IDEA

Innovations Deserving
Exploratory Analysis Programs

NCHRP HIGHWAY

New IDEAS for Highway Systems

Annual Progress Report

January 2017

TRB TRANSPORTATION RESEARCH BOARD

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Publications of the IDEA Programs are available on the internet at *trb.org/IDEA*.
Further information is available by contacting the IDEA Program Office by phone (202-334-3310).

Transportation Research Board publications may be ordered directly from the TRB Business Office (202-334-3213), through the internet at *trb.org*, or by annual subscription through organization or individual affiliation with TRB. Affiliates and library subscribers are eligible for substantial discounts.

For further information, contact the Transportation Research Board Business Office, National Research Council
500 Fifth St., NW, Washington, DC 20001, (telephone 202-334-3214; fax 202-334-2519; or email *TRBsales@nas.edu*).

NEW IDEAS FOR HIGHWAY SYSTEMS

An Annual Progress Report of the NCHRP IDEA Program

2017

TRANSPORTATION RESEARCH BOARD

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
NCHRP-IDEA PROGRAM COMMITTEE

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.national-academies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

INTRODUCTION

This annual report presents a summary of progress on investigations conducted as part of the Innovations Deserving Exploratory Analysis (Highway IDEA) program for the National Cooperative Highway Research Program (NCHRP). The NCHRP-IDEA program is jointly funded by the state highway agencies through membership in the American Association of State Highway and Transportation Officials.

NCHRP-IDEA is one of three IDEA programs managed by the Transportation Research Board (TRB) to foster innovation in highway and intermodal surface transportation systems. NCHRP-IDEA nurtures new concepts for technologies, methods, and processes for application to highway systems in broad technical areas such as highway design and construction, materials, operations, and maintenance. The other IDEA programs are:

- Transit-IDEA, which focuses on products and results for transit practice in support of the Transit Cooperative Research Program; and
- Rail Safety IDEA, which focuses on innovative technologies to improve railroad safety and operations.

All of the IDEA programs are integrated to support advances in highway, transit, safety, rail, and intermodal systems.

The IDEA programs are open to all individuals, including entrepreneurs, small and large businesses, and institutions. The program provides an opportunity to investigate new and unproven concepts or to evaluate novel applications of technologies that have been tried, tested, or used for highway, transit, high-speed rail, or intermodal systems practice.

The selection of each IDEA investigation is made by consensus recommendations from the NCHRP-IDEA Project Committee, which comprises national experts in highway and transportation research and practice and whose members are listed at the beginning of this report. A technical expert is selected from outside TRB to serve as a voluntary advisor to mentor each IDEA project. The technical project advisor provides continuing advice and counsel on the IDEA investigation to the investigator and the IDEA program office. To begin the product transfer process from the initiation of each IDEA project, a regional panel of experts is nominated to work with the investigator on product development and transfer to highway practice. The products emerging from the NCHRP-IDEA program support a range of innovative developments for highway user services and for advancing highway systems.

Section 1 of this report presents short descriptions of projects completed before the 2016 program year. The products and results from these projects have been applied or are available for further investigation for application to highway practice. The product status is described under each project. Because of limitations on IDEA resources, not all IDEA concepts that prove feasible can be accommodated for follow-up funding by the NCHRP-IDEA program for product transfer. Section 2 presents reports of investigations on projects active or completed during the 2016 program year; several projects in this section are in the initial stages of investigation. Section 3 presents IDEA projects performed under a cost-sharing initiative with the National Science Foundation.

In selecting new concepts, the IDEA program balances the quest for new products with an understanding of the barriers each product may face for application to practice. Assessing the level of readiness for deployment of IDEA products and results is important in deciding on follow-up actions that are necessary to transfer the IDEA product to practice. The annual report is intended to provide highway practitioners with the background on each IDEA investigation and product in development so that a dialogue on its potential transfer can take place between the investigator and highway practitioners.

The IDEA program welcomes your comments, suggestions, or recommendations on Highway IDEA projects, products, and results presented in this report. Please forward them to the NCHRP-IDEA Program (attention: Dr. Inam Jawed), Transportation Research Board, 500 Fifth St. NW, Washington, D.C., 20001, Phone: 202-334-1461, Email: ijawed@nas.edu.

TABLE OF CONTENTS

SECTION 1: Completed IDEA Projects

SECTION 2: Active IDEA Projects

SECTION 3: NSF/NRC-IDEA Cooperative Projects

SECTION 1
COMPLETED IDEA PROJECTS

This section presents brief summaries of NCHRP-IDEA projects completed before the 2016 program year. The products from these projects have been applied or are available for further investigation for application to highway practice.

ON-LINE REAL-TIME MEASUREMENT AND CONTROL OF AGGREGATE GRADATION IN ASPHALT PLANTS

NCHRP-IDEA Project 1

Felix Alba [Tel.: (801) 264-8294, Fax: (801) 264-8293]
Felix ALBA Consultants Inc., Murray, Utah

Mike Worischeck and Steve Madrigal
STAKER Paving and Construction Company, Salt Lake City, Utah

This IDEA project developed and tested a non-contact video imaging and analysis system (Figure 1) for continuous on-line measurement and flow control of aggregate gradation (size distribution) in an asphalt plant.

The system's hardware consists of a lamp and a line-scan video camera installed over feeder belts from each of the cold bins. The software system incorporates the principles of machine vision, image processing, stereology, and mathematical analysis. Raw images of the aggregates falling onto the master belt are gathered by frame grabbers and preprocessed by image processing boards connected to the data bus of a host computer. Additional image-processing and particle-recognition algorithms determine the chord-length distribution of aggregates from video images. The chord-length distribution is then transformed into volumetric (sieve) size gradations. Proportioning factors for the bins are applied to comply with the job mix formula, and belt feeder speeds are adjusted accordingly to deliver a uniform flow of aggregates automatically.

Field experiments at an asphalt plant show that the system can measure coarse aggregate gradation (3/4", 1/2", 3/8") with a reproducibility better than 2 percent and an accuracy (relative to standard sieving) better than 4 percent on each mesh. The system slightly underreported finer particles, which was attributed to agglomeration of particles under humid plant conditions. The problem was satisfactorily resolved using a semi-empirical procedure. The final report is available from the National Technical Information Service (NTIS # PB97-141642).

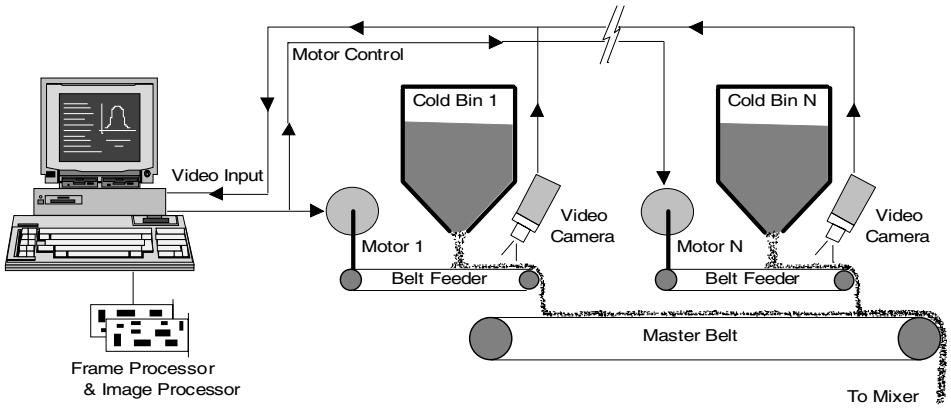


Figure 1

Aggregate gradation control technological concept.

A METHOD FOR MEASURING WATER-STRIPPING RESISTANCE OF ASPHALT/SILICEOUS AGGREGATE MIXTURES

NCHRP-IDEA Project 2

Tinh Nguyen [Tel.: (301) 975-6718, Fax: (301) 990-6891] and Eric Byrd
National Institute of Standards and Technology, Gaithersburg, Maryland

This project developed techniques to assess the stripping resistance of asphalts on siliceous aggregates. The first technique, in situ measurement of the water layer at the asphalt/aggregate interface, is a nondestructive, quantitative technique based on Fourier transform infrared spectroscopy in the multiple internal reflection mode (FTIR-MIR). In this technique, water reaching the asphalt/siliceous aggregate interface is detected by the evanescent wave, which is produced by the total internal reflection of the infrared radiation (Figure 1). This technique provides information on the stripping of asphalt at the molecular level. The second technique relies on the use of a pneumatic pull-off adhesion tester combined with a porous stub that allows water to migrate through the asphalt film to the asphalt/aggregate interface. This reliable and easy to use method provided a rapid laboratory and field test for the water-stripping resistance of asphalt on aggregates.

A number of asphalts from the SHRP Materials Reference Library were used in this investigation. A correlation between bond strength and the amount or thickness of the water layer at the asphalt-aggregate interface was established and formed the basis for a nondestructive test based on FTIR-MIR for determining the water stripping resistance of asphalt-siliceous aggregate mixtures. The concept has proven feasible but the technique is limited to laboratory examination of field samples. The final report is available from the National Technical Information Service (NTIS # PB96-197249).

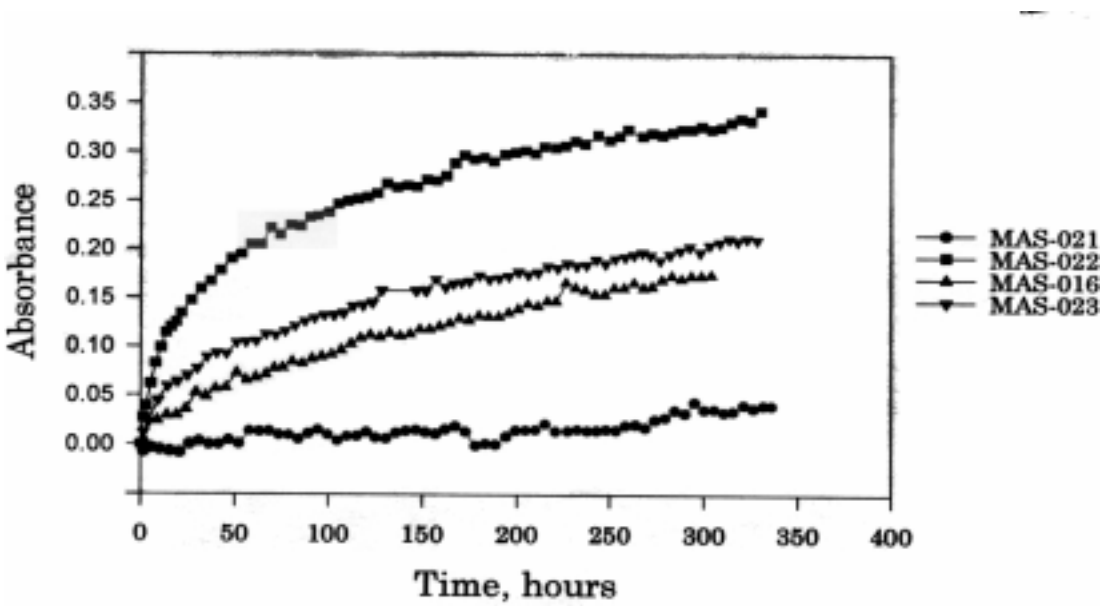


Figure 1

FTIR-MIR intensity of the water layer at the asphalt/siliceous substrate interface for different anti-stripping agents.

GUIDELINES FOR LOW-COST SPRAYED-ZINC GALVANIC ANODE FOR CONTROLLING CORROSION OF REINFORCING STEEL IN MARINE BRIDGE SUBSTRUCTURES

NCHRP-IDEA Project 3

Alberto A. Sagues [Tel.: (813) 974-2275, Fax: (813) 974-3651]
University of South Florida, Tampa, Florida

Rodney G. Powers
Florida Department of Transportation, Gainesville, Florida

The project developed guidelines for using sprayed zinc (as a sacrificial anode system) for protecting reinforcing steel (acting as the cathode) from corrosion in marine bridge structures. Sacrificial cathodic protection by means of sprayed-zinc galvanic anodes is a low-cost alternative to conventional cathodic protection of these substructure components. The surface of the spalled concrete and exposed rebar is abrasively cleaned and sprayed with zinc, using commonly available metallizing equipment. An electrical connection between the zinc and the steel is established directly. Concrete patching is not needed unless required for structural reasons, in which case the zinc is applied over the repaired concrete and a stud is used to connect the steel with the sprayed zinc. The finished cost ranges from \$60 to \$120/m^2. The method is applicable to a wide variety of structural components.

Laboratory and field experiments demonstrated the feasibility of the proposed approach. Additional performance data were obtained in a large-scale field application (Figure 1). The fieldwork was carried out in collaboration with the Florida DOT during the rehabilitation of the Howard Franklin Bridge on Tampa Bay (State Project 15190-3487). The tests showed adequate probe and steel polarization (typically exceeding the 100-mV depolarization criterion) with moderate current demand (below 1 mA/sq ft) indicating continued cathodic protection of steel reinforcement in the substructure. Based on field results, a manual on the use of sprayed zinc for the protection of marine substructures was prepared. A special two-page IDEA product report, Sacrificial Sprayed-Zinc Galvanic Anode System for Corrosion Protection of Reinforced Concrete in Marine Substructures, was released in June 1995. The final report is available from the National Technical Information Service (NTIS # PB97-141766).

Figure 1

Field installation, Bahia Honda Bridge, Florida Keys.

EXPLORING THE FEASIBILITY OF REPLACING LATEX WITH ASPHALT EMULSION FOR USE IN BRIDGE DECK OVERLAYS

NCHRP-IDEA Project 4

Jan Olek, Menashi D. Cohen [Tel.: (317) 494-5018, Fax: (317) 496-1364]
and Sidney Diamond, Purdue University, West Lafayette, Indiana

This project explored the feasibility of using asphalt emulsion as a low-cost replacement for latex in portland cement concrete for highway applications. Research results showed that addition of emulsion reduced the workability and compressive and flexural strengths of concrete as compared with conventional concrete. The addition of emulsion also increased the amount of entrained air in concrete, which partly accounted for the strength reduction. The asphalt-modified concrete, however, showed excellent freeze-thaw durability (Figure 1). Moist curing appeared to have a better effect on strength development than air curing. Tests also showed that using pozzolanic materials (fly ash or silica fume) in combination with asphalt emulsion significantly reduced the chloride permeability of mortars.

Additional research and field evaluation are needed for the implementation of this product for highway applications. The final report is available from the National Technical Information Service (NTIS # PB95-267704).

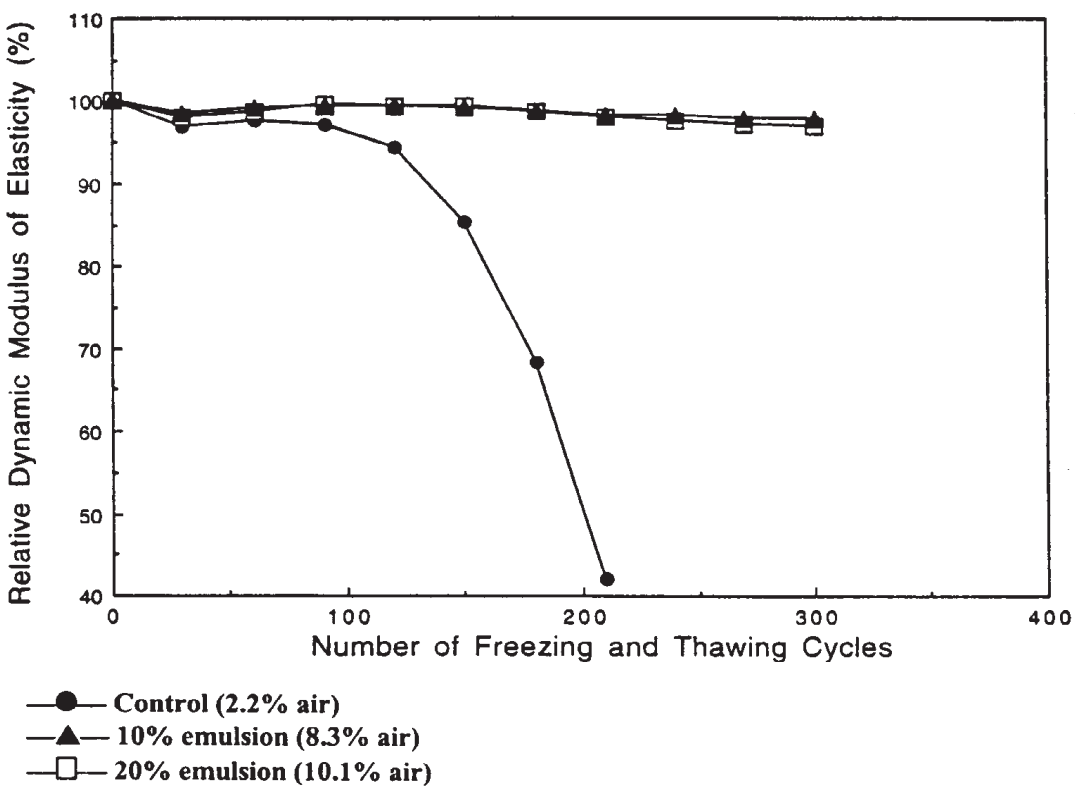


Figure 1

Freezing and thawing test results for plain and asphalt emulsion-modified concrete.

MAGNETIC RESONANCE FOR IN SITU DETERMINATION OF ASPHALT AGING AND MOISTURE CONTENT

NCHRP-IDEA Project 5

J. Derwin King [Tel.: (210) 684-5111, Fax: (210) 647-4325] and Qing Wen Ni
Southwest Research Institute, San Antonio, Texas

This project developed and tested a magnetic resonance-based system for in-motion inspection of asphalt for rapid determination of pavement aging, moisture content, and the condition of asphalt concrete roadways.

A set of asphalt samples from the SHRP Reference Materials Library was used, representing a wide variation in properties that affect asphalt aging. The results showed good correlation of the nuclear magnetic resonance (NMR) data with the viscosity parameters and with aging induced by loss of volatiles and by accelerated oxidation. Electron proton resonance (EPR) studies provided additional information and correlations. EPR studies of neat asphalts showed typical hydrocarbon response from all samples plus a large multipeak vanadium spectrum from some samples. This EPR vanadium signal provides a basis for correction of the NMR data to make the pavement inspection independent of the types of asphalts and aggregates.

The combination of NMR and EPR techniques was shown to be an effective tool for assessing asphalt condition in pavements. The two resonance systems can use the same magnet and be easily integrated to work in tandem to determine asphalt condition. The system can be mounted on a small trailer for mobile in situ inspection. A recommended field design configuration is shown in Figure 1. Extensive field verification of the system is required for the IDEA product transfer. The final report is available from the National Technical Information Service (NTIS # PB95-267688).

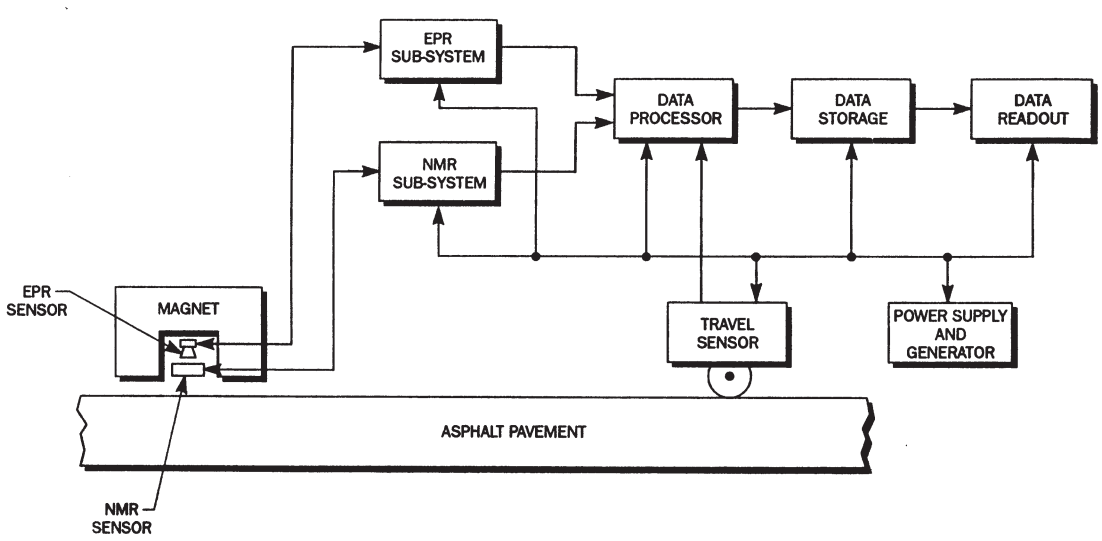


Figure 1

MR system for in situ asphalt inspection.

EXCOGITATED COMPOSITE MULTIFUNCTIONAL LAYER FOR PAVEMENT SYSTEMS

NCHRP-IDEA Project 6

Barry J. Dempsey [Tel.: (217) 333-3963, Fax: (217) 333-4464]
University of Illinois, Urbana-Champaign, Illinois

The project evaluated a concept of a three-dimensional composite layer design for pavement construction for improved performance and service life. The excogitated composite multifunctional (ECM) layer (Figure 1) will satisfy multiple functions in the pavement system by providing for subbase layer-subgrade separation, subbase shear strength, subbase tensile strength, drainage, and protection of the subgrade from surface infiltration.

The work involved material selection and design and fabrication of the composite layer. A number of synthetic and natural materials were evaluated and several performance-related parameters of the layer were measured. The layer strength was increased significantly by changing the polymer blend in the polyethylene structure and by utilizing a stiffer geotextile. The load-deflection relationship and shear stress for this new layer also showed improvements.

The composite layer was evaluated and compared in large-scale laboratory tests. A test cell, 6 ft by 6 ft by 40 in., was constructed with an overhead frame for mounting a hydraulic ram to perform dynamic testing of the composite layer. Load deformation tests showed that the composite layer performed far better than the geotextile and geogrid sections and sections with no separation layer. The large-scale laboratory tests were followed by a limited field test of the composite layer with satisfactory performance results.

The composite layer now needs to be tested in a full-scale field setting. The ECM layer can be shipped to the construction site in rolls and can be easily placed by roll-out procedures similar to those used for geotextiles.
The final report is available from the National Technical Information Service (NTIS # PB96-154414).

