG provided the use of our Vallen AMSY3 AE monitor, sensors, software, and custom fabricated waveguides for use with laboratory load testing machines. Additionally, we trained graduate students in the principles, operation, and interpretation of AE tests. Acoustic emission data gathered during compressive loading and un-loading of samples was used to investigate the internal damage mechanisms which govern the foam’s unique mechanical properties. AE monitoring provided essential information about aluminum foam which could not be obtained by other techniques.
Structural Crack Monitoring of an Historic Church

Civil Data Systems, LLC (www.civildata.com) 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 technologies from the arena of academic research into the private sector.

As the congregation of Grace Episcopal Church in Charleston, South Carolina was preparing to build a major addition, an engineering survey of the 160-year-old church, shown in Figure 48a, revealed serious cracking and differential settlement in both the bell tower and the nave. The addition project was suspended and attention was focused on rehabilitation of the historic structure. In 2006, Charleston-based structural engineers 4SE, Inc. teamed with ITI and Civil Data Systems, LLC, to deploy a system for the continuous remote monitoring of cracks throughout the church building.

The cracks at Grace Church are measured via autonomous crack monitoring (ACM) technology originally developed by a team led by ITI-sponsored researcher Professor Charles Dowding for measurement of cracks in structures exposed to construction and mining vibration. The ACM system at Grace Church comprises sensors throughout the tower and nave attic, and the central data acquisition system, shown in Figure 49a. Electronic instruments may be read more often, more accurately, and more consistently than manually-read instruments. Figure 49b shows an electronic crack sensor next to the visual crack gauge it replaces. Data are automatically displayed on a web site for review by 4SE and concerned parishioners. The Internet data display gives 4SE engineers an at-a-glance indication of any crack changes that would warrant further investigation.

The Grace Church project was a novel deployment of ACM technology, and the goal of the project was, from the beginning, to demonstrate that a private engineering company could successfully deploy an ACM system. Accordingly, ITI engineers taught 4SE personnel to install and operate the sensors and data acquisition hardware and provided one year of technical support, while Civil Data Systems provided Internet data display service and expertise. The first year of the project ended in December 2007; since then, 4SE has continued to employ the crack monitoring system with Internet data display independently of ITI.

48a. The nave of Grace Church in Charleston, South Carolina in which 4SE, Inc. installed an ACM system under the guidance of ITI Research Engineers
The increased awareness of the structural cracking afforded by the autonomous crack monitoring system assures 4SE of the building’s stability on a daily basis. Without the data provided by the monitoring system, 4SE and the Grace Church leadership would likely have been forced to close the nave and hold church services elsewhere during the building rehabilitation. Additionally, all data collected by 4SE is shared with ITI and adds another structure type to our repository of crack response data.

For more information, visit: www.civildata.com
The Midwest Bridge Working Group

Principal Investigator: Daniel Marron

The Midwest Bridge Working Group (MBWG) is a forum for exchanging information about bridges, such as problems, best practices, and research results, 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.

Two meetings were held during Year 8 of TEA-21. A two-day meeting held in Memphis in December of 2006 attracted 76 on-site attendees, including 44 State Department of Transportation employees from 11 states. Ninety-two people attended the two-day meeting in Milwaukee, Wisconsin in May of 2007, including 57 members of 15 state Departments of Transportation. Both of these meetings were broadcast live over the Internet by the ITI Research Engineering Group and dozens of people from across the country participated in part or all of the meetings.

Meeting attendance patterns underscore the value of this forum for highway bridge professions. The attendance has progressively increased 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.

Other regional forums have begun to be formed as word has spread about the importance of this kind of interchange among bridge professionals. During TEA-21 Year 8, ITI helped launch the Northwest and Northeast Bridge Working Groups by designing and deploying web sites for their members.

For additional information see: www.midwestbridge.org
51a. Members of the Midwest Bridge Working Group prepare to tour the Marquette Interchange reconstruction project in downtown Milwaukee, Wisconsin.
Engaging the National Infrastructure Debate

Director Schulz and other faculty affiliated with ITI worked closely with the media in the aftermath of the I-35W bridge collapse in Minneapolis on August 1, 2007. The focus of their contributions was on bridge evaluation and structural health monitoring, the critical importance of the nation’s transportation infrastructure, and the need for timely reinvestment in aging infrastructure.