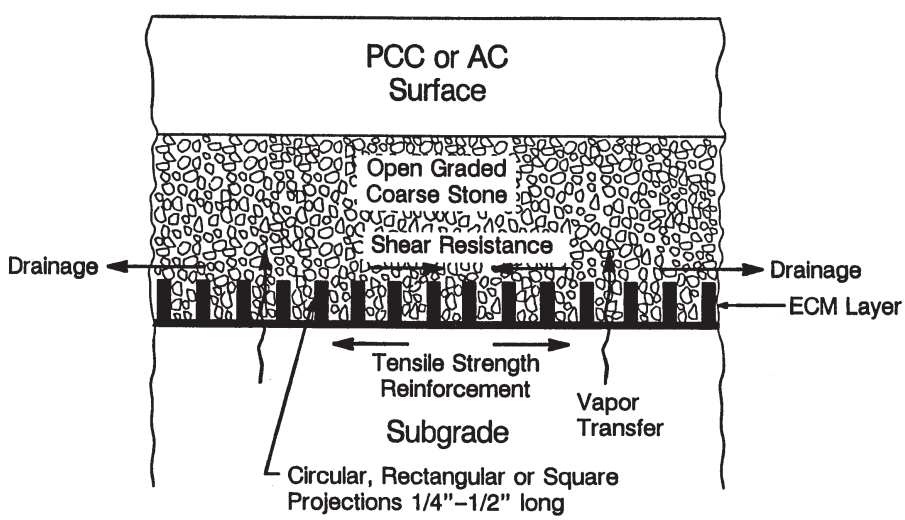


Figure 1

ECM layer concept and functions.

STRATEGY FOR COATING STRUCTURAL STEEL WITHOUT STRINGENT BLASTING REGULATIONS

NCHRP-IDEA Project 7

Simon Boocock [Tel.: (412) 687-1113, Fax: (412) 697-1153]
Steel Structures Painting Council, Pittsburgh, Pennsylvania

The project developed and evaluated an environmentally safe technique for applying durable protective paint coating on structural steel without the need for blast cleaning. The concept is illustrated in Figure 1.

The process employed new high penetration primers with low- or non-organic volatiles. The paint application technology involved embedding collapsible glass microspheres in the primer, which were then broken to interlock the primer with the topcoat. Fracturing the spheres provides a surface profile that "locks in" the topcoat and ensures a strong bond between the primer and the topcoat. Laboratory tests showed that thermal spray-coating systems employing nonvolatile organic compound penetrating sealers loaded with glass microspheres are a viable option for overcoating aged alkyd paints. The addition of glass microspheres to the penetrating primer, however, had no significant effect on the performance of the thermal spray-coating systems.

Microscopic examination of the embedded broken microspheres indicated the potential for enhanced adhesion between the primer and the thermal spray topcoat. The liquid-applied topcoat was also found to be a viable option for overcoating aged alkyd systems.

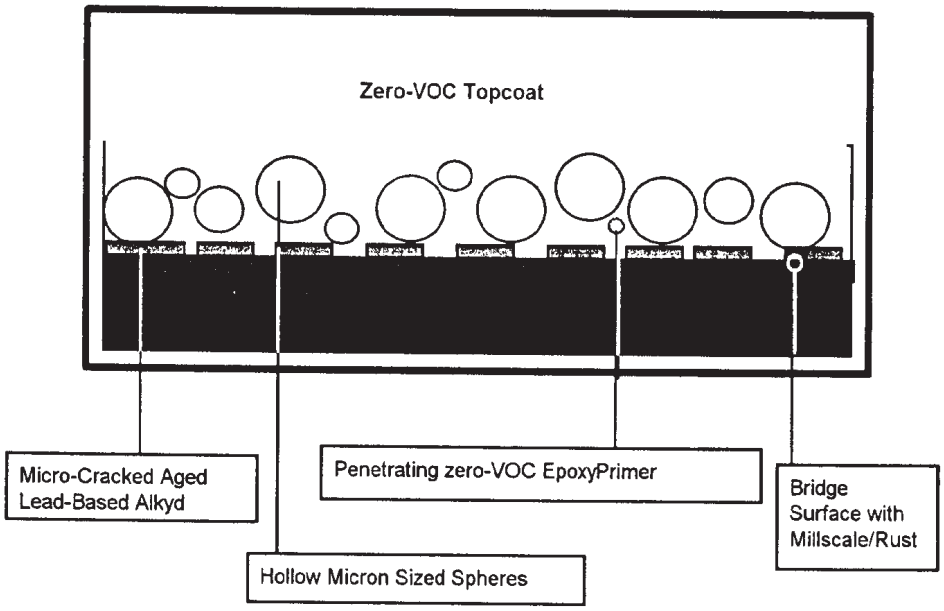


Figure 1

Product applied to bridge use.

A series of factorially designed laboratory tests were performed in accordance with standard procedures to determine the effectiveness of the coating system regarding adhesion, impact resistance, and corrosion protection. The results were satisfactory but not significantly superior to the current practice.

The implementation of this new painting process on highway steel bridge structures will require extensive testing in collaboration with state highway agencies. The final report is available from the National Technical Information Service (NTIS # PB96-147996).

CONSERVATION TRAFFIC CONTROL LOAD SWITCH

NCHRP-IDEA Project 8

Gregory A. Filbrun [Tel.: (614) 895-1212, Fax: (614) 895-1213], Paul Wiese, and Greg Winthrow, CLS Incorporated, Westerville, Ohio

The project developed and tested a new microprocessor-based switch system (Conservation Traffic Control Load Switch), which significantly enhances the service life of traffic lamps by reducing the initial current surge in the filament coil. The conservation load switch system mitigates early lamp failure by increasing the voltage to the lamp over an 80-msec ramp-up period and then regulating it at a preset level somewhat below the standard line voltage. The prototype switch system was shown to function satisfactorily in the traffic control unit (signal cabinet). The system uses much less (about 30 percent less) electrical energy to operate the lamp and can be easily retrofitted into existing applicable signal cabinets. It uses the same connector, housing, and mechanical packaging as the standard National Electrical Manufacturers Association (NEMA) Model 170 and Model 200 traffic control load switch units. It can potentially meet all NEMA and Institute of Transportation Engineers (ITE) specifications. The switching system can be installed within a minute in any unmodified signal cabinet (Figure 1).

Operational tests and field evaluations of the switch system were performed. Over 100 units were assembled and sent to a number of state highway agencies for testing. The feedback from highway agencies confirmed the laboratory test results. A continuation project was awarded (NCHRP-IDEA #26) to perform additional field operational tests of the switch system in collaboration with state highway agencies and to develop product transfer and marketing strategies.

A special two-page IDEA product report, Microprocessor-Based Lamp Switch System Quadruples Traffic Lamp Life and Prevents Early Lamp Burn-out, was released in September 1995. The final report is available from the National Technical Information Service (NTIS # PB97-143838).

Figure 1

Installation of conservation load switch in standard cabinet.

CORROSION-RESISTANT STEEL REINFORCING BARS

NCHRP-IDEA Project 9

David Darwin [Tel.: (913) 864-3826, Fax: (913) 864-3199], Carl E. Locke, Jr.,
Matthew R. Senecal, Jeffrey L. Smith, and Shawn M. Schwensen
University of Kansas, Lawrence, Kansas

The project evaluated the corrosion resistance and mechanical properties of steel rebars produced by new microalloying and rolling procedures that exhibit superior corrosion resistance properties. The bars possess a lower carbon content than is usual in U.S. practice and contain copper, chromium, and phosphorus as additional alloying elements. The phosphorus content exceeds that allowed in ASTM specifications. The bars are quenched and tempered immediately after the rolling operation.

Test results (corrosion potential and time-to-corrosion) showed that microalloying decreased the corrosion rate by one-half compared with conventional steel (Figure 1). Quenching and tempering heat treatment in conjunction with microalloying further enhanced the corrosion resistance of steel. The apparent corrosion-resisting mechanisms involve the reduction of microfractures in the surface from the rolling operation due to the quenching and tempering process and the formation of a corrosion-retarding layer of copper chloride–copper hydroxide and iron–chromium oxide at the steel surface. The latter is a poor conductor and thus reduces the corrosion rate. Quenching and tempering had a beneficial effect on the mechanical properties of the steel. Both the yield and tensile strengths were improved. The test results also showed that a phosphorus content in excess of that allowed under current ASTM requirements did not cause the corrosion-resistant steel to be brittle. The new steel also performed well when used in conjunction with epoxy coating.

Extensive field validation tests are required to transfer project results to practice. The final report is available from the National Technical Information Service (NTIS # PB96-147988).

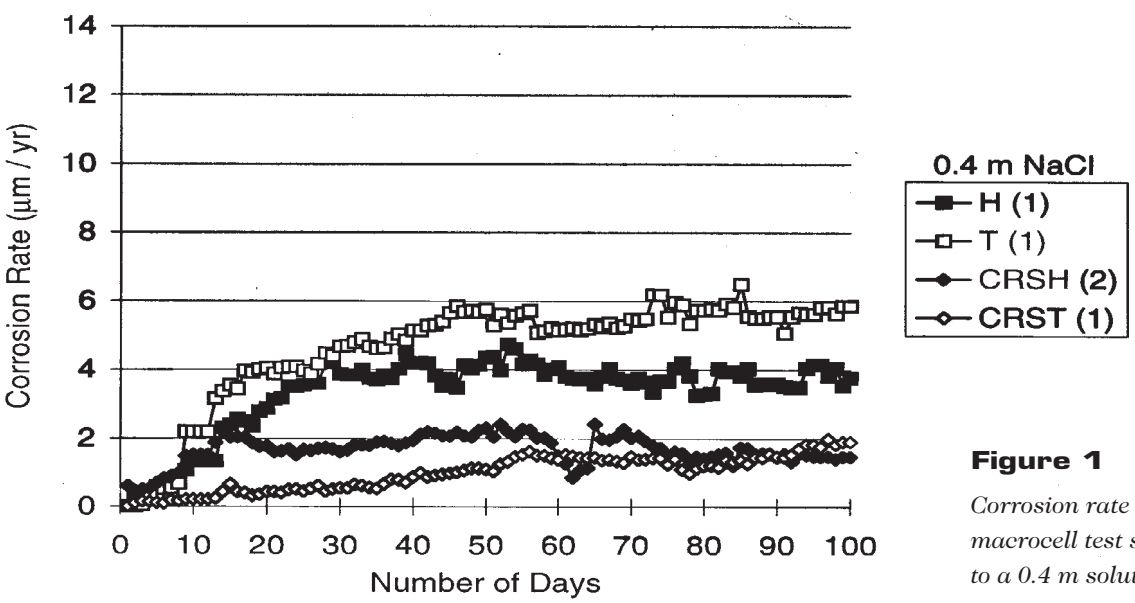


Figure 1

Corrosion rate versus time for macrocell test specimens subjected to a 0.4 m solution of NaCl.

METALLIC COATING FOR CORROSION PROTECTION OF STEEL REBARS

NCHRP-IDEA Project 10

Angel Sanjurjo [Tel.: (415) 859-5215, Fax: (415) 859-2111], Kai Lau, David Lowe,
Palitha Jayaweera, and Gopala Krishnan
SRI International, Menlo Park, California

The project was a follow-up investigation from a previous SHRP-IDEA project in which a corrosion-resistant Si-Ti coating on steel rebars was produced using the fluidized bed technology. The current project was intended to scale up the process to coat rebars up to 3 ft long, as well as to evaluate the coated rebars for corrosion resistance, structural integrity, flexibility, and mechanical properties.

A bench-scale reactor system was designed for coating 3-ft-long steel rebars. The scale-up reactor system appears feasible but may not be adaptable for commercial scale use. The researchers, however, discovered that a strong and coherent coating could be produced simply by spray painting the Si-Ti mixture (along with a flux) followed by a low-heat treatment at about 600°C (Figure 1). This process appears more practical for scaling up for commercial use than the more complex fluidized bed technology.

Because the paint-and-heat or sprayed coatings are not sacrificial, they will provide much superior corrosion protection for a long time. Corrosion tests showed that these coatings reduced the corrosion rate of steel rebars in chloride environments by over one order of magnitude. The preliminary projected cost for the coating appears similar to that of polymer coatings.

The final report is available from the National Technical Information Service (NTIS # PB96-148002).

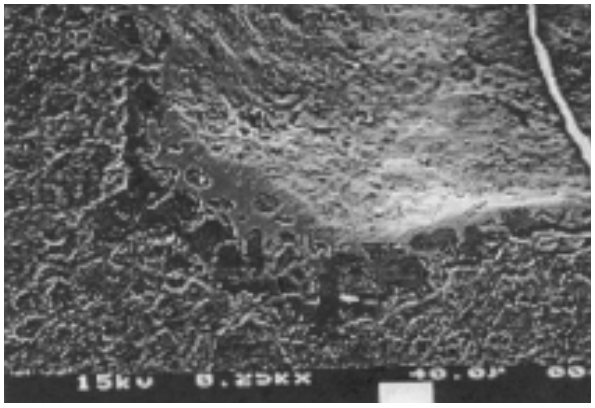


Figure 1

Scanning electron micrograph of coating prepared by paint-and-heat metallization.

REHABILITATION OF STEEL BRIDGES THROUGH THE APPLICATION OF ADVANCED COMPOSITE MATERIALS

NCHRP-IDEA Project 11

Dennis R. Mertz [Tel.: (302) 831-2735, Fax: (302) 831-3640]
University of Delaware, Newark, Delaware

This project evaluated the feasibility of using advanced composite materials for rehabilitation of steel highway bridges as an alternative to conventional repair methods. Stage 1 work performed modeling, fabricating, and testing of two flange repair schemes and proved the feasibility of the concept. Service-load testing on the repair schemes verified that the composite plates increased the stiffness of a section. A finite element model was applied to determine the desired geometry of the composite plate. Rehabilitation schemes were developed and tested for a variety of field geometrics. Figure 1 shows various rehabilitation concepts. Test results showed good agreement with model prediction for stiffness enhancement. Increases in girder flexural modules of 20 to 30 percent were found to be attainable, which corresponds to the level of losses expected to be of concern in deficient bridge girders. Sandblasting the steel surface and using a saline pretreatment resulted in best durability for most adhesives. Results also show accelerated bonding through induction heating to be a viable rehabilitation technique in the field. Work in Stage 2 involved additional service load testing of fabricated scale beams, adhesive durability testing, and large scale testing of composite repair of both virgin and corroded steel beams. The results show improved strength and fatigue life of steel components by composite materials. A concern is bond failure, which occurred frequently in small tests. This failure, however, did not occur in large girder tests. Field validation of the technique is required for product transfer to practice. The final report is available from the National Technical Information Service (NTIS # PB97-141964).

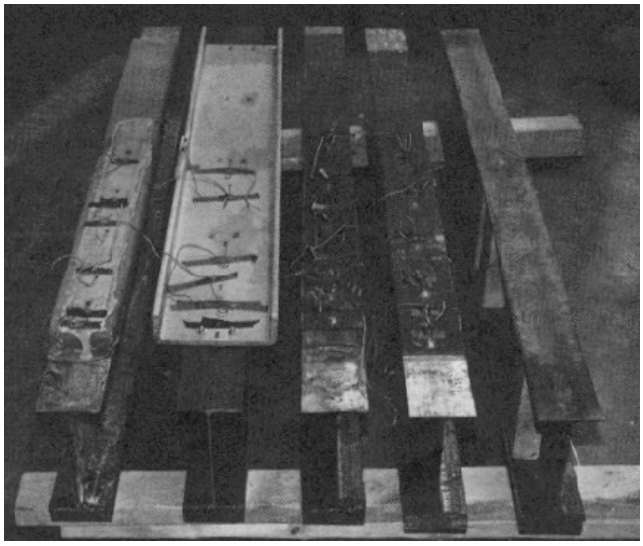


Figure 1

Basic rehabilitation geometries.

ADVANCED TESTING OF AN AUTOMATIC NONDESTRUCTIVE EVALUATION SYSTEM FOR HIGHWAY PAVEMENT SURFACE CONDITION ASSESSMENT

NCHRP-IDEA Project 12

Sidney Guralnick [Tel.: (312) 567-3549, Fax: (312) 567-3634] and Eric S. Suen
Illinois Institute of Technology, Chicago, Illinois

The project refined and field-tested a prototype nondestructive evaluation system previously developed in an FHWA-sponsored project. The system utilizes the Shadow Moiré interferometry method and measures both vertical surface displacement and changes in slope of surface distress. The IDEA research focused on improving the Shadow Moiré inspection technology and completing a comprehensive user-friendly software package to assess road surface distress. Improvements involved an increase of maximum vehicle acquisition speed of 22 percent, new light emitters with special horizontal condensers to improve interference fringe pattern contrast, lightweight grating, as opposed to two smaller gratings for greater road coverage, and a more accurate distance measuring system. Refinements in post-processing included rewriting C-based image analysis algorithms so that they run under the Pentium personal computer (PC) processor rather than slow video processors. Improvements in image digitization were also realized, such as improved image data integrity and large increases in throughput, allowing for faster post-processing of videotape images.

The prototype road inspection vehicle (Figure 1) was an enclosed uni-axle trailer and was capable of acquiring road surface distress information at velocities up to about 55 mph, allowing users to categorize, rate, and determine roadway locations of all out-of-plane surface deformations along a particular roadway. The cost of the road inspection system is estimated to be about $60,000.

Ford Motor Company donated a full-size field vehicle to replace the trailer system for performing field tests. The system is ready for field validation under operational conditions.

A special two-page IDEA product report, Surface Condition Assessment and Profiler System for Pavements Using Shadow Moiré Interferometry, was released in June 1995. The final report is available from the National Technical Information Service (NTIS # PB97-151617).

Figure 1

Automated road inspection vehicle during field testing.

NEW ADDITIVE FOR IMPROVED DURABILITY OF CONCRETE

NCHRP-IDEA Project 13

Jack E. Stephens [Tel.: (203) 486-4014, Fax: (203) 486-2298] and James Mahoney
University of Connecticut, Storrs, Connecticut

James R. Humphrey
Todd Chemical, Cheshire, Connecticut

The project evaluated a class of organic compounds (diammonium salts of alkenyl dicarboxylic acids) as additives for concrete that may improve the concrete's durability against freezing and thawing and reinforcement corrosion. The material also reduces heavy metal leachate, potentially making environmentally acceptable the use of incinerator ash (both bottom and fly ash) in concrete.

Freeze-thaw, compression, and indirect tension tests were performed to determine the effect of additives on concrete properties. Porosity and permeability measurements also were done to determine additives' effectiveness in preventing chloride salt solution from accessing the steel. Results showed a rather adverse effect of admixtures on concrete workability and strength. Also, the permeability was not significantly improved. However, the concrete showed excellent freeze-thaw resistance (Figure 1). Furthermore, leaching tests showed that the admixtures significantly decreased the leaching of lead from the concrete. The admixtures have potential to be effective air-entraining agents for concrete for improved freeze-thaw durability. The final report is available from the National Technical Information Service (NTIS # PB96-147970).

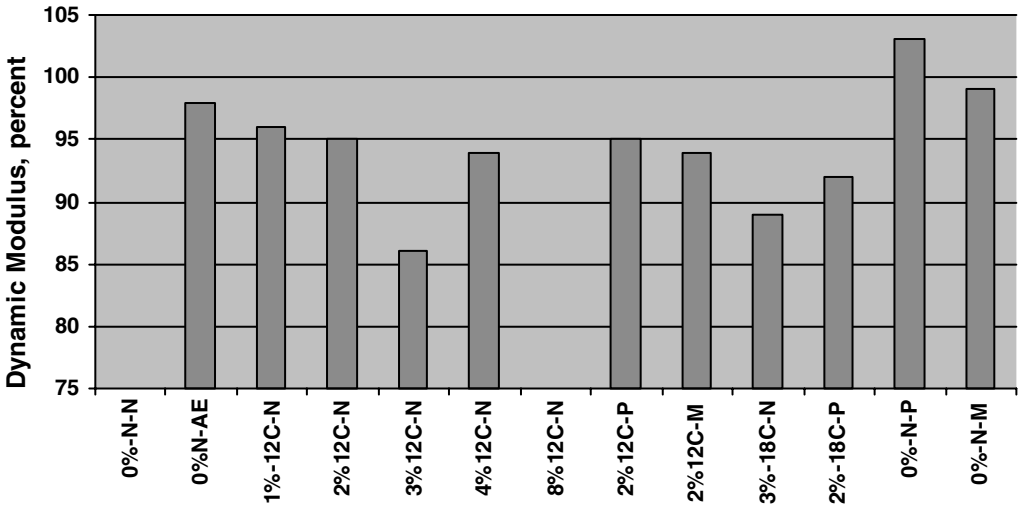


Figure 1

Freezing and thawing test results for concrete specimens containing organic additives.

UNREINFORCED, CENTRALLY PRESTRESSED CONCRETE COLUMNS AND PILES

NCHRP-IDEA Project 14

D.V. Reddy [Tel.: (407) 367-3443, Fax: (407) 367-3885]
Florida Atlantic University, Boca Raton, Florida

Paul F. Csagoly
Clearwater, Florida

This project tested the concept of centrally prestressed, unreinforced concrete (CPUC) columns and piles for application to highway structural systems. In the CPUC column, the innate incompatibility between concrete and steel is eliminated by removal of the latter; but flexural resistance and ductility are restored by the application of a centrally located prestressing tendon or closely spaced strands. This concentration of steel results in a significant increase in concrete cover for better corrosion protection without loss of strength.

Specimens of CPUC columns and piles were evaluated to assess the feasibility and practicality of the concept. Test results showed that the prestressed column provided a substantial increase in effective cross section to withstand both axial and shear loading compared to conventional reinforced concrete columns. Figure 1 illustrates the second innovation, labeled as an extended performance flexural (EPF) device. The EPF device is not a shock isolator, but a completely structural device intended for connecting pier columns to either the superstructure or the substructure, or both, and transmitting considerable moments while permitting large rotations. It sustained several cycles of rotations up to ±10 percent without damage. Analytical application of the EPF device to a bridge structure indicates close to one order of magnitude increase in the fundamental period of vibration and a decrease of 65 percent in the equivalent static lateral force used in earthquake design. Large-scale field tests on actual highway structures are needed for implementation of this IDEA product. The final report is available from the National Technical Information
Service (NTIS # PB97-160816).

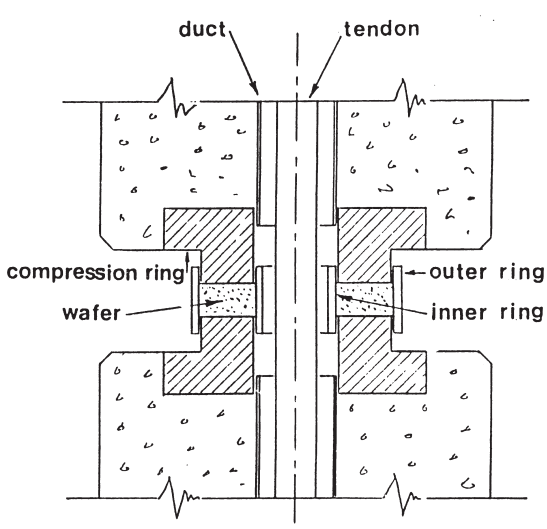


Figure 1

EPF device schematic.

PORTABLE LASER ROAD CREW WARNING SYSTEM

NCHRP-IDEA Project 15

Keith Higgenbotham [Tel.: (703) 367-6838, Fax: (703) 367-2370] and Rudolph Gammarino
Lockheed Martin Corporation, Manassas, Virginia

The project applied a laser technology to develop a portable warning system to improve safety for highway workers (Figure 1). The system consists of a battery-powered master laser transmitter mounted on a traffic cone, one or more laser receiver-transmitters also mounted on traffic cones, and a worker-notification warning system. A pulsed laser beam from the master laser transmitter is directed toward the laser receiver-transmitter located at the end of taper. The beam is detected by the receiver at that point. The detection event triggers the laser that is co-located with the receiver, and it transmits laser pulses toward a second receiver located at the end of the work zone. The retransmitted beam is received by the final detector at the end of the work zone. If the first beam or the retransmitted beam is interrupted by an errant vehicle at any point, the lack of a laser signal at the final receiver causes an electrical signal to be generated that activates an alarm system, notifying workers to take evasive action. In this way, the laser beam acts as an electro-optical barrier along the taper and the work zone.

The system configuration can be modified to suit the size and nature of highway maintenance activity. A field demonstration was carried out at the contractor's facility in California with satisfactory performance. The final report is available from the National Technical Information Service (NTIS # PB97-143861).

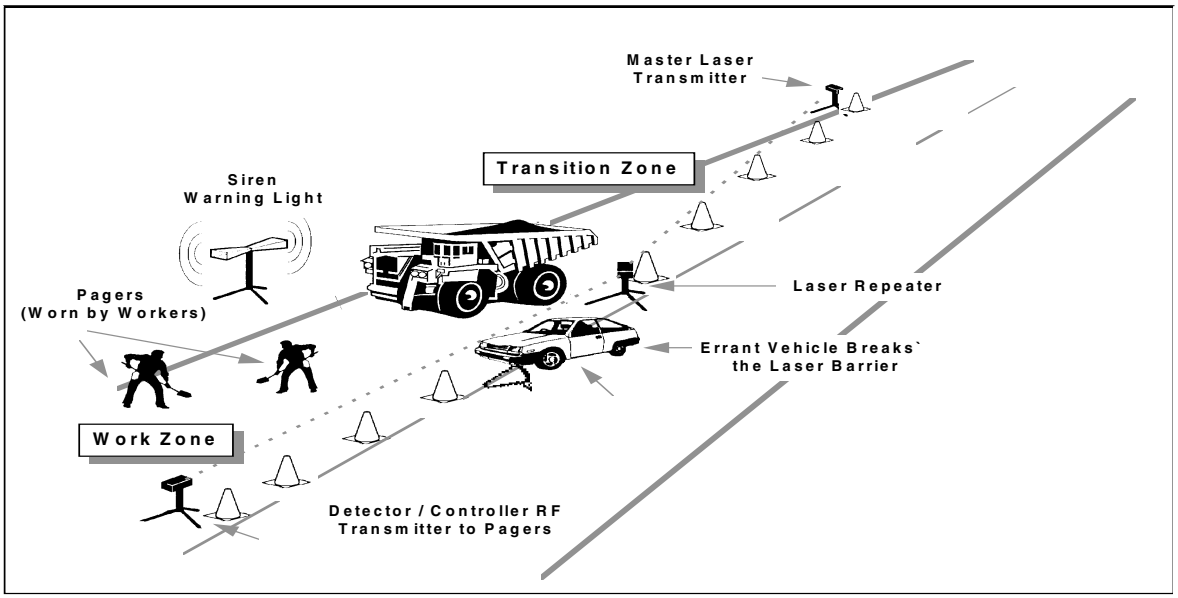


Figure 1

Road crew portable laser warning system.

LASER REMOVAL OF PAINT ON PAVEMENT

NCHRP-IDEA Project 16

Hans Pew [Tel.: (801) 225-0930, Fax: (801) 221-1121] and James Thorne
MOXTEK, Incorporated, Orem, Utah

The goal of this project was to develop a mobile highway paint removing system based on pulsed laser. The concept was to apply a succession of short, intense laser pulses that create destructive shock waves rather than heating paint to the point where chemical reactions occur. The product's impact will be (a) the elimination of the usual environmental contaminants such as grit, dust, smoke, and chemicals; (b) prevention of damage to pavement during paint removal; and (c) complete removal for compliance with federal codes that require no visible trace of temporary markings on newly constructed roadways. Work in the initial phase of the project established the feasibility of using a laser to remove markings from highway materials. A prototype portable laser was developed for removal of paint from the pavement of highways, parking lots, and airfield runways. The removal was clean, but not fast. Several methods that would possibly speed the removal were defined and investigated. The dominant variables were power density (watts/cm^2) and pulse duration. Work then focused on selecting and testing a laser that could be used to demonstrate removal of markings in field conditions. The laser needed to meet certain specifications and still remove a painted stripe as rapidly as possible (hopefully at a rate that is competitive with sandblasting). The requirements included reliability in a highway environment (flash lamps easy to change, realignment not necessary, etc.), optimum pulse energy density, pulse duration and wavelength, and, most important, maximum average power for the size and cost of the laser. Consequently a new more powerful system was designed.

The present system uses a new high-power laser that produces short pulses at 1.06-μm wavelength and has shown promising results on asphalt and concrete surfaces in laboratory tests. The paint removal efficiency of the laser system also depends on the type of the paint. Epoxy-based paints were removed with better efficiency than other paints. The system was attached to a mobile carriage for field demonstration. Further optimization and field trials are needed in order to establish the effectiveness of the system in the field.

The final report is available from the National Technical Information Service (NTIS # PB2000-104071).

SELF-CONTAINED PORTABLE DEVICE FOR SHRP BINDER TESTING: FIELD QC/QA TESTING WITH THE DUOMORPH

NCHRP-IDEA Project 17

Samuel H. Carpenter [Tel.: (217) 333-4188, Fax: (217) 333-9464]
University of Illinois, Urbana-Champaign, Illinois

The project developed a portable field device (Duomorph) for testing asphalt binder properties that will complement the SHRP (Strategic Highway Research Program) dynamic and bending beam rheometers. Figure 1 shows typical Duomorph assemblies. The research was intended to improve and refine Duomorph technology by using new piezoelectric materials, sensors, improved digital technology, newer electronic equipment, and finite element modeling to make and validate a self-contained portable device for field use at temperatures ranging from -28°C to +80°C, the Superpave range of temperature. In Stage 1, a Duomorph testing system (Duomorph Asphalt Rheology Test or DART) was assembled and shakedown tests were performed in the laboratory using SHRP reference asphalt binders. The tests have demonstrated that the DART system is durable and provides data that compare well with standard SHRP equipment. A 2-inch gauge size appears satisfactory for testing. Stage 2 work performed a functional testing system and extensive experimentation to establish operational characteristics at various temperatures as required in SHRP binder specifications. A supplemental award (NCHRP-IDEA Project 41) was made for further refinement of the device and for field testing and demonstration to state highway agencies. The final report is available from the National Technical Information Service (NTIS # PB97-143879).

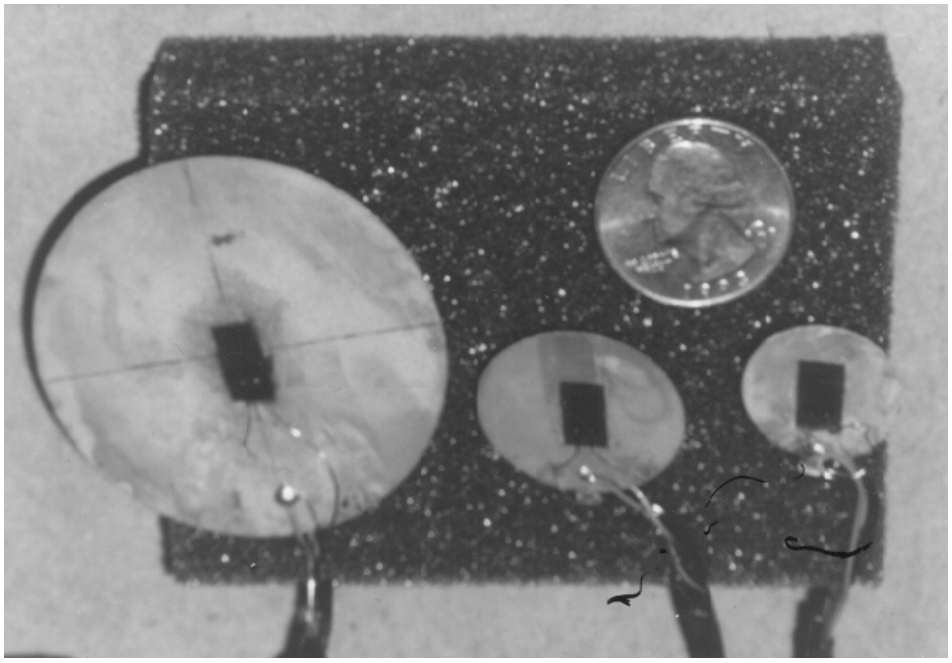


Figure 1

Duomorph assemblies.

NEW PRINCIPLES OF DESIGN FOR CUTTING TOOLS TO REPAIR AND REMOVE PAVEMENTS BASED ON THE EFFECT OF LATERAL PROPAGATION OF CRACKS UNDER CONTACT LOADING

NCHRP-IDEA Project 18

Igor Sveshnikov [Tel.: +7 (044) 263-84-07, Fax: +7 (044) 265-09-95]
POTOK Centre, Kiev, Ukraine

This project developed tool designs for energy-efficient cutting and removal of concrete pavement. The concept takes advantage of the lateral propagation of cracks in concrete produced by using indentors with unconventional asymmetric geometric shapes (Figure 1). The production of lateral cracks in hard rocks facilitates the breaking and removal of material with reduced energy consumption and improved efficiency and productivity. The effectiveness of various indentor configurations was investigated for crack initiation and propagation in rocks, such as limestone, and model materials, such as unreinforced optical glass. Results of theoretical modeling and experimental tests show that cutters with an asymmetric elliptical insert are most effective in producing cracks and breaking the rocks with considerably reduced energy consumption. Based on theoretical and experimental work, the tool designs were developed and prototypes were fabricated and delivered.

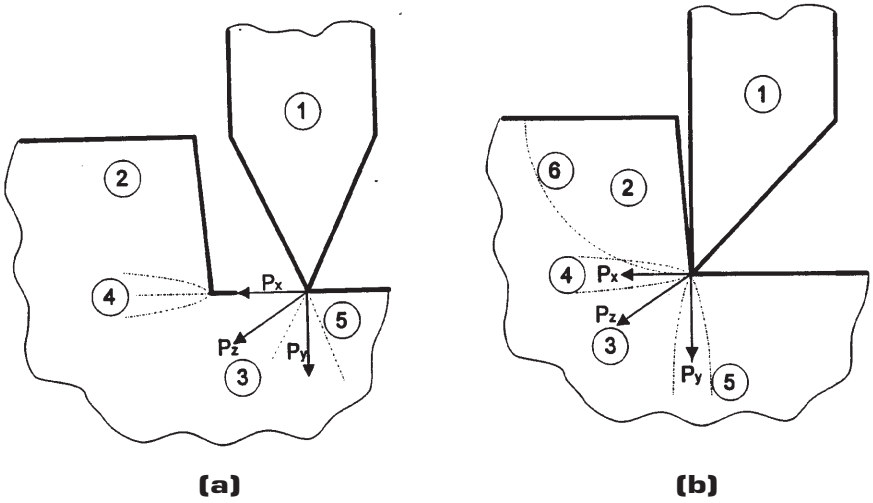


Figure 1

Crack propagation of friable material under contact of (a) indentor of traditional shape and (b) indentor of special shape (1, cutter; 2, rock; 3, element of cutting strength; 4, system of subhorizontal cracks; 5, system of vertical cracks; 6, trajectory of rock mass destruction).

ALUMINUM BRONZE ALLOY FOR CORROSION-RESISTANT REBAR

NCHRP-IDEA Project 19

David Stein [Tel.: (817) 473-1996, Fax: (817) 463-1997]
Man-Tech Development Inc., Mansfield, Texas

This project evaluated aluminum bronze alloy as a possible alternative to steel for corrosion-resistant concrete reinforcement. Rebars from aluminum bronze alloy were fabricated for laboratory and field evaluations. Initial tests showed rather low mechanical properties for alloys as compared to steel. Further work focused on improving the strength and mechanical properties of the alloy by optimizing its composition and fabrication process. The process eliminated the hot rolling operation and entailed direct continuous casting of aluminum bronze to a near net size and shape of rebar followed by cold drawing the bar to finished size and shape. The cold drawing operation increased the strength of aluminum bronze rebars close to that of mild steel rebar, meeting the ASTM specifications (Figure 1). In corrosion tests, the aluminum bronze alloy showed high resistance to seawater corrosion as compared to mild steel and ductile steel (Figure 2). Cost analysis of aluminum bronze rebars showed a cost of $0.85 per lb as compared to $1.20 per lb for stainless steel at current metal prices. The final report is available from the National Technical Information Service (NTIS # PB97-141972).

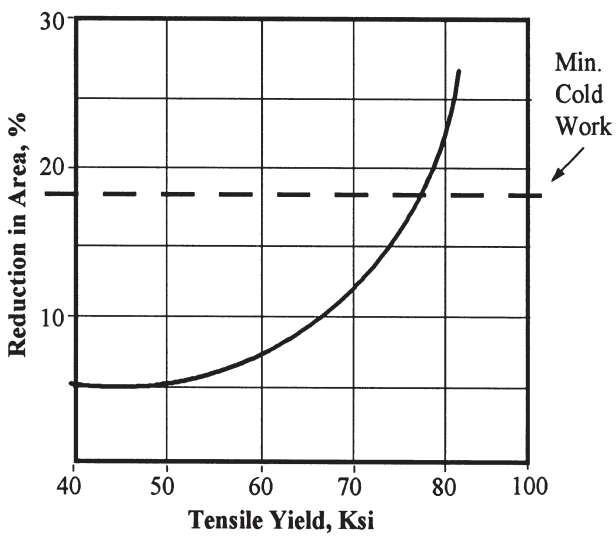


Figure 1

Tensile yield strength of aluminum bronze as a function of strain hardening.

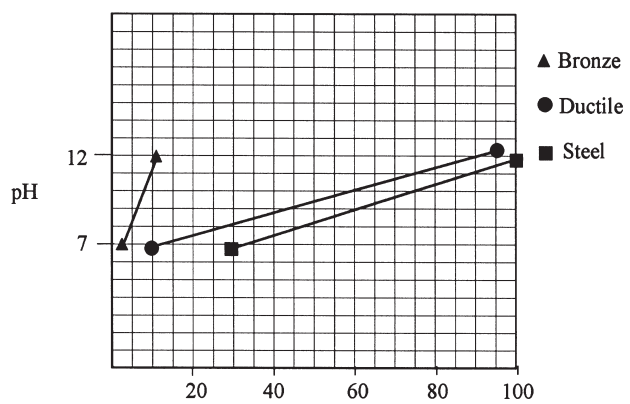


Figure 2

Corrosion rates of three alloys to chloride ion corrosion.

CARBON DIOXIDE (DRY ICE) CLEANING TO REMOVE HIGHWAY ROAD MARKINGS AND STRIPES

NCHRP-IDEA Project 20

Andrew W. Pazahanick [Tel.: (800) 832-4262, Fax: (404) 985-9179]
Tomco Equipment Company, Loganville, Georgia

This project developed and tested an environment-friendly process for pavement paint removal using CO_2 pellets. The system uses either air or an electric motor to propel the dry ice pellets. Dry ice pellets are directed at an accelerated rate from a centrifugal system through a gunlike nozzle attached to a single hose (Figure 1) onto the pavement for cleaning paint markings. The centrifugal system propels dry ice pellets at a significantly higher rate than the pneumatic system.

The pneumatic CO_2 cleaning system showed excellent results on core samples. However, it was impracticable to use a 2-inch nozzle to remove road marks and stripes on highways. In addition, the exit pattern from the centrifugal system needed to be designed for removing various sizes of road markings and stripes. The test results, however, show that the process is especially suitable for cleaning road markings and stripes. The process can, therefore, be used to restore the brilliance and extend the life of markings and stripes by removing a very fine layer from the top of the existing markings and stripes. In addition, it can be used to remove temporary road markings and stripes. The dry ice consumption was about 150 lbs per hour using the pneumatic system. At this rate, if cleaning could be accomplished in one pass, CO_2 cleaning would be cost-effective as compared to burning or grinding markings and stripes.

Further field testing is needed in order to develop a commercially feasible system.

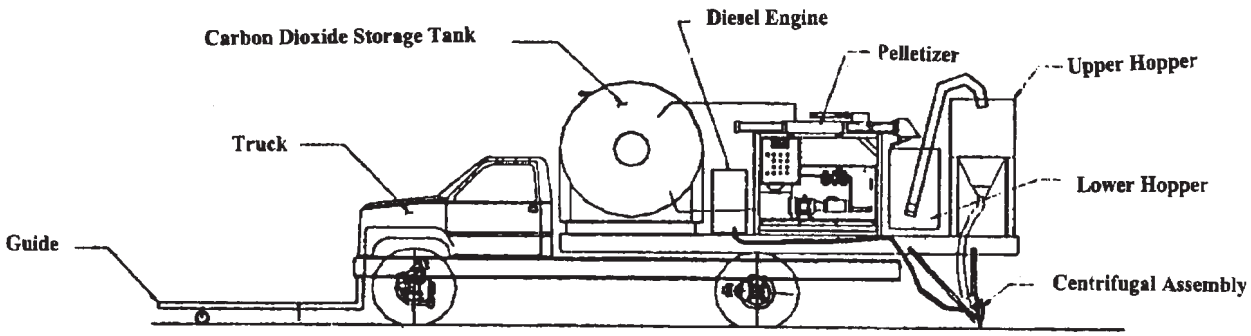


Figure 1

Drawing of proposed centrifugal transport.

DEVELOPMENT OF LED LIGHT SOURCE FOR TRAFFIC CONTROL DEVICES

NCHRP-IDEA Project 21

Mark Finkle [Tel.: (814) 355-4479, Fax: (814) 355-5817]
The Last Resource Inc., Bellefonte, Pennsylvania

This project produced a multi-use, light-emitting device with delineation and warning capabilities based on light-emitting diode (LED) technology (Figure 1). The LEDs have a much longer life span than conventional lamps and require less power to operate. The internal light source can be placed in different types of housings that would allow the device to be used as a delineator, raised pavement marker, or steady-burn/flashing warning light. The result is a device that requires less maintenance and is more flexible in its use. The development of a prototype traffic control device (TCD) involved design and construction of the internal hardware for the LED light source and different types of housing required for the TCD system. Results based on accelerated testing show that the LED light source concept works as expected and produces significant gains over conventional light sources (Figure 2). The system now needs to be tested by state highway agencies.

The commercialization of the IDEA product was explored. Various TCD manufacturers were contacted. Because the light source and power controller are separate modules, that application of the active power management appears more attractive to manufacturers than the complete product. The final report is available from the National Technical Information Service (NTIS # PB97-143846).

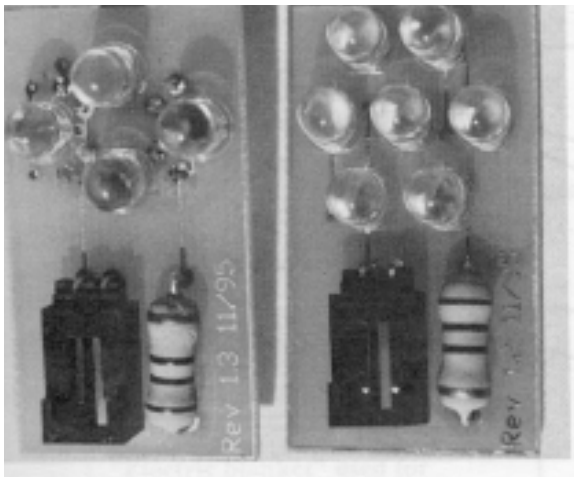


Figure 1

High- and low-intensity LED devices.

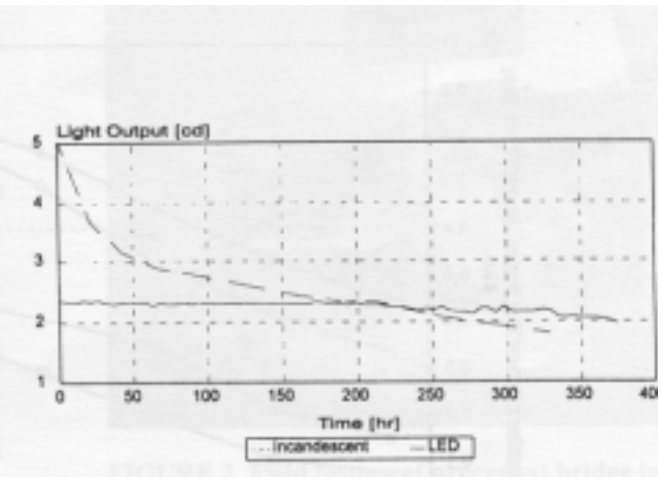


Figure 2

Results of endurance testing.

USE OF PHASE CHANGE MATERIALS TO PREVENT OVERNIGHT FREEZING OF BRIDGE DECKS

NCHRP-IDEA Project 22

Ival Salyer [Tel.: (543)229-2654, Fax: (543) 229-4251]
University of Dayton Research Institute, Dayton, Ohio

This project evaluated a class of polymeric materials (linear crystalline alkyl hydrocarbons) that store and release heat energy as a result of phase change in freezing temperatures for use in concrete to prevent overnight freezing of bridge decks. The phase-change materials were encapsulated in high density polyethylene pellets and either mixed with or installed around concrete to provide heat energy. Modeling verification of the thermal response of bridges and roads under varying climatic conditions and with various phase-change materials and application methods was performed. This was followed by laboratory tests and limited field evaluation to establish material performance and effectiveness in the highway freeze-thaw environment.

The test results show that the addition of phase-change materials to the concrete prevented freezing on the surface (Figure 1). However, the addition of the materials also decreased the conductivity of concrete slabs, which slowed its warming and also adversely affected the performance of phase-change materials. Placing the material at the bottom of the concrete slab delayed the cooling of the slab top surface. It also slowed its warming, which was not desirable. Darkening the top surface had a beneficial effect on the slab surface temperature. The final report is available from the National Technical Information Service (NTIS # PB97-143820).