In addition, Director Schulz and Professor Joseph Schofer contributed to the public discussion on transit funding for northeastern Illinois through media contacts and appearances and the publication of an editorial opinion (Figure 55a, Next Stop Transit Chaos, Chicago Tribune, August 21, 2007).

During the spring and summer of 2007, Director Schulz and Professor Schofer planned the Inaugural William O. Lipinski Symposium on Transportation Policy in conjunction with the Metropolitan Planning Council, the premier regional public interest group in the Chicago metropolitan area. This event was held on October 15, 2007.
Next stop: transit chaos

By Joseph L. Schofer and David F. Schult

Only two years ago in these pages, we warned against the dangers of a “Transit Armageddon,” our metaphor for an impending meltdown of the nearly bankrupt CTA threatening Draconian service cuts and fare increases.

Following normal practice, the Illinois General Assembly at that time bailed-out the problem by shifting responsibility for paratransit to Pace and picking up an insufficient share of the costs, only postponing the day of reckoning. Now northeastern Illinois once again faces a looming transit crisis. And frankly, we are beginning to run out of metaphors: Is this an oncoming “train wreck”? Is transit about to “go over the edge of the cliff”?

The consequences of this failure to ensure a financially stable, high-quality transit system go far beyond transportation, and so we offer a different metaphor: Let’s play truth and consequences. The truth is every person in this region will be harmed to some extent if the extensive transit-service cuts and fare increases scheduled for next month are allowed to take place. And the consequences will be both severe and long-lasting.

The truth is those who currently ride CTA and Pace will be harmed. CTA estimates 100,000 people will literally lose their rides and will have to find some other way to work, school, doctor, shopping or church. Hundreds of thousands of others will have their daily trips unduly lengthen their lives significantly disrupted. But what if you are a driver and never use public transit? The truth is this will affect you too. Those left waiting for the bus are going to try to get to their destinations somehow. Some will walk, some will bike, some will ride-share, and some who can will drive alone. Highways will be even more congested, and driving will become even more frustrating and unpredictable.

The Pace promise to eliminate Metra shuttle services will exacerbate regional congestion because Metra park and ride lots are now full. So drivers, too, will feel the consequences of transit funding madness. All of us—even those who don’t travel much—will pay the price of worsened air quality in a customers will be inconvenienced. The economic losses will be very substantial.

And the impact won’t end there. The Chicago area is on a quest to establish itself as a world-class city, most visibly in its bid for the 2016 Olympic Games. Every city in the last half-century that has hosted the Olympics has first made major improvements to its public transportation system. The truth is Chicago cannot invite the rest of the world here for the quadrennial competition without having first put its transit house in order. The consequence of this craziness of 2007 may be the loss of a once-in-a lifetime opportunity for the region to win big in the 2016 Olympic Games. And this brings us truly dismayed that the consequences that could be are so near.

They spend summer vacation reading more than they admit. I believe. And I think about the books, though not primarily. They have boyfriends, and there’s the learner’s permit to study for, so why doesn’t the driver’s manual count as at least one book?

Teens balance reading, living

By Daphne Simpkins

If my friend Rick, a retired literature professor, went off hiking the Lewis and Clark Trail, he could be very popular with my 15-year-old niece, who is supposed to have read “The Great Gatsby” before school starts.

Katie’s been turning Gatsby’s pages, but not because she thinks F. Scott Fitzgerald’s classic is a page turner.

Katie has mowed out her mother’s sunroom garden, will go to a private school, and has heard versions of this: “If we’re going to spend that much money on school, you are going to read at least one book on that list!”

There have been some heavy-duty conversations about that reading list. Katie hints at the nature of these discussions in between telling me about her new boyfriend.

When the story of her boyfriend began, she said simply: “I had an epiphany that I like him.”

Katie uses words differently than the way I try to teach them to her. I introduced “epiphany” in a discussion about James Joyce.

In an effort to bend, I confessed that I had not finished reading Joyce’s “Ulysses.”

I feel guilty about this, but not enough to try again. That’s how Katie feels about reading.