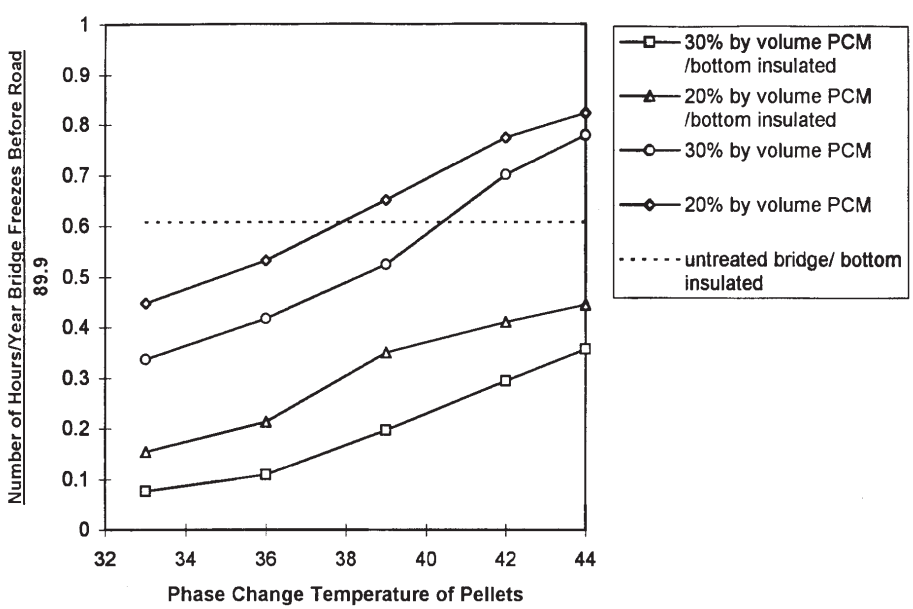


Figure 1

Hazard reduction as affected by phase change temperature for an 8-inch-thick deck with phase-change material pellets in the top half.

LEAD-BASED PAINT REMOVAL FROM STEEL STRUCTURES

NCHRP-IDEA Project 23

Rudolf Keller [Tel.: (412) 325-3260, Fax: (412) 335-8402]
EMEC Consultants, Export, Pennsylvania

This project evaluated an electrochemical cathode debonding process for stripping paint from highway steel structures (Figure 1). The method eliminates airborne paint particles and is a viable alternative to the common abrasive blasting of lead-based paint. In addition, toxic lead components can be collected and recycled. Laboratory tests were carried out to determine concept feasibility and to optimize process parameters. The process effectively debonded and removed paint from steel surfaces in one to two hours using 10-cm x 10-cm electrolytic patches under a constant voltage of 8 to 12 V and a current of 7.5 A or less. A prototype paint removal equipment system was designed for larger-scale testing.

After additional process optimization in the laboratory, small-scale field tests on highway bridges and steel structures were performed to establish the application's feasibility in actual highway structures (Figure 2). The field work showed promising results. Some initial surface preparation may be necessary to initiate the process. A supplemental IDEA award was approved for full-scale field demonstration of the technology on highway bridges in collaboration with the Virginia Department of Transportation (NCHRP-IDEA #38). The final report is available from the National Technical Information Service (NTIS # PB97-141980).

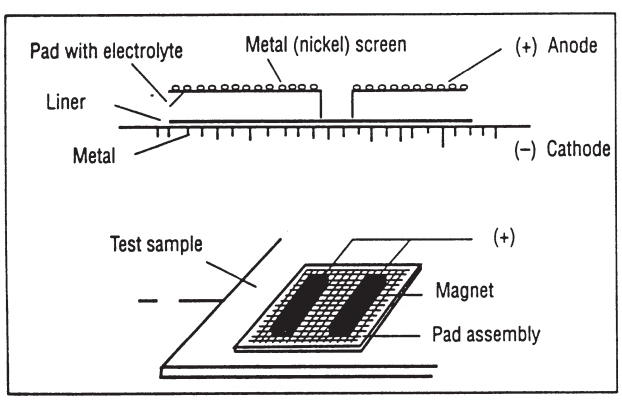


Figure 1

"Electric blanket" used for electrochemically assisted paint removal.

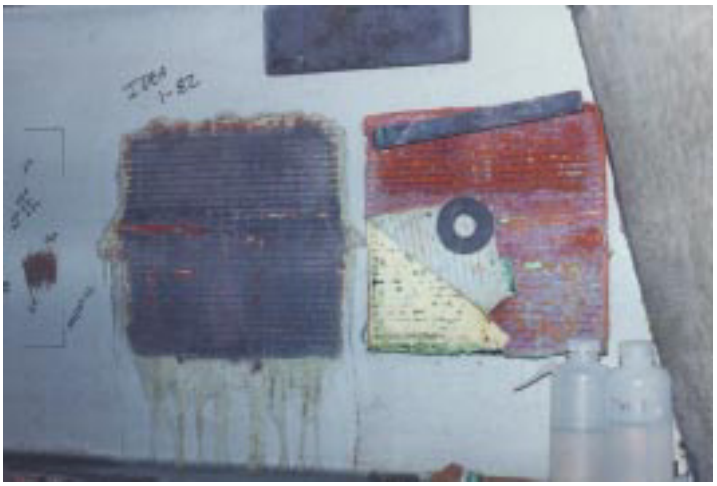


Figure 2

Field testing of process at bridge in Pennsylvania.

FIBER-OPTIC STRAIN SENSOR SYSTEM FOR LONG-TERM MONITORING OF HIGHWAY STRUCTURES

NCHRP-IDEA Project 24

Ken Lou [Tel.: (602) 730-4446, Fax: (602) 893-8643]
Simula Government Products Inc., Phoenix, Arizona

The project investigated the feasibility of a fiber-optic (FO) strain sensor system for long-term monitoring of highway structures. The principle of operation relies upon measuring the time-of-flight of an optical signal's propagation through an optical fiber and then its converstion to mechanical strain. By segmenting an optical fiber string with optical reflectors, the strain of in-line segments can be determined separately. This method enables strain mapping of an entire structure with a finite-element sensor grid and is capable of detecting localized damage, such as cracking and stress corrosion. The monitoring system includes a high-resolution optical time domain reflectometer (OTDR), FO data acquisition (FODAC) software, and FO strain gauge patches (FOSGPs), which allow monitoring of integral strain in large structures (Figure 1). The FOSGPs are flexible sensor patches that can be embedded in or attached to the structure to be monitored.

Tests with steel and composite coupons showed that, using the latest OTDR, the FOSGP sensors achieved a resolution of 0.01 percent strain and could resolve tensile strain in reinforced concrete just before failure due to fracture.

The sensitivity of the FOSGP sensor appears to be limited by the OTDR system. Also, the potential to multiplex patches in-line (to interrogate multiple locations) was limited because of increased attenuation of the FO sensors by the glass-reinforced epoxy carrier material. For the time-delay strain measurements to be practical for structural monitoring, OTDR accuracy must be improved to at least better than 3.0 ps. The smaller 3-m patches may be multiplexed, but would require an OTDR with a resolution of better than 1.0 ps. The sensors appear to be most successful at detecting strain if placed at compression locations on concrete structures. The final report is available from the National Technical Information Service (NTIS # PB98-139074).

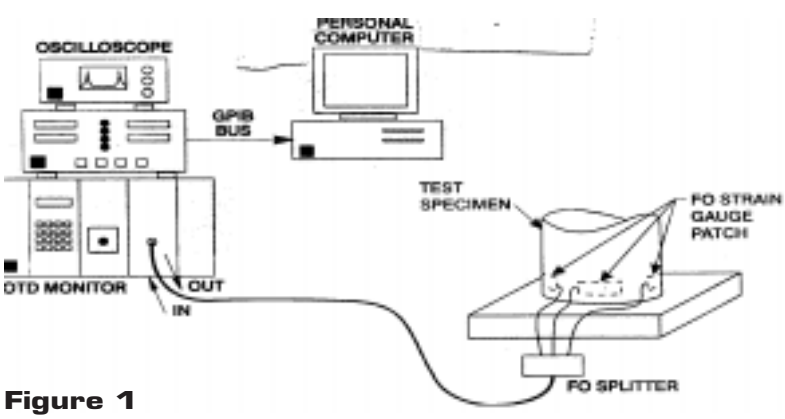


Figure 1

Fiber-optic sensor data acquisition system.

BASALT FIBER COMPOSITE REINFORCEMENT FOR CONCRETE

NCHRP-IDEA Project 25

V.B. Brik [Tel.: (608) 244-1349, Fax: (608) 244-9071]
Research and Technology Inc., Madison, Wisconsin

This project explored the feasibility of using rebars made from braided basalt fiber strands as concrete reinforcement (Figure 1). The material is expected to be a low-cost, high-strength, high-modulus, and corrosion-resistant alternative to steel for concrete reinforcement. The basalt fibers were produced using a process developed in Ukraine. Several types of basalt fibers were procured from Ukraine and evaluated for strength, brittleness, and tensile properties. A continuous basalt fiber, 9 to 15 mm in diameter, was determined to be most suitable for rebar fabrication. The rebars, consisting of about 80 percent to 90 percent fibers and an organic binder, were fabricated and tested for mechanical properties (strength and modulus) and corrosion resistance. Test results established the suitability of basalt composite rebars for use as concrete reinforcement (Table 1).

A supplemental IDEA award for large-scale and field operational testing of basalt rebars as concrete reinforcement was approved (NCHRP-IDEA 45). The final report is available from the National Technical Information Service (NTIS # PB97-161335).

TABLE 1. Mechanical Test Data for Epoxy-Bonded Basalt Fiber Composite Specimens.

Specimen No.	Width (mm)	Thickness (mm)	Failure Load (pounds)	Ultimate Strength (psi)	Elastic Modulus (msi)	Poisson's Ratio
1	25.0	3.3	10,340	83,738	4.52	0.128
2	25.0	3.3	10,340	83,738	4.52	0.128
3	24.8	3.1	10,512	37,745	5.40	0.205
4	24.8	3.2	10,040	81,558	4.61	0.210
5	25.0	3.3	10,368	83,952	4.98	0.177

Figure 1

Basalt fiber composite rebars.

CONSERVATION CONTROL LOAD SWITCH OPERATIONAL TESTS

NCHRP-IDEA Project 26

Greg Filbrun [Tel.: (614) 895-1212, Fax: (614) 895-1213]
CLS Inc., Westerville, Ohio

This is a follow-on project for a previous IDEA project (NCHRP-IDEA Project 8) to perform field operational testing of an improved conservation traffic control load switch system. This microprocessor-controlled switch system extends the life of incandescent traffic lamps by reducing the initial current surge in the filament coil. About 100 units were assembled and provided to highway agencies for evaluation. Based on the users' feedback, the switch housing design was modified. The Institute of Transportation Engineers (ITE) and the National Electrical Manufacturers Association (NEMA) specifications were met and NEMA certification of conformance for the switch system was completed. The device is mechanically compatible with NEMA model 200 cabinets and, with minor housing adjustment, also with 170 signal cabinets.

Figure 1 compares historical and expected lamp maintenance expenditures for a standard three-lamp signal head and a three-lamp signal head using the IDEA product. The product was further evaluated in a pooled-fund study by a number of states. The final report is available through the National Technical Information Service (NTIS # PB97-143853).

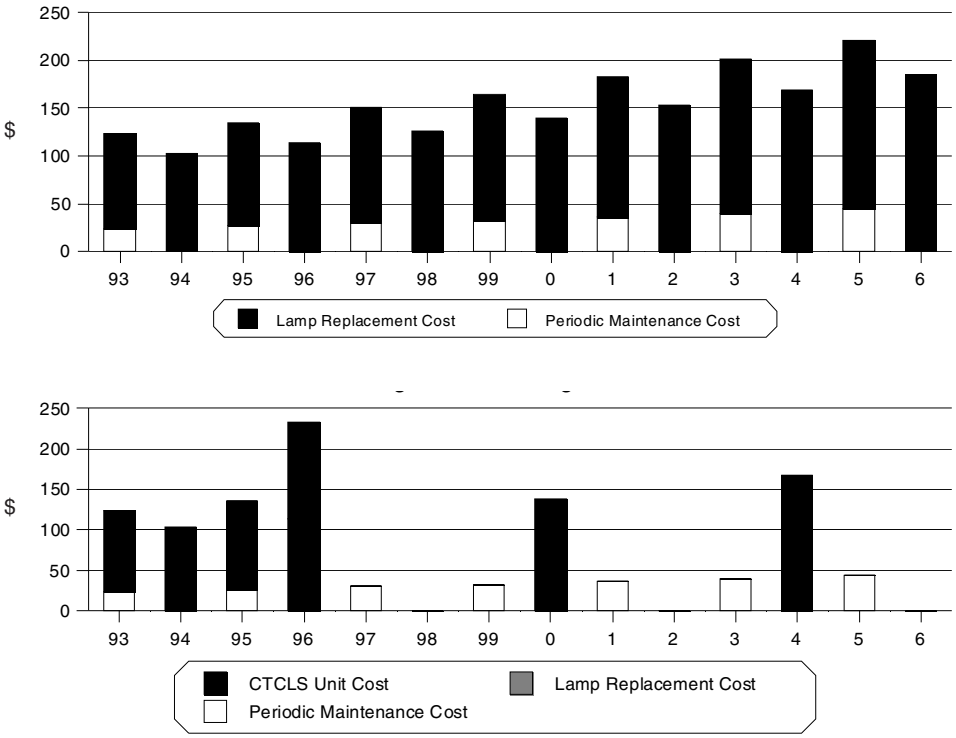


Figure 1

Historical and expected lamp maintenance expenditures. Top: *Standard three-lamp signal head.* Bottom: *Three-lamp signal head using the IDEA product.*

AUTOMATED BRIDGE DECK ANTI- AND DEICING SYSTEM

NCHRP-IDEA Project 27

Rand Decker
University of Utah, Salt Lake City, Utah

This project developed and tested an automated bridge deck anti- and deicing system. The system uses accepted deicing liquids, such as sodium or magnesium chloride, and traditional spray application techniques coupled with a modern roadway weather information system (RWIS) and novel data communication and process control to perform the task. Fixed snow and ice control systems are used in Western Europe to spray bridges with liquid snow and ice control materials. This system improves European practices and adapts them to U.S. highway practice. The innovative element of the system includes the provision for automated process control. The decision to apply anti- and deicing fluid to the bridge can be controlled by a knowledge-based algorithm (Figure 1), initialized on a process control computer located at the bridge. The process control algorithm uses data from the sensors of a modern RWIS. In addition, system status checks and manual operations may be carried out remotely using a cellular phone and voice/keypad menu commands. The anti- and deicing process can be initiated from the cab of a vehicle located at the bridge.

A prototype automated bridge anti-icing system was designed for and installed at the 6200 South Street overpass of I-215 in suburban Salt Lake City, Utah. The American Public Works Association, the British Ministry of Highways, the Kansas City Department of Public Works, the Japan Ministry of Construction, the Nevada Department of Transportation, and the Priority Technologies Project Office of FHWA showed interest in using the system for road applications. The final report is available from the National Technical Information Service (NTIS # PB99-130718).

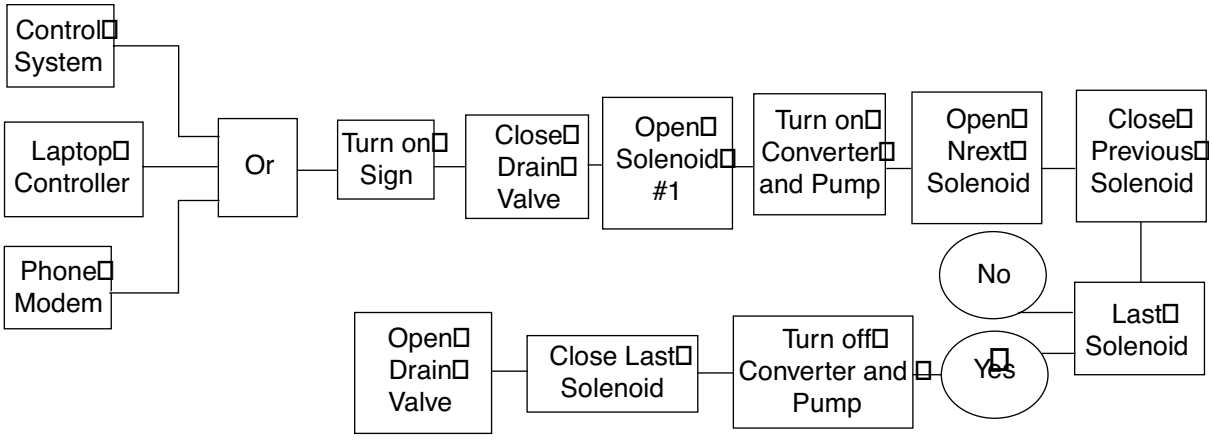


Figure 1

Spray system controller flowchart.

CORROSION-RESISTANT LOW-CARBON STEELS FOR CONCRETE REINFORCEMENT

NCHRP-IDEA Project 28

Gareth Thomas [Tel.: (510) 486-5696, Fax: (510) 653-0965] and David Trejo
University of California, Berkeley, California

This project designed and produced dual-phase ferritic martensitic (DFM) reinforcing steel with improved mechanical properties and corrosion resistance. DFM steel is a low-alloy, low-carbon steel produced by simply quenching the alloy from the two-phase ferrite/austenite field, thus producing a mixture of ferrite and martensite. The major strength source in the DFM structure originates from the presence of the inherently strong martensite phase, which provides the load-carrying constituent of the alloy. The soft ferrite phase provides the alloy with ductility.

Electrochemical evaluations were performed for in situ and ex situ conditions. The ex situ electrochemical test results provided different conclusions on the performance of the reinforcing steels. Anodically polarizing the steels in a de-aerated, decanted cement solution with 3.5 percent NaCl indicated that the DFM steel is more resistant to corrosion (Figure 1), while the ASTM A615 steel shows substantial corrosion products from the exposure. ASTM G-61 results indicate that the DFM steel is more susceptible to chloride-induced localized corrosion in the decanted, de-aerated cement solution. The ASTM G-61 results did not correlate with the in situ testing results and further investigations are required to determine these discrepancies.

In situ testing included Lollipop mass loss testing, Southern Exposure macrocell current testing, and Southern Exposure mass loss testing. All in situ tests indicated that the DFM reinforcing steel was more resistant to chloride-induced corrosion when embedded in concrete than commercially available reinforcing steels. The investigator negotiatedwith Nucor Steel, a steel manufacturer, for production of a 50-ton heat of DFM steel. Bars from Nucor were tested for mechanical and conversion properties. The final report is available from National Technical Information Service (NTIS # PB-139060).

Figure 1

ASTM A615 and DFM steels after ex situ imposed polarization testing.

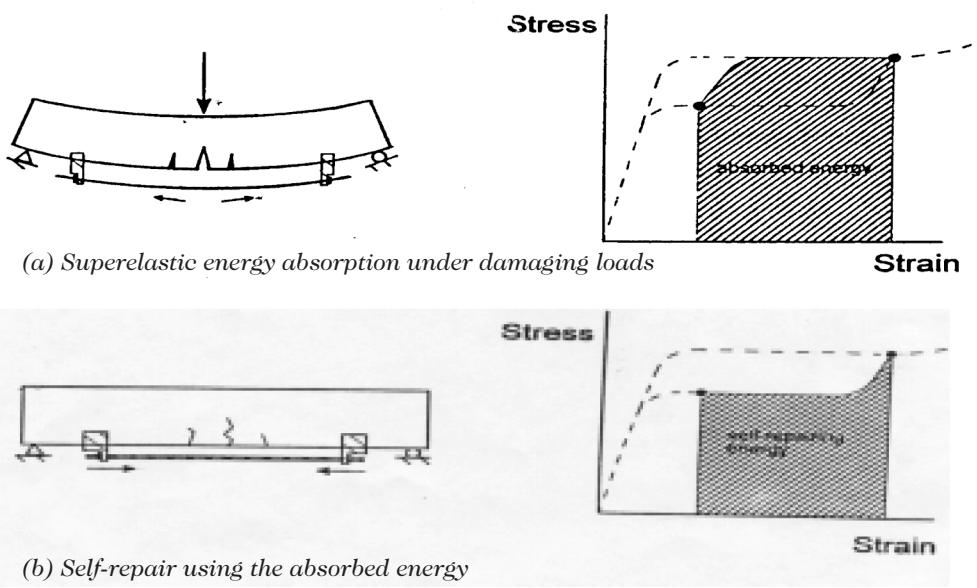
SUPERELASTICITY-BASED MATERIALS FOR BRIDGE REHABILITATION

NCHRP-IDEA Project 29

Jer-Wen Hsu and Ken Ostowari [Tel.: (517) 349-5653, Fax: (517) 349-5653]
DPD Inc., Lansing, Michigan

Parviz Souroushian
Michigan State University, East Lansing, Michigan

The project developed and demonstrated the application of superelastic shape-memory alloys for the rehabilitation of bridge structures. These materials undergo phase transformation under stress and, after an apparent plastic deformation, return to their original shape when heated (Figure 1). A nickel-titanium-chromium alloy was selected and optimized based on strength and elongation capacity requirements. Structural design procedures for rehabilitation based on superelastic post-tensioning systems as well as rehabilitation schemes using shape-memory and superelastic alloys were developed. Results of tests on concrete beams demonstrated the effectiveness of rehabilitation by shape-memory reinforcement in eliminating excess deformations and crack widths after failure. The beams satisfied all the serviceability and strength requirements under twice the original live load after they were repaired. Work on using superelastic (in place of shape memory) reinforcement for rehabilitation showed that the superelastic reinforcement was able to recover up to 8 percent strain, which is estimated to be adequate for self-repair after substantial cracking and deformation. The superelastic reinforcement system was also processed into polymer matrix composite sheets and glued onto concrete structures for rehabilitation and self-repair. Testing verified applicability of the composite system to the self-rehabilitation technology. Large-scale demonstration of the rehabilitation technology in collaboration with the Michigan DOT was performed in a follow-up IDEA project. The final report is available from the National Technical Information Service (NTIS # PB98-13508).



(a) Superelastic energy absorption under damaging loads

(b) Self-repair using the absorbed energy

Figure 1

Schematics of the superelasticity-based post-tensioning system.

RAPID REPLACEMENT COMPOSITE BRIDGE NO. 1

NCHRP-IDEA Project 30

Jerry D. Plunkett [Tel.: (913) 483-2589, Fax: (913) 483-5321]
Kansas Structural Composites Inc., Russell, Kansas

This project designed, fabricated, and tested a lightweight composite bridge made of fiberglass-reinforced polymer honeycomb structural panels. The composite bridge was designed in accordance with U.S. Highway Bridge Code HS-25. The key strength requirement was that the span to deflection ratio be 750 under a 40,000-pound load. The bridge was constructed over No-Name Creek in Russell County, Kansas, using three fiberglass honeycomb panels with interlocking edges. Each panel was about 23 feet long and 9 feet wide. The bridge installation time was less than six hours. The bridge performance was tested by driving heavy vehicles onto the bridge panels and measuring the deflections (Figure 1). The performance measurements were within the bridge code requirements. The bridge is now open to traffic. A ribbon-cutting ceremony was performed in December 1996. A supplemental award (NCHRP-IDEA Project 46) was made to prepare specifications and guidelines for installing the composite bridge and for field evaluating the honeycomb panels in bridge decks on highway bridges in Kansas in coalition with the Kansas Department of Transportation. The final report is available through the National Technical Information Service (NTIS # PB97-201511).

Figure 1

Composite bridge under test in Russell, Kansas.

COST-EFFECTIVE MICROWAVE SENSOR TO DETECT HIGHWAY ROAD CONDITIONS

NCHRP-IDEA Project 31

Robert Kubichek [Tel.: (307) 776-3182, Fax: (307) 766-4444] and
Suzanne Yoakum-Stover, University of Wyoming, Laramie, Wyoming

This project developed a method using active microwave sensing technique to measure moisture, snow, and ice accumulation on rural highways (Figure 1). The system uses a low-power microwave transmitter and incorporates neural network and pattern recognition techniques for assessing road surface conditions. The basic system was designed, built, and, after laboratory testing, installed at an outdoor location to collect data. Pattern recognition techniques were applied to the data to identify road conditions based on microwave signatures and yielded 80-90 percent accuracy in detecting ice, snow, wet, and dry road conditions. The classifier's accuracy was improved to over 95 percent by using a neural network technique. Several configuration modifications were made to the system to improve its performance. Field test of the system was conducted in cooperation with the Wyoming DOT during the 1997-98 winter season. Several companies have expressed interest in collaborating in commercializing the technology. However, additional design optimization and field tests are need to implement this technology. The project received media attention through regional newspaper articles, TV and radio segments, and also was described in journal articles including the October 1997 issue of Popular Science. The final report is available from the National Technical Information Service (NTIS # PB98-141187).

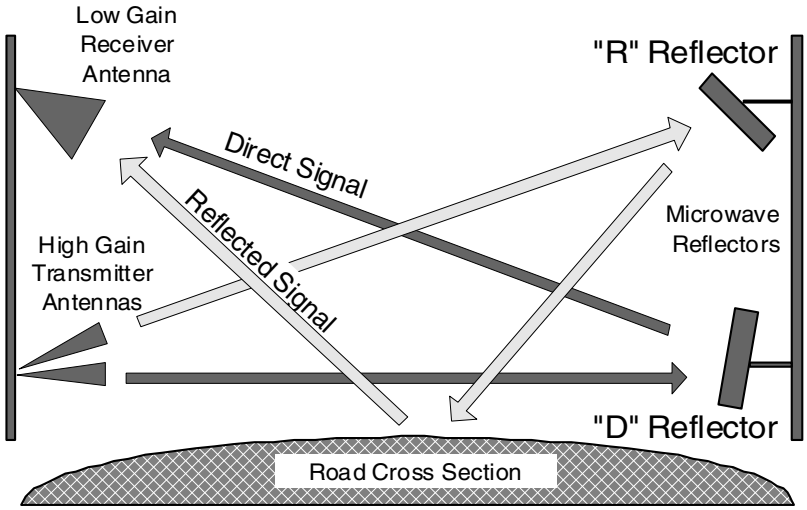


Figure 1

Antenna and reflector geometry, showing reflected and direct paths. Shown is the 10-GHz system; an identical 2-GHz system is implemented using dish antennas.

TESTING AND TRIAL DEPLOYMENT OF A COST-EFFECTIVE AND REAL-TIME ASPHALT PAVEMENT QUALITY INDICATOR SYSTEM

NCHRP-IDEA Project 32

Harry Apkarian [Tel.: (518) 370-5558, Fax: (518) 370-5538], Raymond J. Piascik, and Frank S. Ralbovsky, TransTech Systems Inc., Latham, New York

The project designed and tested a low-cost pavement quality indicator based on capacitance energy dissipation to measure density of asphalt pavements as a rapid, convenient, and safe alternative to nuclear gauge. A prototype system was designed (Figure 1) and tested on calibrated hot-mix asphalt cores of various thicknesses as well as on a variable-density stack of thin glass plates separated by measured air gaps to verify the system's accuracy, repeatability, temperature stability, sensitivity, and time stability. Also, the effects of various probe configurations and carrier frequencies were investigated. The prototype was subjected to preliminary field tests, and modifications of the system were made that included fine-tuning of the electrical circuit. Three prototype units were fabricated for field evaluation. The field test results were carried out at six sites in Nevada, New York, and Indiana. The field results showed that the instrument measures to a 2.5-in. depth at a speed of about five seconds per reading with good accuracy and reproducibility. The field performance was unaffected by temperature and moisture variations. The probe and the sensor circuit were redesigned to improve their accuracy. A market research study was conducted to determine the competition and demand for the IDEA product. The final report is available from the National Technical Information Service (NTIS #PB97-201503).

Figure 1

Advanced prototype of TransTech System's pavement quality indicator.

EVALUATION OF A NEW REHABILITATION TECHNOLOGY FOR BRIDGE PIERS WITH COMPOSITE MATERIALS

NCHRP-IDEA Project 33

Roberto Lopez-Anido, Rakesh Gupta,
Hota V.S. GangaRao [Tel.: (304) 293-7608, Fax: (304) 293-7609]
Udaya B. Halabe, Sachin Kshirsagar, and Reynold Franklin
West Virginia University, Morgantown, West Virginia

This project evaluated a bridge rehabilitation technology using glass fiber-reinforced fabric encasing on deteriorated bridge columns and piers. Laboratory test results showed significant increase in compressive strengths of concrete cylinders with composite wraps. The composite bond integrity under various environmental conditions was also established. The composite fabric rehabilitation technology was field tested in collaboration with the West Virginia DOT on Pond Creek Road bridge in Wood County, West Virginia. Three columns of the bridge were hand-wrapped with composite fabric (Figure 1) and three additional columns with composite shells. The repaired columns were monitored for durability and bond integrity. Results showed excellent performance. The final report is available from the National Technical Information Service (NTIS # PB2000-103402).

Application of fiber composite wrap on Pond Creek Bridge.

Pier concrete column after wrapping.

Figure 1

Field installation of the composite wrap rehabilitation technology.

HIGHWAY GUARDRAIL INFRASTRUCTURE: SAFER TERMINAL DESIGNS

NCHRP-IDEA Project 34

James F. Wilson [Tel.: (919) 660-5194, Fax: (919) 660-5219]
Duke University, Durham, North Carolina

This project developed a unique class of guardrail terminal retrofits suitable for secondary roads (Figure 1). These new terminal structures do not penetrate errant vehicles but bend upon impact and form sufficient frontal area to mitigate vehicle spearing. Made of mild steel, these terminals curve away from the direction of traffic flow, have variable depth corrugations, have an increasing flare toward the impact end, and have breakaway supporting posts. Low-speed crash tests were performed on half-scale terminal models in which the test car, traveling at about five mph and without bumper shock absorbers, impacted the models head-on. These results showed that the plastic failure zones occurred further toward the tip of impact than for static loading, or at about the two-thirds point from the fixed end.

The ideal final design of a guardrail will incorporate the following features.

- A retrofit that is low cost, simply fabricated, and easily installed.
- A retrofit that buckles plastically near mid-length.
- A retrofit that helps redirect impacting vehicles and minimizes fatalities for their occupants.
- A retrofit that limits the ridedown deceleration of the impacting vehicle to 15 g.

The product is available for potential product developers for licensing to manufacture and commercialize the product. The final report is available from the National Technical Information Service (NTIS # PB98-139058).

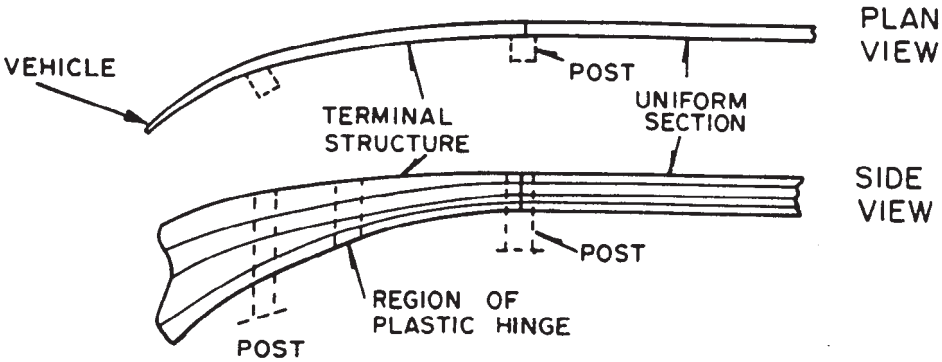


Figure 1

A terminal structure concept designed to avoid vehicle spearing.

IN-SERVICE REPAIR OF HIGHWAY BRIDGES AND PAVEMENTS BY INTERNAL TIME RELEASE OF REPAIR CHEMICALS

NCHRP-IDEA Project 37

Carolyn Dry [Tel.: (217) 333-1913, Fax: (217) 244-2204]
Illinois Universities Transportation Research Consortium, Chicago, Illinois

This project evaluated the concept of self-repairing, concrete-containing fibers filled with adhesives (Figure 1) in large-scale laboratory and field tests. Four specific applications for this concept were explored in the laboratory and field experiments. In frames in the laboratory, it was shown that adhesive release from ruptured fibers helped distribute stress over the entire structure. In four full-scale bridge decks, the adhesive-filled tubes were put near the surface to function as creators of automatically fillable control joints. Surface-shrinkage cracking acted to pull the brittle tubes apart and the sealant/adhesive flowed to fill the cracks. In another application, the adhesive-filled tubes were placed in the body of the deck to break due to shear cracking and repair these cracks. This type of release not only strengthened the decks but also distributed the stress to other locations. In the final application, large beams containing adhesive-filled tubes were tested to failure. The results showed added strength due to release of adhesives. The study also established the survival of adhesive-filled tubes during mixing in the concrete mixer, maintenance of the liquid phase of the adhesive, ease of finishing the concrete containing adhesive-filled fibers. Long-term field evaluation of bridge decks and pavements in a highway environment is needed to implement the rehabilitation technology. The final report is available from the National Technical Information Service (NTIS # PB2001-108551).

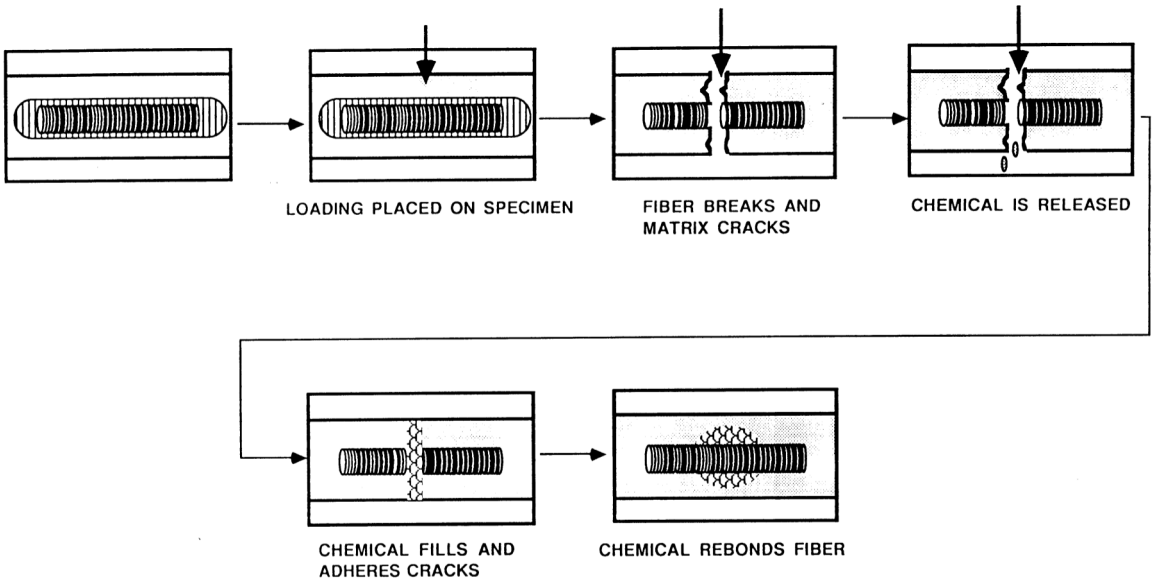


Figure 1

Concept of in situ self-repair of concrete by adhesives in embedded hollow fibers.

PAINT REMOVAL FROM STEEL STRUCTURES: TESTING AND DEMONSTRATION OF ELECTROSTRIP™ PROCESS

NCHRP-IDEA Project 38

Rudolf Keller [Tel.: (724) 335-2666, Fax: (724) 335-8402] and Brian J. Barca
EMEC Consultants, Export, and New Kensington, Pennsylvania

This follow-on IDEA project demonstrated the field application of an electrochemical paint removal process, developed in an earlier IDEA project (NCHRP-IDEA 23). Equipment components to treat up to 50 ft^2 in one application were acquired and preliminary field tests were performed in Pennsylvania and Virginia. Based on test results, supplies and equipment were selected for a full-scale field demonstration to remove paint from an area of 800 ft^2 at the I-66 Westmoreland Street overpass in Arlington, Virginia. The field demonstration was successfully carried out in May 1998, in collaboration with Virginia DOT (Figure 1). A showcase event, highlighting the IDEA technology and organized by the Virginia DOT, preceded the field demonstration. The test was completed ahead of schedule, and results were consistent with the targeted removal rate of 40 ft^2 per hour. Prior to the field demonstration, tests were performed to monitor environmental and occupational exposure. The exposure of personnel was well below the specified OSHA level for particulates and no changes were detected in soil samples.

Cost projections indicate a competitive price of $7 to $10 per ft^2 for full paint removal and repainting and are comparable to quoted average costs for traditional abrasive blasting. However, full commercial implementation will require scale-up equipment and additional process optimization. Additional process demonstrations will also be needed on a non- or near-competitive basis. The final report is available from the National Technical Information Service (NTIS # PB99-117087).

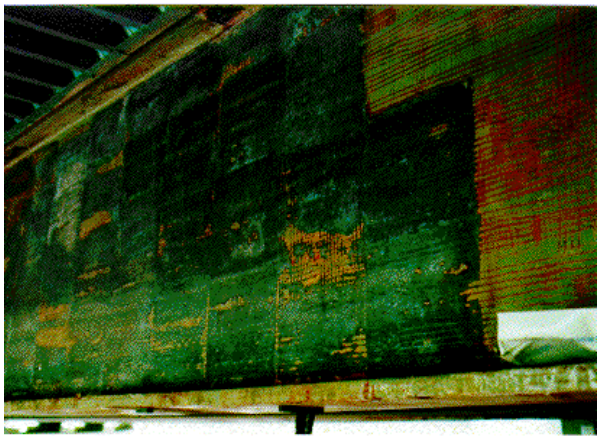


Figure 1

Treated area after initial cleaning.

ESTIMATING TRUCK ATTRIBUTES FROM BRIDGE STRAIN DATA USING NEURAL NETWORKS

NCHRP-IDEA Project 40

Ian Flood [Tel.: (352) 392-7287, Fax: (352) 392-9606]
University of Florida, Gainesville, Florida

This project developed a neural network-based method of estimating truck attributes (such as axle spacing and axle loads) from strain response of the bridge over which the truck is traveling. The research showed that this could be accomplished fairly accurately using a two-layered artificial neural network (Figure 1). In particular, the EHAM (an extended Hamming network) method provided results as reliable as RGIN (a radial-Gaussian network that uses incremental training algorithm) method for classifying trucks and outperformed RGIN in the speed with which it can develop a working model for the bridge. However, work on improving the classification accuracy (and, thus, ultimately the accuracy of estimates of truck attributes such as axle loads and spacing) by allowing a SORG (a self-organizing network) method to develop its own classification system for trucks were inconclusive. The project generated interest from the industry, and an international consortium explored the possibility of adopting and implementing this technology. The final report is available from the National Technical Information Service (NTIS # PB2000-103400).

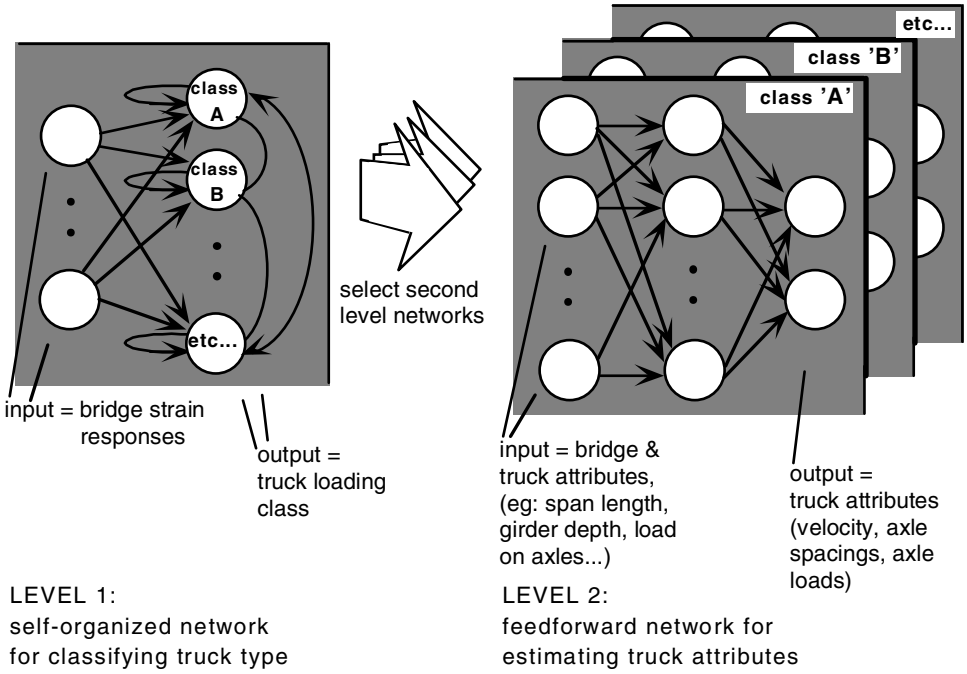


Figure 1

Architecture of proposed networking system.

FIELD TESTING WITH THE DUOMORPH: A SELF-CONTAINED PORTABLE DEVICE FOR SHRP BINDER TESTING

NCHRP-IDEA Project 41

Samuel H. Carpenter [Tel.: (217) 333-4188, Fax: (217) 333-1924]
University of Illinois, Urbana-Champaign, Illinois

This project refined and tested a portable Duomorph Asphalt Rheology Tester (DART) developed in an earlier IDEA project (NCHRP-IDEA 17). The device tests rheological properties of asphalt for pavement construction. The Duomorph is a piezoelectric sensor that can be embedded in a viscoelastic material to determine the modulus and phase angle of the material, the same data required for the Superpave binder grading. A testing program demonstrated that DART provided good stiffness values that compared favorably with dynamic shear rheometer and bending beam test data over the range of temperature of interest. The equipment's data repeatability was better than that of the dynamic shear rheometer. The phase angle data was, however, inconsistent. To address this inconsistency, an analytical scheme based on viscoelastic properties and a three-dimensional finite element analysis was developed. The results show that the analytical approach can model the DART behavior precisely. The system was automated for data collection and reduction capabilities.

The DART has the potential to provide a portable field device that can be used at a plant or refinery to verify the more extensive laboratory testing program used for material certification. It can be used on modified asphalts with particulate matter such as crumb rubber modified binders. It can be used at the plant to test asphalt that has been blended with a polymer to verify the blending process. It can be used on material sampled directly from a tanker to verify that the material is the same as what was specified. This ability to provide a rapid indication of product acceptability before use could result in significant savings by avoiding using materials that later are proven to be unacceptable. This use as a fingerprinting tool for monitoring material variability using the same material properties that are determined in the full grading acceptance scheme provides a unified process in a real-time format not previously possible. Implementation of the system will require a commercial prototype and field trials.The final report is available from the National Technical Information Service (NTIS # PB2001-101279).

DUAL-CORE FIBER OPTIC WIM SYSTEM

NCHRP-IDEA Project 42

Ramesh B. Malla [Tel.: (860) 486-3683, Fax: (860) 486-2298] and Norman W. Garrick
University of Connecticut, Storrs, Connecticut

This project incorporated a new optical fiber design in a weigh-in-motion (WIM) system and tested its performance under simulated highway conditions. The fiber design consisted of a dual-core system using two light-guiding regions of different effective optical path lengths. This design enables us to measure magnitude as well as positions of forces that are applied at multiple locations along a single fiber and to use a single light source and photodetector. A prototype fiber optic WIM system was designed, fabricated, and tested under both static loading and in an actual vehicle (Figure 1). The static loading tests showed good correlation between load and changes in optical signal. The location of the load was also determined fairly accurately. Changes in optical signal under vehicle testing were similar to those under static loading. The system was optimized and refined with attention to the optical set-up, data gathering capability, and fiber optic configuration. The results showed a good potential of the WIM system for determining the magnitude and location of vehicle loads. However, additional refinements and prototype tests are needed before the technology will be ready for field implementation.The final report is available from the National Technical Information Service (NTIS # PB2001-100953).

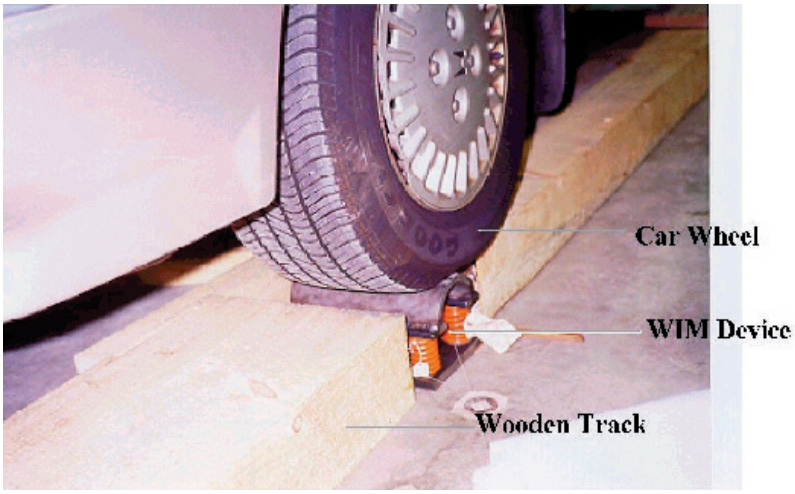


Figure 1

Car wheel testing in progress.