She would like to be someone who has read. (Life would be easier!) She just doesn’t read very well. (It takes too much time away from spring life.)

Reading is on Katie’s mind though, as it is on the minds of her friends. When the gang congregated at the school-uniform store to buy their new books, I witnessed a fierce compare-and-contrast discussion that first day.

“I hated ‘The Great Gatsby,’” the student clerk who was working her first job complained.

“I liked ‘Wuthering Heights,’” though. It’s a love story.”

“Gatsby was OK,” replied another girl with unruly brown hair.

“‘Catchers in the Rye’ is awesome, and ‘Huckleberry Finn’ is good. When book titles were mentioned, Katie asked, “How big is that book?”

She didn’t mean, what makes it a classic?

Both girls used their thumbs and forefingers to indicate book size.

“Gatsby” got the smallest pinch, although Ernest Hemingway received major credit for writing short sentences. “I’ll read ‘The Great Gatsby’,” Katie declared.

They spend summer vacation reading more than they admit. I believe. And I think about the books, though not primarily. They have boyfriends, and there’s the learner’s permit to study for, so why doesn’t the driver’s manual count as at least one book?

That reading list causes discussions and tensions every summer. I wish I had remembered these tensions earlier, before Rick found the cabin where we once shared shoulders to teach Fitzgerald.

Consequences of proposed transit-service cuts and fare increases in the Chicago region will be substantial if state leaders don’t provide financial aid.

SUCCESS IN MANAGEMENT & POLICY
CENTER OF EXCELLENCE
Center of Excellence

During the TEA-21 years, Northwestern University's Infrastructure Technology Institute has developed and applied a broad array of structural health monitoring tools to highways, bridges, buildings and underground excavation sites across the U.S. These applications have detected and resolved problems of our critical surface transportation infrastructure, helped to ensure some of the essential material resources for infrastructure construction and repair, and facilitated infrastructure projects in the confines of densely-built cities.

Our research engineers have created wireless communications technologies and web-based applications that support remote infrastructure monitoring over extended time periods. Our faculty researchers have also developed new steel and concrete materials that can make building and maintaining surface transportation infrastructure more efficient and less costly.

ITI has built strong relationships with private and public deployment partners through the nation and has established a national reputation that draws more collaborators to our research programs.

Through our work, we have trained a cadre of students at the undergraduate and graduate levels who are carrying their infrastructure design and management skills through the profession, the nation and the world. Through participation in conferences, support of public decision makers, and cooperation with the media, our Director and affiliated faculty have made important contributions to the infrastructure policy process.

These activities and achievements provide us with a strong platform from which to continue to advance surface transportation infrastructure monitoring, management, and development in the years to come.
59a. Dedication of the William O. Lipinski Floor of the Ford Motor Company Engineering Design Center at Northwestern University

Left to Right: Former Congressman William O. Lipinski and Mrs. RoseMarie Lipinski, Northwestern University President Henry S. Bienen, ITI Director David F. Schulz
ITI Founding Director David F. Schulz

September 24, 1949 - October 7, 2007
In Memoriam: Executive Director David F. Schulz

ITI’s founding director, David F. Schulz, passed away on October 7, 2007, after a long illness. Schulz, who also served as Adjunct Professor of Civil and Environmental Engineering, grew ITI from an idea to an active force in infrastructure research and policy. He brought faculty and staff together to make a broad impact on the field of continuous, remote monitoring of civil infrastructure systems. Through his leadership of ITI he facilitated its people, giving them the freedom to discover, achieve, and excel.

He was a devoted teacher, an expert on transportation and public management, and articulate spokesman for civil engineering and infrastructure. David Schulz was the expert that the media turned to first for a clear and informed understanding of contemporary transportation and infrastructure issues.

Professor Schulz graduated from Purdue University in Civil Engineering, and then earned an MBA in Public Management from Northwestern’s Kellogg School of Management, and at the same time pursued graduate studies in transportation engineering at Northwestern. His work experience in transportation planning and public management was both broad and deep. He worked with the Chicago Area Transportation Study and the Southeastern Wisconsin Regional Planning Commission. He was Deputy Public Works Commissioner for Chicago’s Major Jane Byrne, and Budget Director for Mayor Harold Washington. He later became Fiscal and Budget Administrator and then Parks Commissioner for Milwaukee County, Wisconsin. He completed his career in the public sector in a four year term as elected County Executive of Milwaukee County.