ROBOTIC SYSTEM FOR UNDERWATER BRIDGE INSPECTION AND SCOUR EVALUATION

NCHRP-IDEA Project 43

James DeVault [Tel.: (913) 532-4594, Fax: (913) 532-1188]
Kansas State University, Manhattan, Kansas

The project investigated the feasibility of using a semiautonomous robotic system to position a sensor platform in close proximity to underwater bridge support structures while providing video or other sensory information to support evaluation and documentation of structural condition, including scour. The primary system consists of two or more identical mobile robots designed to travel along opposite surfaces of submerged structures while connected to one another by a cable and winch system (Figure 1). Each robot contacts the surface through cleated rubber tracks (or, alternatively, wheels and rubber tires) that are driven by internal motors. Tensioning the cables that connect the two robots provides traction. In response to an operator's command to move to a new position, the robot team automatically coordinates both movement and cable tension. A graphical user interface provides the operator with status information and control options. This robotic system may be used to augment traditional diver inspections, thereby reducing diver time and cost and enhancing safety.

Two prototype systems were constructed and tested, and the findings applied to development of a third system of significantly different design. This system has a broad array of potential applications for inspection of submerged physical structures, such as bridge substructures, pipelines, water towers, industrial smokestacks, nuclear cooling towers, oil rigs, oil derricks, floating platform support structures, and docks.

Initial estimates of the manufactured costs of the system range from $25,000 to $50,000. The final report is available from the National Technical Information Service (NTIS # PB99-130700).

Figure 1

Two mobile robots connected to each other travel opposite sides of a structure to provide video and sensory information to remote users.

ROLLER-MOUNTABLE ASPHALT PAVEMENT QUALITY INDICATOR USING DIFFERENTIAL MICROWAVE SIGNALS

NCHRP-IDEA Project 44

Edward J. Jaselskis [Tel.: (515) 294-5225, Fax: (515) 294-8000]
Iowa State University, Ames, Iowa

This project developed a technique using microwave sensors installed on a pavement roller for real-time measurement of asphalt pavement density. Two microwave antennas, one in the front and the other at the back of a paving roller, measure microwave signals reflected from asphalt, and the difference between the signals is correlated with the degree of compaction of asphalt pavement (Figure 1). Following laboratory evaluation of the interaction of microwaves with asphalt, a prototype system was designed and field tested. The field tests verified a relationship between asphalt pavement density and microwave signal variance. The signal variance decreased with increasing asphalt density, but increased rather abruptly near the point of optimum compaction. These characteristics can be used to develop a non-contact method for a real-time assessment of the degree of compaction of asphalt pavements. However, additional system refinement and field evaluation are necessary to make this technology fully implementable. The final report is available from the National Technical Information Service (NTIS # PB2000-10340).

Figure 1

Prototype system for asphalt pavement density determination.

PERFORMANCE EVALUATION OF BASALT FIBERS AND COMPOSITE REBARS AS CONCRETE REINFORCEMENT

NCHRP-IDEA Project 45

Vladimir Brik [Tel.: (608) 244-1349, Fax: (608) 244-9071]
Research and Technology Inc., Madison, Wisconsin

V. Ramakrishnan
South Dakota School of Mines and Technology, Rapid City, South Dakota

This project evaluated the suitability of basalt fibers and basalt fiber composite rebars in concrete as an economical and durable alternative to reinforcing steel. Concrete specimens reinforced with basalt fiber composite rebars and basalt fibers (up to 2 percent by volume) were tested in accordance with ASTM standard test procedures. The basalt composite rebar exhibited tensile strength three times that of steel rebar. However, the mechanical performance of prestressed specimens was poor because of creep developed at the cement matrix-basalt composite interface. This limits its application for prestressed concrete reinforcement. Use of basalt fibers in fiber-reinforced concrete appears promising. Basalt fiber-reinforced concrete specimens showed a significant increase in toughness and impact strength (Figure 1) and a reduction in crack intensity and size as compared to plain concrete. The overall performance of basalt fibers in concrete was found to be similar to that of polypropylene fibers. It appears feasible to use locally available basalt mineral from northern Wisconsin and Minnesota for manufacturing basalt fibers and basalt fiber composite materials. The final report is available from the National Technical Information Service (NTIS # PB99-145104).

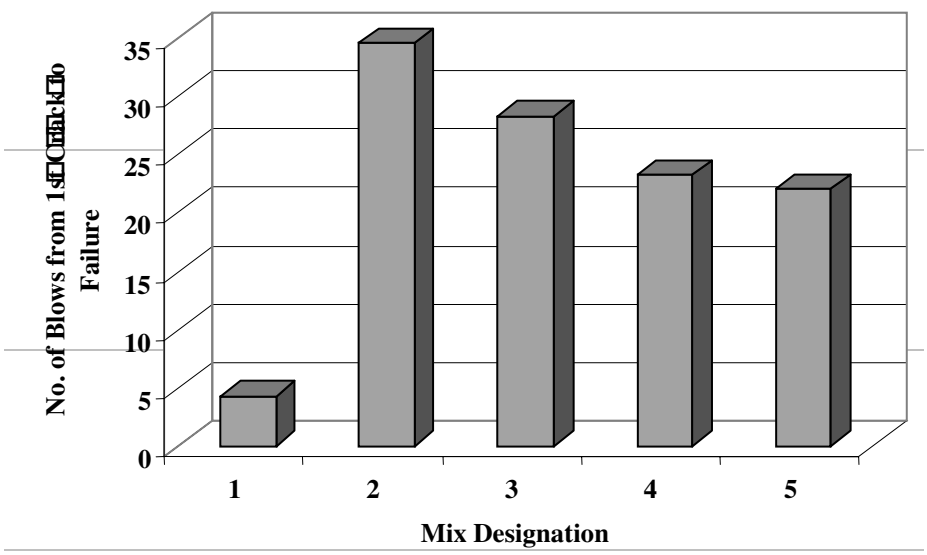


Figure 1

Toughness and impact test results for basalt fiber-reinforced concrete (Mix designations #1, 2, 3, 4, and 5 correspond to basalt fiber contents of 0%, 0.5%, 0.4%,0.25%, and 0.1%, respectively).

TESTING, EVALUATION, AND INSTALLATION OF FIBER-REINFORCED POLYMER HONEYCOMB COMPOSITE PANELS IN BRIDGE DECK APPLICATIONS

NCHRP-IDEA Project 46

Jerry D. Plunkett [Tel.: (785) 483-2589, Fax: (785) 483-4535] and Stephen R. Gill
Kansas Structural Composites Inc., Russell, Kansas

This follow-on project of a previous IDEA project (NCHRP-IDEA 30) performed field testing of bridge deck panels made from fiber-reinforced polymer (FRP) honeycomb composites. Existing methods of rehabilitating bridge decks are time consuming and create long traffic delays. Using the system developed under this project, it will be feasible to rebuild bridge decks rapidly and to greatly reduce these traffic delays. The project was carried out in collaboration with the Kansas DOT and involve re-decking two highway bridges, each 32 ft wide and 45 ft long, in Crawford County. Lightweight deck panels of FRP honeycomb sandwich construction, approximately 5 in. thick with a 3/8-in. polymer concrete wear surface, were fabricated. The total weight for the deck for each of these bridges was approximately 25 kip and replaced an estimated 88 kip of existing roadbed—a 70 percent reduction in dead load. The decks were supported, with an attachment device, on saddles that are also of FRP honeycomb construction and designed to straddle the existing beam fringes. The attachment device is a clamp that can be installed from the deck surface. The decks were installed on both bridges in the fall of 1999, and the highway was reopened to traffic after installation. The performance of the bridges is being monitored by the Kansas DOT. The composite bridge project has received considerable media coverage and several awards for technology innovation. A Web site (www.ksci.com/crawford.html) was set up to provide updated information on the project.

The technology developed through this project was used for two bridge decks in Missouri and one in West Virginia. The FRP composite technology permits the removal and replacement of damaged bridge deck panels and the removal and re-use of bridge decks from bridges that are no longer in service or that are to be upgraded. Bridges will no longer be torn down but can be removed and re-used easily and cheaply. Thus, bridges using this technology will possess a large salvage/re-use value. The final report is available from the National Technical Information Service (NTIS # PB2000-108042).

PAVEMENT QUALITY INDICATOR: FIELD OPERATIONAL TESTING AND PRODUCT TRANSFER

NCHRP-IDEA Project 47

Harry Apkarian [Tel.: (518) 370-5558, Fax: (518) 370-5538] and Peter Sawchuk
TransTech Systems, Latham, New York

This is a follow-on project for field testing and implementation of a pavement quality indicator (PQI) system developed in a previous IDEA project (NCHRP-IDEA 32) for real-time asphalt pavement density measurements (Figure 1). The project was carried out in collaboration with the New York State Energy Research and Development Authority and the U.S. Army Corp of Engineers. The test program produced several design improvements that included sensing probe design, averaging capability of microprocessor logic, backlit readout screen, and calibration capability enhancement. Test results showed that the equipment performed equal to or better than the nuclear density gauge both in accuracy and reproducibility. The equipment is commercially available. More than 500 units have been sold both in the United States and abroad. The PQI system was also evaluated for field performance by a number of states in a pooled-fund study. The final report is available from the National Technical Information Service (NTIS # PB99-117095).

Figure 1

Pavement quality indicator prototype.

FIELD TRIAL OF SHAPE MEMORY-BASED REHABILITATION SYSTEM

NCHRP-IDEA Project 48

Ken Ostowari [Tel.: 517-349-5653, Fax: 517-349-5653]
DPD Inc., Lansing, Michigan

Parviz Soroushian
Michigan State University, East Lansing, Michigan

This project demonstrated the application of superelastic shape memory alloys for the rehabilitation of bridge structure. Shape memory alloys recover deformations induced at lower temperatures upon heating above a transformation temperature; restraint of this shape recovery generates relatively large stresses. These stresses are used here to transfer corrective forces to structural systems for strengthening and repair effects. For this purpose, shape memory rods are pre-elongated, anchored to the structure, and subjected to electrical resistance heating to transfer corrective forces to the structure. The project used iron-based shape memory alloys of relatively low cost; the alloy composition was selected to yield relatively high and stable levels of restrained shape recovery stresses. Laboratory tests verified the ability of pre-elongated rods anchored onto damaged structural systems to restore structural integrity through application of corrective forces. Subsequent damaging effects could also be overcome by electrical resistance re-heating of rods.

A reinforced concrete bridge structure with beams lacking sufficient shear strength at longitudinal bar cut-off locations was selected for field demonstration of the technology. A design methodology was developed and verified through laboratory tests simulating conditions of the selected bridge structure. Subsequently, a detailed design was developed, and the approach was successfully implemented under field conditions (Figure 1). The final report is available from the National Technical Information Service (NTIS # PB2000-105060).

Figure 1

Field implementation of shape memory-based rehabilitation technology (final field set-up for application of local corrective forces).

AUTOMATION OF LEGENDS PAINTING

NCHRP-IDEA Project 49

Duc Huynh [Tel.: (510) 438-9714, Fax: (510) 438-0194]
Pavement Marking Technologies Inc., Menlo Park, California

This project developed and tested an automated, computer-controlled, robotic prototype system (Roadwriter) with multiple axis movement capability to paint patterns and legends on highway pavements (Figure 1). Initially, a prototype system was designed, assembled, and tested. The test performance data were used to define operational algorithm, performance criteria, and system integration guidelines and to develop necessary hardware and software to produce a second-generation prototype. The new prototype showed improved features regarding safety, speed, quality, cost, and versatility and included a laser guidance system that allowed the operator to visually locate and orient the position where the legends were to be painted. Other improvements included a new spray head, a new long-life tip, and a new less temperature-sensitive marking material. The computer system was also miniaturized and additional software was developed to improve the "smoothness" of the system. The Roadwriter system is estimated to cost about $300,000 and is believed to pay for itself in 18 months time not counting the savings resulting from improved worker, driver, and pedestrian safety and from reduced injuries and property damage. Additional refinement and field testing are needed for a full implementation of this technology.

Figure 1

Truck-mounted RoadWriter™ prototype system in field operation.

DAMPER SYSTEMS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

NCHRP-IDEA Project 50

Habib Tabatabai and Armin B. Mehrabi [Tel.: (847) 965-7500, Fax: (847) 965-8997]
Construction Technology Laboratories Inc., Skokie, Illinois

This project developed and evaluated damper systems for suppression of bridge stay cable vibrations. Three damping approaches—a tuned-mass damper (TMD), a liquid damper, and wrapping cable with damping tape—were tested using various grout mixes and cable models. In addition, a concept based on cable guide pipe filled with polyurethane material was also evaluated. The latex grout improved damping by about 60 percent as compared to the conventional grout. Use of neoprene washers also improved the damping significantly. However, neither of these improvements was adequate to control rain-wind vibrations based on current criteria. Use of a damping tape on the outside surface of the cable produced no significant improvement. The results show the tuned-mass damper (TMD) system, which can be applied anywhere along the length of the cable, to be the most cost-effective temporary or long-term solution to the rain-wind vibration problem (Figure 1). A follow-on project for field evaluation and implementation of the technology was approved by the NCHRP-IDEA Project Committee. The final report is available from the National Technical Information Service (NTIS # PB2000-15409).

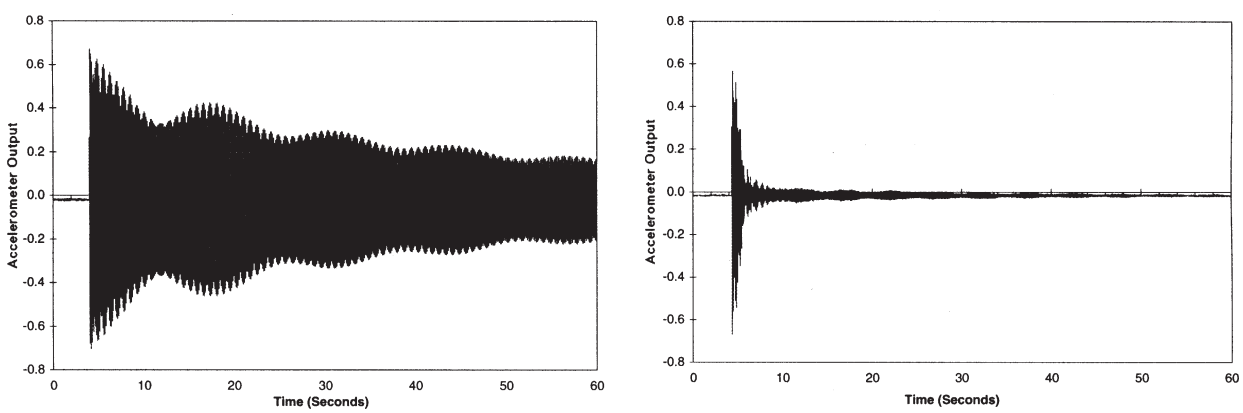


Figure 1

Comparison of cable responses, (a) without TMD; (b) with TMD.

APPLICATION OF ADVANCED COMPOSITES TO STEEL BRIDGE RETROFITTING

NCHRP-IDEA Project 51

Dennis R. Mertz [Tel.: (302) 831-2735, Fax: (302) 831-3640]
University of Delaware, Newark, Delaware

This follow-on project to a previous IDEA project (NCHRP-10) demonstrated the field use of advanced composites to strengthen and stiffen highway steel bridges (Figure 1). An in-service steel bridge was identified for retrofitting and field evaluation in collaboration with the Delaware DOT. Two full-scale steel bridge girders were rehabilitated in the laboratory by bonding carbon fiber-reinforced polymer (CFRP) composite to the top and bottom of the tension flange of the girders. The girders were fatigued and subjected to static tests. Both test data and inspection showed no changes in the overall stiffness or bond integrity after 10 million fatigue cycles. The same girders were also subjected to a sustained load, and strain gauges and load cells were implemented to record any changes over time. After successfully addressing the issues of force transfer, fatigue resistance, and durability, a full-scale rehabilitation of a steel bridge on I-95S over Christina Creek near Newark, Delaware, was carried out using two types of structural adhesives to bond CFRP to steel. Monitoring of the bridge for performance and durability of the CFRP-steel bond will continue for several years. The final report is available from the National Technical Information Service (NTIS # PB2002-103162).

Figure 1

Bridge girders rehabilitated with carbon fiber-reinforced polymer plates.

ENVIRONMENTALLY FRIENDLY PASSIVATING COATINGS FOR STEEL REBARS

NCHRP-IDEA Project 52

James E. Neely, Jr. [Tel.: (724) 482-2163, Fax: (724) 482-2767]
Neely Industries Inc., Butler, Pennsylvania,

Alberto Sagues
University of South Florida, Tampa, Florida,

Rodney Powers
Florida Department of Transportation, Gainesville, Florida, and

Richard Brown
University of Rhode Island, Kingston, Rhode Island

This project developed and tested a new class of nontoxic water-based inorganic polymer coatings for corrosion protection of concrete reinforcing steel rebars for highway applications. A.C. (alternating current) impedance spectroscopy and salt fog tests were conducted on polymer coatings applied to steel panels and bars. Based on test results, coating formulations with superior corrosion protection characteristics were identified. Of these, two formulations were selected for evaluation by the ASTM G109 test for corrosion protection. Tests on coated steel reinforcing rebars in concrete were way for over 15 months at the Florida DOT. Initial results showed no noticeable corrosion activity on coated rebars. To accelerate the onset of corrosion, the saline concentration of the test solution was raised. Results to date for coated rebars have been very promising and Florida DOT has decided to continue monitoring of the specimens beyond the completion of this IDEA project.

A number of options for implementing the results within highway practice are possible. Once the passivating coatings are certified for use by the Federal Highway Administration and state departments of transportation, the next step for implementation would be providing commercial quantities of inorganic polymer coatings. One option for Neely Industries Inc. (NI) to provide such quantities would be by licensing the technology to established coating manufacturers a strategy successfully utilized by NI for other product developments. Another option is the formation of a joint venture company to manufacture the coatings. The regional manufacture of coated rebar will be done by licensing individual fabrication and coating companies. The final report is available from the National Technical Information Service (NTIS # PB2001-104274).

NOVEL APPROACH FOR PREDICTING REMAINING LIFE OF CONCRETE BRIDGE STRUCTURES

NCHRP-IDEA Project 54

C. S. Desai [Tel.: (520) 621-6569, Fax: (520) 621-6577], T. Kundu, and M. Keller
The University of Arizona, Tucson, Arizona

This project developed a new approach based on constitutive models and Lamb wave technique that could be used to predict the remaining service life of concrete bridge structures. The prediction is based on the stress-strain response of materials in concrete bridge structures experiencing deterioration due to highway traffic and environmental conditions. The project was focused on establishing the correlation between the Lamb wave data and the disturbance (damage) from the stress-strain, and on the design and integration of the NDT system with a constitutive model. Concrete beams and flat specimens were cast for evaluating stress-strain and Lamb wave propagation characteristics. Tests were performed on specimens under normal conditions and in salt solutions, and data on tension and compression and lamb wave characteristics were collected at various time intervals. A methodology was developed to evaluate stress-strain location, elastic modulii and peak stress (strength) of the material at a given stage during the life of the structure. Results for salt-treated specimens were compared with those for untreated specimens and correlation between mechanical and Lamb wave test data was investigated. It was concluded that the integration of nondestructive testing with constitutive models can form the basis to develop new equipment using Lamb wave technique.The final report is available from the National Technical Information Service (NTIS # PB2002-101163).

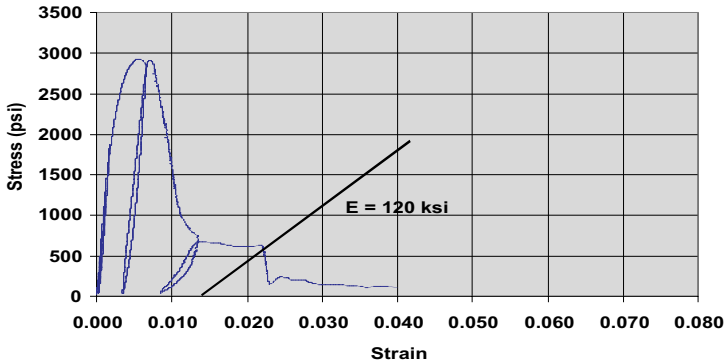


Figure 1

Stress strain response—compression test.

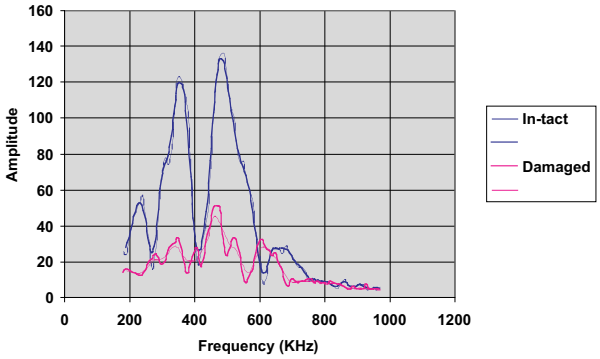


Figure 2

Voltage amplitude vs frequency: Incidence angle 25 deg.

DESIGN, DEVELOPMENT AND VERIFICATION OF AN ADVANCED IN-SITU SHEAR STRENGTH TEST FACILITY FOR ASPHALT CONCRETE PAVEMENTS

NCHRP-IDEA Project 55

A. O. Abd El Halim, [Tel.: (613) 520-5789, Fax: (613) 520-3951], Wael Bekheet, and Yasser Hassan, Carleton University, Ottawa, Canada,

Stephen N. Goodman
Canadian Strategic Highway Research Program, Ottawa, Canada

The project developed a surface plate type method for measuring the in-situ shear strength of asphalt pavements (Figure 1). The device is called the In-Situ Shear Strength/Stiffness Test (InSiSST™). Data collected with the InSiSST™ will provide input for more accurate measurement and performance modelling of in-service pavement performance—the fundamental basis of the SHRP Superpave system. The method involves applying a torque directly to the asphalt pavement surface and relating the maximum applied torque to the shear strength of the asphalt pavement layer. Initially, a preliminary design of a shear test device was developed along with a framework for a set of analytical models to predict pavement performance based on field shear data. Based on test results, the final design of the shear test device was developed and the system was tested to ensure proper functioning of all of its components. Field testing of the prototype system was performed on asphalt pavements at various locations in the United States and Canada.

In addition to IDEA Program funding, the Ontario Ministry of Transportation (MTO) and Regional Municipality of Ottawa-Carleton committed financial and in-kind support for this investigation. Furthermore, a number of independent consultants expressed interest in the potential of the InSiSST™. The final report is available from the National Technical Information Service (NTIS # PB2001-108550).

Figure 1

The in situ shear strength test (InSiSST™) at Carleton University.

BRIDGE INSPECTION WITH SERPENTINE ROBOTS

NCHRP-IDEA Project 56

Howie Choset [Tel.: (412) 268-2495, Fax: (412) 268-3348]
Carnegie Mellon University, Pittsburgh, Pennsylvania

This project developed an automated remote-controlled bridge inspection technology with flexible, jointed, serpentine robotic arms (Figure 1). These new types of robots have multiple joints that enable them to flex, reach, and approach all points on the bridge. Algorithms for the serpentine motion control were developed for a working system. A new method for using roadmaps to perform path planning with snakes, based on density functions, was developed. An inspection of a highway bridge was conducted to determine issues with bridge inspection using serpentine robotic system. The bridge symmetry posed some problem for geometric algorithms that was successfully resolved. A new serpentine robot prototype was designed that represented an improvement over the previous serpentine mechanism developed by the Jet Propulsion Laboratory (JPL). This new design involves an angular bevel joint that utilizes a special kind of angular bevel gear that allows larger ranges of motion and produces a stronger snake robot. A new cellular decomposition suitable for motion planning of serpentine robots was developed. Work on path planning and control of serpentine robot resulted in further improvements. Additional development and testing will be needed for the implementation of this technology in the field.

The developments of this project form the first step towards the envisioned bridge inspection and other similar systems and are critical to the successful transfer to an application program in the field. The technology also holds promise for other applications, such as search and rescue, pipe inspection, and bridge painting. The final report is available from the National Technical Information Service (NTIS # PB2001-104275).

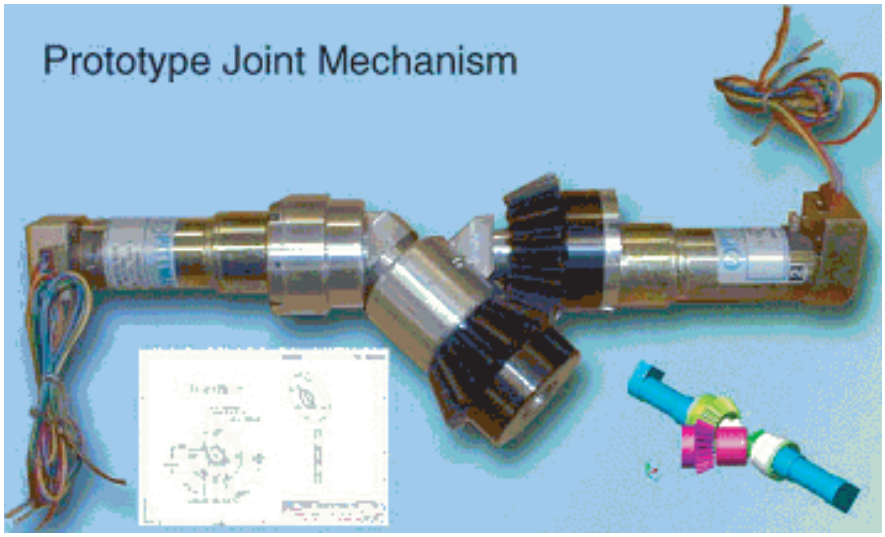


Figure 1

The angular bevel gear provides a wider range of motion and a stronger snake robot than previous designs.

STABILIZATION OF LANDSLIDES USING HORIZONTAL WICK DRAINS

NCHRP-IDEA Project 57

Paul M. Santi [Tel.: (303) 273-3103, Fax: (303) 273-3859]
Colorado School of Mines, Golden Colorado

C. Dale Elifrits
University of Missouri, Rolla, Missouri

This project investigated the use of horizontal wick drains to stabilize slopes and landslides (Figure 1). Several landslide sites, identified with the assistance of the Missouri and Colorado DOTs and the Colorado Geological Survey, were stabilized by wick drains and monitored. The field experience led to several improvements in the design and installation of wick drains. Additional landslides were stabilized in Colorado, and the experience led to further improvements in the installation process. The landslides were monitored for water levels as well as for slope and roadway movements. Simulation and interpretation of rainfall at the test embankment were accomplished, and guidelines for wick layout were developed. The results showed that wick drainage was highly dependent on hydraulic conductivity of shallow soil and that drains significantly lowered the water table and reduced soil settlement. For example, at one of the Colorado sites, the wick drains lowered the water table by 15 feet. TA video illustrating the technique for wick drain installation and use was prepared and is available for instructional purposes. The principal investigator has set up a web page that describes and updates the IDEA project activities and illustrates the wick installation process (http://www.umr.edu/~psanti/wick.html). The final report is available from the National Technical Information Service (NTIS # PB2002-103444).

Figure 1

Completed landslide drain system in a fan pattern. Note the water exiting the wick drains (inset: closeup of water drainage from a wick drain).

LONG GAUGE-LENGTH INTERFEROMETRIC FIBER-OPTIC SENSORS FOR CONDITION ASSESSMENT OF BRIDGE STRUCTURES

NCHRP-IDEA Project 58

Jeffrey A. Laman [Tel.: (814) 863-0523, Fax: (814) 863-7304], Timothy E. McDevitt, and Karl M. Reichard
Pennsylvania State University, University Park, Pennsylvania

This project developed a long gauge-length sensor system for monitoring the condition of bridge structures (Figure 1). The sensor system was designed and tested to optimize features important for concrete bridge applications and incorporated into a specially designed monitoring system. A concrete test beam was constructed, and techniques for sensor attachment, isolation, entrance, and exit were evaluated for their practicality in field applications. The optical sensors performed well in laboratory tests under dynamic loads responding at all frequencies of interest. The data analysis and correlation showed the system's promise in detecting damage changes in the structure. An in-service concrete bridge near Unionville, Pennsylvania, was identified for instrumenting with the fiber-optic prototype system for field evaluation. The sensor and the data acquisition system functioned well in the field conditions at the bridge. Strain time-history data were successfully collected for several truck passages under normal traffic. The system needs to be made more rugged and further developed for full-scale field deployment with regard to the size of the input and output devices and the sensitivity of the initiation procedure to focus the input light. The final report is available from the National Technical Information Service (NTIS # PB2002-103163).

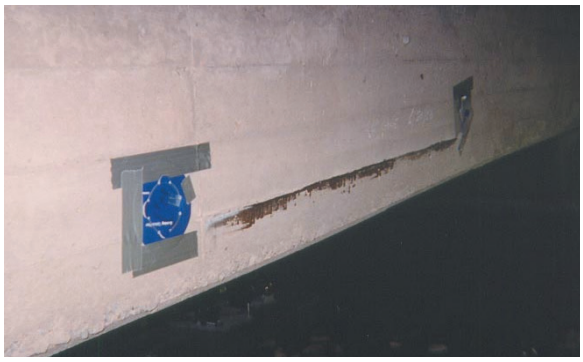


Figure 1

Installed optical sensor.

CONTROL SYSTEMS FOR LIVE LOAD AND LIVE LOAD EFFECTS ON BRIDGES

NCHRP-IDEA Project 59

Andrzej S. Nowak [Tel.: (734) 764-9299, Fax: (734) 764-4292]
University of Michigan, Ann Arbor, Michigan

Funded jointly by NSF and NCHRP-IDEA, this project developed a system for monitoring live load and verifying the live load carrying capacity of highway bridges. The NSF part of the work focused on fundamental work on the development of the truck control system while the IDEA portion dealt with practical applications, field measurements, and integration of the system with the intelligent transportation system (ITS). The field testing program involved verifications of girder distribution factors (GDF), dynamic load factors (DLF), truck load effect on newly applied fiber sheets, and truck load carrying capacity. The individual components of the comprehensive testing program were verified on 17 bridges. The final, multi-objective tests were carried out on a selected structure in Florida. The load was applied in the form of fully loaded (up to the legal limit) trucks. The considered loading combinations include a single vehicle and two trucks side-by-side. The results of these and previous tests indicate that the girder distribution factors (GDF) specified by AASHTO for the spans from 10 to 30m are rather conservative. Dynamic load factors (DLF) were also measured for a single truck and two trucks side-by-side. It was observed that the dynamic load is not related to static load, and therefore DLF (defined as the ratio of dynamic load and static load) decreases for larger static load. Figure 1 shows a plot of DLF against static and dynamic strain recorded for heavy trucks. Deflections due to truck loads are also considerably lower than analytically predicted values. The field tests confirmed that the developed procedures are efficient and can be used as an alternative way to evaluate the adequacy of the bridge.

The control system for highway load effects has already been applied on selected bridges in collaboration with the state DOT's in Michigan, Wisconsin, and Florida. The final report is available from the National Technical Information Service (NTIS # PB2004-102286).

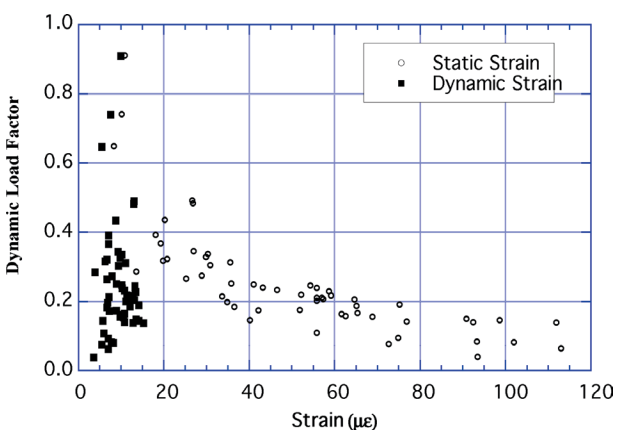


Figure 1

DLF vs. static and dynamic strain.

THE HYBRID-COMPOSITE BEAM SYSTEM

NCHRP-IDEA Project 60

John R. Hillman [Tel.: (847) 722-4072; Email: hillmanjr@hcbridge.com]
Teng and Associates, Inc., Chicago, Illinois

This joint High-Speed Rail/NCHRP IDEA project developed and demonstrated a hybrid-composite beam (HCB) as a structural member for use in railroad and highway bridges (Figure 1). The HCB is comprised of three main subcomponents that are a shell, compression reinforcement, and tension reinforcement. The shell is comprised of a fiber-reinforced plastic (FRP) box beam. The compression reinforcement consists of portland cement concrete, which is pumped into a profiled conduit within the beam shell. The tension reinforcement consists of steel fibers anchored at the ends of the compression reinforcement. The HCB weighs approximately one-tenth of what a typical precast concrete beam weighs for the same span length, improves the speed of construction, and is well suited for modular bridge installation (accelerated bridge construction). In general, HCB is suitable for 50- to 120-ft span bridges for highways and for 30- to 45-ft span bridges for rail.

HCB was successfully tested on a railroad test track in Pueblo, Colorado. Since then, the beams have been installed in 17 highway bridges in nine states (Colorado, Illinois, Kentucky, Maine, Maryland, Missouri, New Jersey, Virginia, and West Virginia) and one Canadian province (British Columbia). At least seven more HCB projects are under consideration for construction in Maine, New Jersey, Washington State, and the provinces of British Columbia, Ontario, and Saskatchewan. The U.S. Army Corp of Engineers used HCB on a bridge in Kentucky. The IDEA inventor has signed licensing agreements with companies in the European Union, Russia, Kuwait, and Brazil. AASHTO's Technology Implementation Group selected HCB as a focus technology for implementation in 2011.

Figure 1

Hybrid composite beam being installed on High Road Bridge in Lockport Township, Illinois.

THE PAVEMENT THICKNESS DENSITY METER

NCHRP-IDEA Project 61

Kenneth R. Maser [Tel.: (781) 648-0440, Fax: (781) 648-1778]
INFRASENSE Inc., Arlington, Massachusetts

This project developed and tested an automated portable device, using a low-power-pulsed electromagnetic wave detection technique, for determining asphalt pavement thickness and density during construction. The work involved antenna evaluation, software development, field data analysis, system specifications, and prototype development. Three different antenna configurations were evaluated, and based on performance data, a horn antenna was selected. Field data on a newly paved road section was collected to further test the antenna configurations, evaluate potential thickness accuracy, and to provide a data set for software development. A real-time prototype software was developed and tested on the field data. The antenna system was further improved with respect to electronic performance and packaging. Laboratory and field tests show that the device with the new horn antenna can accurately determine the dielectric constant of asphalt and can provide pavement thickness accuracy to within 0.2 inch. The test results also show a correlation of asphalt dielectric constant with its air content.

The PTDM will enable agencies to maximize pavement life and minimize life cycle costs by accurately and completely determining, at the time of construction, if pavement has been built according to specifications. With this capability, agencies will be able to save millions of dollars in premature, unplanned, and unnecessary repairs, and rehabilitation caused by inadequately constructed pavement. The final report is available from the National Technical Information Service (NTIS # PB2003-100546).

Figure 1

Portable PTDM.

A NEW TECHNIQUE FOR CHARACTERIZING PAVEMENT SURFACE PROFILES AND TEXTURES

NCHRP-IDEA Project 62

Cam Nguyen [Tel.: (979) 845-7469, Fax: (979) 845-6259] and Tom Scullion
Texas A&M University, College Station, Texas

This project investigated developing a high-resolution millimeter sensor and demonstrating its use in real-time measurements of transverse and longitudinal profiles and micro/macro textures of pavements. A millimeter-wave sensor prototype (Figure 1) was designed, integrated, and tested. The compact and low-cost sensor was completely realized using millimeter-wave integrated circuits. Laboratory tests provided promising results on the feasibility of the system in mapping surface profiles. In one test, the prototype measured the surface profiles of a metal foil deposited on top of a foam block. The measured contour resembled very closely the shape of the actual sample. In another test, the sensor system imaged several tiles placed next to each other at different heights. Again, the sensor produced a profile closely resembling the actual surface.

The results indicate that the system can map surface profiles with sub-millimeter resolution. The prototype is ready for laboratory and field evaluations to measure macro and micro textures of pavement. However, a redesign of the sensor and a new horn antenna should further improve the performance of the system. The final report is available from the National Technical Information Service (NTIS # PB2002-103443).

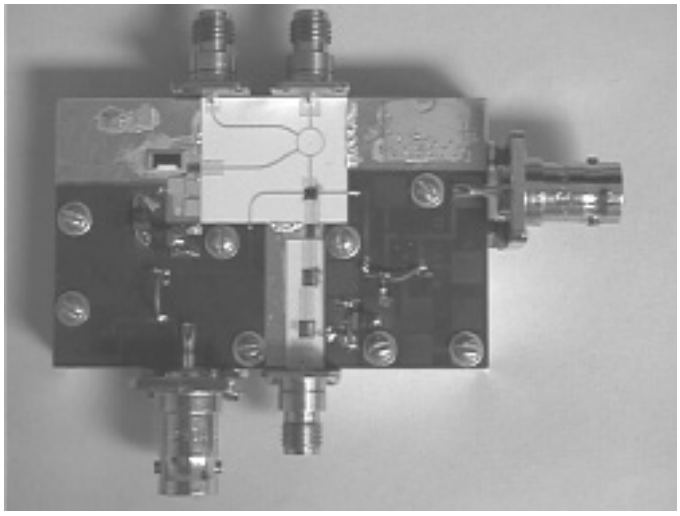


Figure 1

The millimeter-wave sensor prototype.

MANUFACTURE AND TESTING OF A FILAMENT WOUND COMPOSITE BRIDGE SUPERSTRUCTURE

NCHRP-IDEA Project 63

Dennis Parsons [Tel.: (217) 333-2690, Fax: (217) 333-9464] and Scott White
University of Illinois, Urbana-Champaign, Illinois

The project investigated the manufacturability and structural performance of filament-wound, fiber-reinforced plastic composite bridge structures (Figure 1). The bridge structure consists of two components: a series of inner cells, lying parallel to the direction of traffic, and an outer shell. Following preliminary specimen calculations and the mandrel and fixture designs, finite element analyses were conducted to determine the physical dimensions of the prototype bridge superstructure. Specifications and geometry of the prototype were finalized and designs for the inner cell mandrel and fixtures needed to wind the outer shell and test on the bridge superstructure were completed. Laboratory tests were performed to determine the accuracy of finite element models with promising results. Tests were then performed on three model bridges. Results indicate that the finite element models provide good predictions of the stiffness and strength of the models. These finite element models were refined by incorporating the results of material tests. The findings of this project need to be further verified with full-scale, actual size bridges in the field. The final report is available from the National Technical Information Service (NTIS # PB2002-104355).

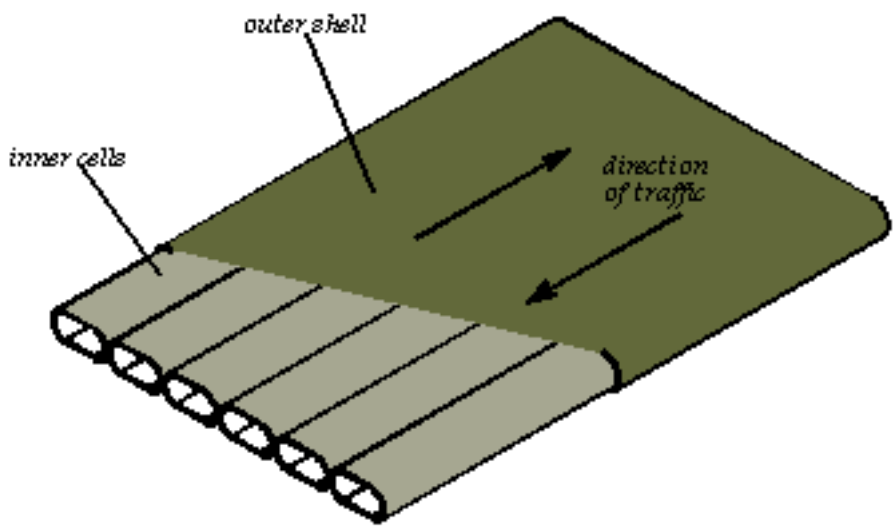


Figure 1

Bridge structural system.

QUANTITATIVE CHARACTERIZATION OF ASPHALT CONCRETES USING HIGH-RESOLUTION X-RAY COMPUTED TOMOGRAPHY (CT)

NCHRP-IDEA Project 64

Richard A. Ketcham [Tel.: (512) 471-0260, Fax: (512) 471-9425] and William D. Carlson
University of Texas, Austin, Texas

The project develops an asphalt pavement evaluation methodology based on high-resolution X-ray computer tomography (CT) to obtain three-dimensional imagery of asphalt concrete. The thrust of the project was to develop a software application called "Blob3D" which utilizes industrial high-resolution X-ray computed tomography data to provide quantitative, nondestructive evaluation of asphalt concrete pavements (Figure 1). The project accomplished the initial conception, design, and development of the software program to obtain the required analysis. During the first phase, the program architecture was laid out and the data analysis was divided into three stages: segregation, separation, and extraction. Software to accomplish each of these tasks was developed in parallel and successively improved and tested to achieve a working package. Once a CT data volume has been segmented and separated, it can be mined to get the desired data. The data that can be extracted from the system includes particle (or void) volume, center of mass, surface area, aspect ratio, long axis orientation, and location, direction, and surface area of all particle-particle contacts. A series of controlled tests was performed to verify that the information produced by the analysis was correct. In all cases, the test results met expectations.

The techniques developed in this project can aid in the formulation of mixing methods by comparing experimentally mixed cores; poor-performing mix designs can be identified and eliminated. Such an analysis can also be used as a forensic tool to investigate pavement failures. These investigations should allow for the building of higher-quality and more durable pavements, with large indirect savings from reduced need for maintenance and replacement. Five hundred million tons of asphalt concrete is laid down each year as overlays, full-depth pavements, and other applications, at a cost of up to $15 billion. Any incremental savings enabled by improved pavement design should result in considerable savings. Reduced wear on vehicles due to better pavements also constitutes an indirect but potentially large payoff. The final report is available from the National Technical Information Service (NTIS # PB2001-102198).

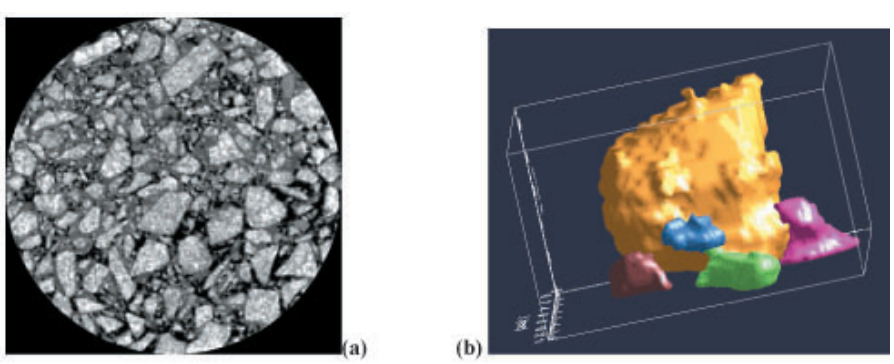


Figure 1

(a) Example CT scan of an asphalt concrete core. Field of view is 145 mm. (b) Sample Blob3D program view showing 3D processing to extract aggregates from scan data.

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 65

Reginald DesRoches [Tel.: (404) 385-082, Fax: (404) 894-0211]
Georgia Institute of Technology, Atlanta, Georgia

This project demonstrated the feasibility of using shape memory alloy (SMA) devices (restrainer cable and core elastomeric bearings) for seismic rehabilitation of highway bridges (Figure 1). By concentrating energy dissipation in controlled locations, these devices can be used to limit the relative hinge displacement and reduce the demand on individual frames in typical bridges. The research evaluated the characteristics of nickel-titanium shape memory alloy rods and wires under compression-tension cycles as a function of diameter size, loading frequency and temperature in order to establish their suitability for bridge rehabilitation. SMA restrainer bars, one inch in diameter, were subjected to uniaxial tension, in full-scale tests. The bars were also subjected to cyclical strains up to 8 percent with minimum residual deformation. The effectiveness of SMA restrainer bars in bridges was further evaluated by an analytical study of a simply supported multi-span bridge. The relative hinge displacement in a bridge was compared for retrofits for conventional steel restrainer cables and SMA restrainer bars. The comparison showed that the SMA restrainers reduced the relative hinge displacements at the abutment much more effectively than conventional steel cable restrainers. In addition the superelastic properties of the SMA restrainers resulted in energy dissipation at the hinges. Finally, the evaluation of the multi-span, simply-supported bridge subjected to near-field ground motion showed that the SMA bars were very effective in limiting the response of bridge decks to near-field ground motion. The increased stiffness of SMA restrainers at large strains provided additional restraint to limit the relative openings in a bridge.