David Schulz’s passing is a significant loss for ITI, for the McCormick School of Engineering and Applied Science, for Northwestern University, and for the transportation infrastructure community, but most importantly for those of us who knew him well as a friend, supporter, and mentor.
Appendix 1: Funding Sources and Expenditures

**Funding Sources: $3,969,710**

- **Federal Share**: 47%
- **Research Partners/Faculty**: 50%
- **Northwestern**: 3%

**Total Expenditures: $3,969,710**

- **Center Director Salary**: 50%
- **Faculty Salaries**: 16%
- **Administrative Staff Salaries**: 8%
- **Student Salaries**: 7%
- **Exp Property & Supplies**: 5%
- **Staff Benefits**: 3%
- **Scholarships**: 3%
- **Domestic Travel**: 2%
- **Other Direct Costs**: 2%
- **F & A (Indirect) Costs**: 1%
- **Matching Share**: 1%
Appendix 2: Research Projects

New Projects in Year 8:

A211: Compendium of NDE Methods
PI: Professor Jeffrey Thomas

A215: Design and Application of Low Compaction Energy Concrete for Use in Slip-form Concrete Paving
PI: Professor Surendra Shah

A216: Instrumentation Conference Support
PI: Professor Charles Dowding

Ongoing Projects:

A210: Introducing Size Effect into Design Practice and Codes for Concrete Infrastructure
PI: Professor Zdeněk Bažant

A212: Monitoring and Advising on Lake Villa Bridge
PI: Professor Morris Fine and Professor Semyon Vaynman

A213: Condition Monitoring of Urban Infrastructure
PI: Professor Richard Finno

A214: Autonomous Crack Monitoring
PI: Professor Charles Dowding

A217: Wireless Sensors
PI: Professor Charles Dowding

A218: Improved Condition Monitoring for Bridge Management
PI: Mr. David Prine and Mr. Daniel Marron

Completed Projects:

A438: Micropiles
PI: Professor Richard Finno

A447: Minimizing Shrinkage, Creep and Cracking Damage to Concrete Bridges
PI: Professor Zdeněk Bažant

A453: Life Cycle Management of Steel Bridges Based on NE and Failure Analysis
PI: Professor Brian Moran and Professor Jan Achenbach

A454: Commercialization of NUCu Steel
PI: Professor Morris Fine and Professor Semyon Vaynman

A462: ICCML as a Teaching Tool
PI: Professor Roberta Massabo

A463: NDE of Foundations
PI: Professor Richard Finno

A469: Managing Large Scale Transportation Disruptions
PI: Professor Joseph Schofer

A474: Materials Science of Cement Primer
PI: Professor Hamlin Jennings

A483: Time Domain Reflectometry
PI: Professor Charles Dowding

A484: Biological Age Dating of Infrastructure Cracks
PI: Professor Charles Dowding

A491: Life Cycle Cost of Bridges
PI: Professor Raymond Krizek

A493: Maintenance of NDE Websites
PI: Professor Charles Dowding

A495: Concrete Evaluation Using Guided Waves
PI: Professor Richard Finno

A496: Ultrasonic Technique for In-Situ Monitoring of the Setting, Hardening and Strength Gain of Concrete
PI: Professor Surendra Shah

A498: Informational Website on the Science of Cement
PI: Professor Jeffrey Thomas

A499: Safety Concrete
PI: Professor Hamlin Jennings and Professor Jeffrey Thomas
Appendix 3: Publications by Project

A210: Size Effect on Mean Strength and Failure Risk of Concrete Structure
PI: Zdeněk P. Bažant


A212: Commercialization, Development, and Monitoring of Steel in Lake Villa, Illinois Bridge
PI: Morris Fine


A213: Condition Monitoring of Urban Infrastructure
PI: Richard Finno


APPENDICES


A215: Design and Application of Low Compaction Energy Concrete for use in Slip-form Concrete Paving
PI: Surendra Shah


A217: Wireless Micro Electro-Mechanical System (MEMS)
PI: Charles H. Dowding


Appendix 4: Directory of Key Personnel

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