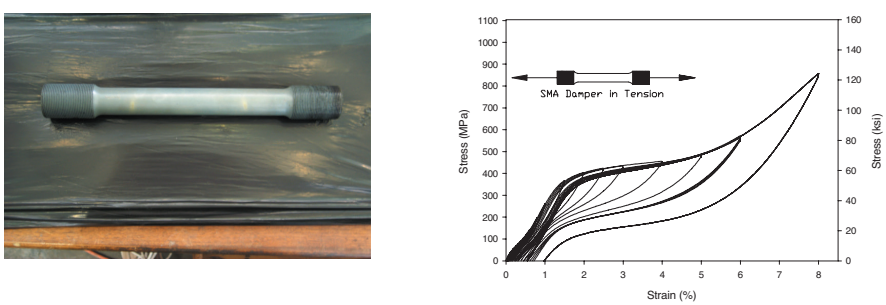


Figure 1

(left) Proposed SMA damper, and (right) Stress-strain relationship for nitinol shape memory alloy damper.

There are thousands of bridges in the United States that are in need of seismic retrofit. Should this technology prove effective and cost efficient, it can become a widely used seismic retrofit technology. Collaboration with Shape Memory Alloy manufacturers and end-users is essential to ensure the transfer of the research results to practice. The final report is available from the National Technical Information Service (NTIS # PB2002-103441).

DEVELOPMENT OF AN INNOVATIVE CONNECTOR SYSTEM FOR FIBER-REINFORCED POLYMER BRIDGE DECKS TO STEEL STRINGERS

NCHRP-IDEA Project 66

Julio F. Davalos [Tel.: (304) 293-3031, ext. 2632, Fax: (304) 293-7109] and Karl E. Barth
West Virginia University, Morgantown, West Virginia, and

Pizhong Qiao
The University of Akron, Akron, Ohio

This project developed and tested a connector system (Figures 1 and 2) for attaching fiber-reinforced polymer (FRP) bridge decks to support steel stringers. The connector dimensions were defined through finite element analyses. The connector design was experimentally evaluated first, by, testing a single connector between a section of the FRP deck and a steel wide-flange beam. The ultimate strength of the connector was obtained, and the loads-slip response was defined along with an evaluation of the failure modes. The results were used to redesign the connector and make it simpler and more economical. The performance of the connector-stringer design was evaluated for a number of loads to establish the required number of connectors for adequate deck restraint, percent of composite action, and effective flange width for a deck/stringer system. The contractor worked with West Virginia and Kansas DOTs to implement this concept in their bridge projects. The final report is available from the National Technical Information Service (NTIS # PB2004-100134).

Figure 1

Photo of steel-sleeve connector.

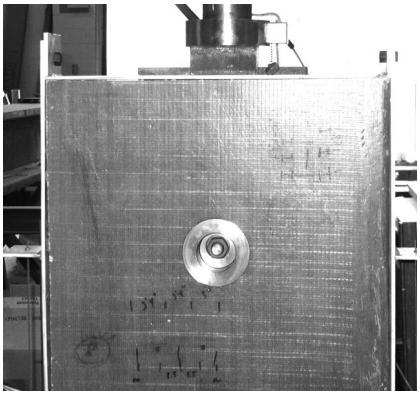


Figure 2

Photo of FRP panel and connector.

ALL COMPOSITE BRIDGE SIDEWALK

NCHRP-IDEA Project 67

D. Thomson [Tel.: (781) 622-5505, Fax: (781) 890-0488] and T. Campbell
Foster-Miller Inc., Waltham, Massachusetts, and

G. E. Johansen
E.T. Techtonics Inc., Philadelphia, Pennsylvania

This project developed and tested a lightweight cantilevered, fiber-reinforced composite sidewalk for roadway bridges (Figure 1). Work performed in collaboration with the Vermont Agency of Transportation (VAOT) defined performance specifications for the sidewalk with reference to material and mechanical properties for bridge application, including specific strength and deflection requirements for cantilevered sidewalk system design. The system has a single molded component for cantilevered support. The cantilevered support,which consists of carbon fabric and epoxy resin, is a constant cross section I-beam with an overall height of 18 in. and weighs approximately 125 lb. The length of the cantilevered support is 11 ft and the width of the walkway portion of the sidewalk system is 6 ft. The flange width, flange thickness, and web thickness are 12.75, 0.5, and 0.25 in. respectively. The composite sidewalk system was sized for a minimum factor of safety (FS) of 3. Validation of design was performed through the use of static and creep tests at the University of New Hampshire. The composite I-beam developed in this project was displayed at the Smithsonian Cooper-Hewitt National Design Museum's exhibit, Extreme Textiles: Designing for High Performance, in New York in 2005. The final report is available from the National Technical Information Service (NTIS # PB2002-1000006).

427-P-98595-7

Figure 1

E. T. Techtonics composite pedestrian bridge.

GEOCOMPOSITE CAPILLARY BARRIER DRAIN FOR LIMITING MOISTURE CHANGES IN PAVEMENT SUBGRADES AND BASE COURSES

NCHRP-IDEA Project 68

John Stormont [Tel.: (505) 277-6063, Fax: (505) 277-1988]
University of New Mexico, Albuquerque, New Mexico, and

Karen Henry
US Army Cold Regions and Research Engineering Laboratory
Hanover, New Hampshire

This project developed and evaluated the effectiveness of a geocomposite capillary barrier drain (GCBD) system (Figure 1) in preventing pavement damage by controlling moisture movement in pavement subgrade and base course. A number of geotextiles were evaluated for their suitability as a transport layer using a series of tests that included capillary rise, moisture retention, function measurements, siphoning, and transmissivity under suction. At infiltration rates that occur in the field, the GCBD drained water from overlying base material that was not saturated. Furthermore, the GCBD prevented the moistening of the subgrade at many of the filtration rates tested. This allows the design of unsaturated soil drainage to help extend pavement life by limiting the time the bases are saturated and by diverting large volumes of water to a drainage system before it reaches the subgrade. In the specific GCBD tested, water drained from overlying base soil when subjected to suction head of 100 mm and greater. Furthermore, at long term infiltration rates of 0.1 to 0.15 mm/hr, the GCBD prevented infiltrating water from reaching the subgrade. Finally, the GCBD recovered its function and protected the subgrade following a test in which a small amount of water had broken through the GCBD into the subgrade. Further development is needed before the technology can be implemented and before a transport layer—more economical than the one tested in this project—would make GCBD more affordable and implementable. The project was highlighted in a recent issue of *Progressive Engineer,* an on-line engineering magazine and information source. The final report is available from the National Technical Information Service (NTIS # PB2003-101349).

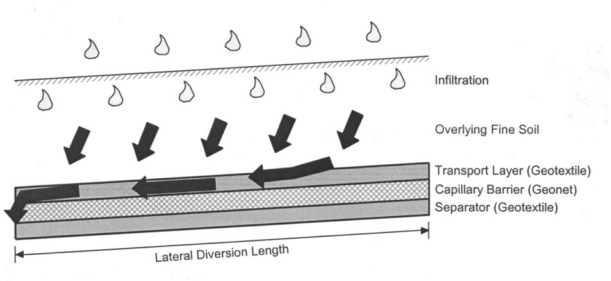


Figure 1

Geocomposite capillary barrier drain.

DEVELOPMENT OF A CONDUCTIVITY SPECTRUM PROBE (CSP) FOR PREDICTING CHLORIDE PERMEABILITY IN CONCRETE

NCHRP-IDEA Project 69

Kenneth R. Maser [Tel.: (781) 648-0440, Fax: (781) 648-1778]
INFRASENSE Inc., Arlington, Massachusetts

This project developed and tested a portable conductivity spectrum probe (CSP), for in situ determination of chloride permeability of concrete (Figure 1). Laboratory equipment for conductivity and dielectric measurements was assembled and calibrated with known reference materials. A number of concrete specimens, covering a range of mix design parameters and chloride concentrations, were prepared and characterized for chloride contents using standard methods. Following a preliminary testing of these specimens, the CSP was tested on a number of additional well-characterized samples obtained from the W.R. Grace laboratories in Cambridge, Massachusetts, that covered a range of concrete mix formulations, rebar configurations, and chloride exposures. The tested samples were soaked in water for six days and retested in saturated state followed by testing in a partially dried state. The test data were correlated with chloride permeability that was determined independently using standard test methods. Known relationships between conductivity and chloride permeability were used to establish a functional form for relating the measured CSP data to the chloride permeability data. Additional development and refinement of the equipment is needed for its field application and implementation. The final report is available from the National Technical Information Service (NTIS # PB2003-102867).

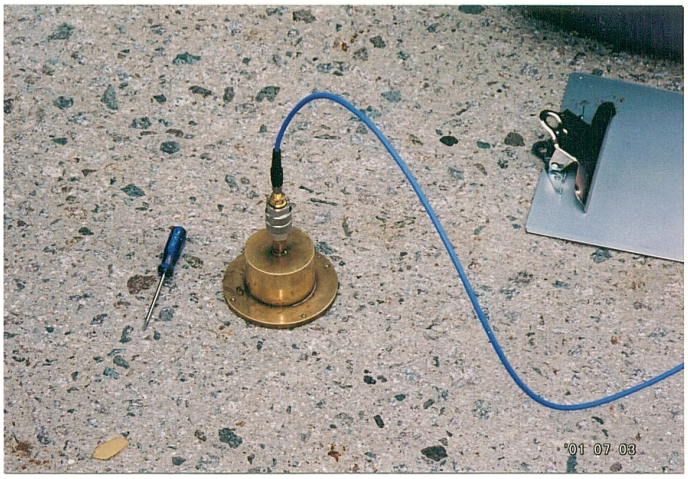


Figure 1

CSP probe.

FLAMESPRAY COATING AS AN ENVIRONMENTALLY ACCEPTABLE PAVEMENT MARKING TECHNIQUE

NCHRP-IDEA PROJECT 70

Anthony L. Andrady [Tel.: (919) 541 6713, Fax (919) 541 8868]
Chemistry and Life Sciences, Research Triangle Institute, Durham, North Carolina

This project tested an environmentally safe flamespray coating technique using new polymer formulations for pavement marking. Initial investigations of commercially available alkyd thermoplastic resins suggested their suitability for flamespray applications. However, the resins contained premixed glass beads that made them unsuitable for flame spray applications. Also, the resin particle size was found to be too large to allow a uniform flame spraying. These problems were addressed by custom blending the alkyd resin without glass beads, melt extruding, and cryogenic grinding to reduce particle size. However, the process produced very fine dust-like particles and the nonresin components in the mix tended to separate when the material was fluidized. Two new formulations with different levels of solid plasticizer in base resin were compounded via extrusion followed by cryogenic grinding to reduce the particle size of the product. These formulations, which, could be flamesprayed onto concrete substrates showed good adhesion and abrasion resistance. The approach appears feasible but will require modification of the spray gun to obtain better edge definition. Also, the glass beads will have to be used as a "drop on" application immediately following the resin spraying. Further work is necessary to optimize the resin formulations and to evaluate their long-term weather durability. The final report is available from the National Technical Information Service (NTIS # PB2003-102865).

IMPLEMENTATION OF TUNED DAMPERS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

NCHRP-IDEA Project 71

Armin B. Mehrabi [Tel.: (847) 965-7500, Fax: (847) 965-8997]
Construction Technology Laboratories Inc., Skokie, Illinois

Habib Tabatabai
University of Wisconsin, Milwaukee, Wisconsin

Niket M. Telang
Construction Technology Laboratories Inc.

This project was a follow-on activity for an earlier IDEA project (NCHRP-50) to demonstrate the effectiveness of tuned mass dampers (TMD) in minimizing stay cable vibrations in a full-scale field trial on an actual highway bridge. Several visco-elastic materials and model configurations were investigated to identify models that could be considered for full-scale prototype adaptation. Simultaneous to experimenting with various models, analytical investigations were conducted to calculate required properties and dimensions of the full-scale versions of the models. The analytical evaluation identified a problem in adapting the scaled models to full-scale sizes due to low-frequency vibrations of the actual bridge stay cables. This problem was addressed by using a hybrid of impact and tuned damper. Laboratory tests, conducted on model cables using two types of tuned impact dampers (TID), showed the TID to be more effective than the TMD. The TID was also found to be effective at low frequencies. Using the evaluation results, a full-scale refined TID system was designed and fabricated. The prototype system was installed on experimental basis on the Talmadge Bridge in Savannah, Georgia. The field test results confirmed the efficiency and applicability of the TID system for increasing the cable apparent damping ratios and suppression of excessive vibrations. The final report is available from the National Technical Information Service (NTIS # PB2003-102863).

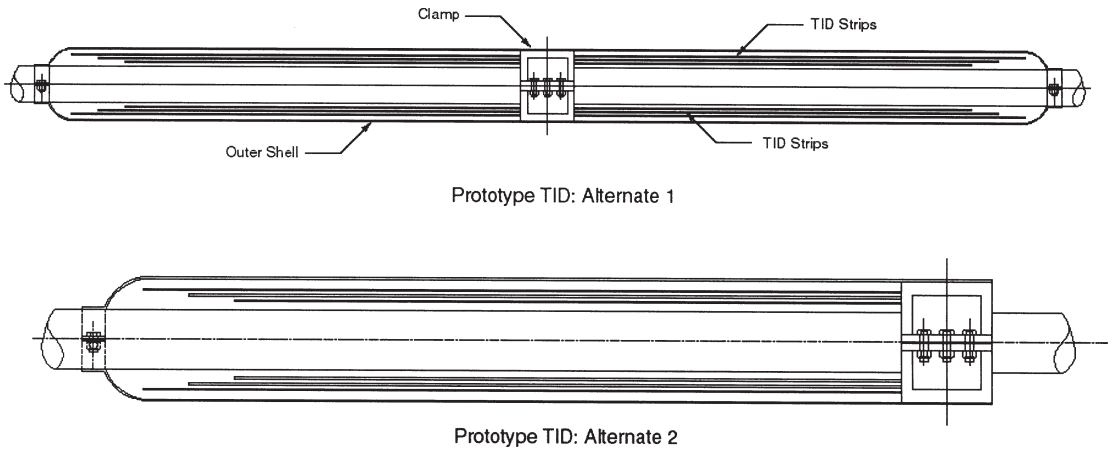


Figure 1

Tuned Induced Damper (TID) system.

IMPROVED FILTRATION OF WASH WATER GENERATED DURING BRIDGE MAINTENANCE PAINTING

NCHRP-IDEA Project 72

Robert Lewallyn [Tel.: (404) 894-0281, Fax: (404) 894-2481]
Georgia Tech Research Institute, Atlanta, Georgia, and

Theodore Hopwood
Kentucky Transportation Center, University of Kentucky, Lexington, Kentucky

This project designed and tested a filtration system (Figure 1) for removing both particulate and soluble lead from wash water generated by pressure washing lead-based paint from highway bridges during painting operations. The filtration system relies on a granular compound capable of chemically binding free lead into an insoluble lead mineral. A literature search identified several commercial hydroxypyromorphite compounds suitable for binding lead in an aqueous environment along with many apatite minerals that appeared to stabilize lead. Bench-scale testing of three commercial filter media containing lead-stabilizing compounds, based on aluminum silicate and calcium phosphate, were conducted under simulated field conditions.

All three systems performed adequately in removing both total and dissolved lead from the synthetic effluent. Based on test results and cost considerations, LeadX was selected as the primary medium for lead removal. A full-scale prototype filtration system capable of handling 400 gallons of water per hour was designed and fabricated. It consisted of a flow equalization tank followed by a trickling sand filter (to remove large particulates) and an upflow filter column containing the filter medium. The prototype was tested on two bridge washing projects at two locations in Kentucky. In both instances, the filtration system proved effective in removing lead from the washwater. The total lead concentrations were reduced to 20 ppb or less from 10 ppm. The final report is available from the National Technical Information Service (NTIS # PB2003-102869).

Figure 1

Wash water filtration system.

DEVELOPMENT OF A SCREED TO DETECT AND MEASURE SEGREGATION OF HMA PAVEMENTS

NCHRP-IDEA Project 73

Mary Stroup-Gardiner [Tel.: (334) 844-6280, Fax: (334) 844-6290]
Auburn University, Auburn, Alabama

This project developed and tested an infrared sensor-based screed attachment for asphalt paving equipment to monitor temperature differentials as a method for detecting and measuring segregation during construction. The prototype system consists of a transverse line of infrared sensors, signal conditioners, computer data acquisition system, and a global positioning system (GPS). The system is capable of continuously monitoring temperature differentials during construction. Real time transverse temperatures are plotted on a computer screen for use by the paving crew. The software produces a summary of potentially segregated areas by level of segregation (i.e. low, medium, and high) as well as the number of paver stops over one minute for use by the state agency. Preliminary testing with the system on existing pavement surfaces shows that the system can adequately evaluate the transverse temperature differential (Figure 1). The low-budget GPS system is found to be reasonably accurate over multiple runs for locating pavement anomalies. The software is easy to use and automatically prepares a report that locates all nonuniform transverse temperature areas. The final report is available from the National Technical Information Service (NTIS # PB2003-102864).

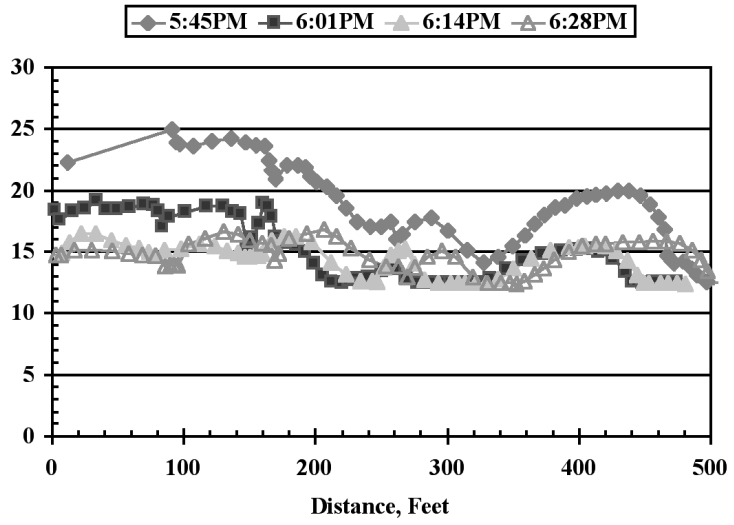


Figure 1

Temperature ranges for four runs on an existing pavement.

ADHESION TOOL FOR OVERCOATING RISK-REDUCTION ANALYSIS

NCHRP-IDEA Project 74

Moavin Islam [Tel.: (703 679-9220, Fax: (703) 679-9220]
Corrpro Companies Inc., Chantilly, Virginia, and

James A. Ellor
Corrpro Companies Inc., Arlington, Virginia

This project's goal was to develop a new coating adhesion test that is based on induced stress to determine the suitability for overcoating of an existing highway structure. Laboratory test procedures for measuring coating stresses were explored that included deflection measurements using a capacitive sensor and direct measurements using a miniature surface, mounted fiber-optic strain gage. Based on test results, the direct measurement method using miniature strain gages was selected since it provided more reliable and reproducible data than the deflection measurement test. Two types of prototype testers were then fabricated for laboratory and field evaluation: prestressed elastic material adhesion tester and the mechanical shear stress adhesion tester. The tests were performed on a number of overcoating materials that included a polysilicone enamel, an acrylic, a moisture-cured urethane, and two different epoxies. The results showed the elastomeric device to be most promising for adhesion testing. It maintained a near constant level of stress on test panels throughout the monitoring period and appeared to be most suitable for time-dependent failure evaluation. The present device, however, is not capable of producing 10 MPa stresses over test panels representative of an existing structure and needs further refinement and evaluation in order to make it into a field tester for coating adhesion. The final report is available from the National Technical Information Service (NTIS # PB2003-102866).

AUTOMATED MOBILE HIGHWAY SIGN RETROREFLECTIVITY MEASUREMENT

NCHRP-IDEA Project 75

Norbert H. Maerz [Tel.: (573) 341-6714, Fax: (573) 341-4368]
University of Missouri, Rolla, Missouri

This project developed and tested a prototype digital video image analysis system (Figure 1) to measure highway sign retroreflectivity. A literature review was conducted to obtain additional relevant information on highway sign retroreflectivity. The image processing hardware was procured and checked. An image-processing algorithm to perform real time analysis was developed. Signs were obtained from the Missouri DOT to calibrate the system. An outdoor measuring range with interchangeable sign mounted on a signpost was set up for experimental development. Following laboratory and outdoor evaluations, a prototype system to measure highway sign reflectivity was developed and tested under highway conditions. The results show the feasibility of developing a mobile vision-based system to classify and measure the visibility of road signs. The results also showed a rather poor correlation between retroreflectivity and visibility. Retroreflectivity was found to be a poor predictor of the visibility of white, yellow and—to a lesser extent—orange signs. It is, however, a relatively good predictor of the visibility of red and—to a lesser extent—of green and blue signs. Brown signs were found to be of low retroreflectivity and visibility. The method developed in this project is the closest possible analog to what the eye sees when looking at signs under the normal illumination provided by the headlights. The method should be used at night and may be limited to use with high beams. The final report is available from the National Technical Information Service (NTIS # PB2003-102868).

Figure 1

Imaging equipment mounted in a vehicle.

STABILIZATION OF LANSDLIDES USING HORIZONTAL WICK DRAINS

NCHRP-IDEA Project 76

Paul M.Santi [Tel.: (303) 273-3108, Fax: (303) 273-3859]
Colorado School of Mines, Golden, Colorado, and

C. Dale Elifrits
University of Missouri, Rolla, Missouri

This project was a follow-on activity of an earlier IDEA project (NCHRP-57) for field testing and implementing the horizontal wick drains technology for stabilizing landslides. Work in this follow-on project involved installing and evaluating new field sites and completing the monitoring of the field sites stabilized with horizontal wick drains that had been previously installed in the NCHRP-57 project. The work also addressed technical and economic issues related to the clogging of the drains. In total, more than 170 drains totaling over 8,600 feet in length were installed in eight sites in Missouri, Colorado, and Indiana. The drain installation rates averaged over 60 feet per day for cost estimated at approximately $2.50 per foot. Laboratory experiments conducted over a period of two years to assess the potential clogging of wick drains showed varying amounts of fine particles coating the inside strands of the drain fabric. However, the drain's ability to transmit water was not affected. Finally, a procedure was developed to estimate the shape of the water table surface for drained landslides, using parameters easily measured in the field and laboratory. The wick drain technology to stabilize landslides is now available for implementation. The final report is available from the National Technical Information Service (NTIS # PB2003-102861).

Figure 1

Completed set of drains near Boonville, Missouri. Water flow out of center drain is being measured.

THE DEVELOPMENT OF A COMPUTER CONTROLLED IMAGE ANALYSIS SYSTEM FOR MEASURING AGGREGATE SHAPE PROPERTIES

NCHRP-IDEA Project 77

Eyad Masad [Tel.: (509) 335-9147, Fax: (509) 335-7632] and Tom Papagiannakis
Washington State University, Pullman, Washington

This project developed and tested an automated image analysis system (AIMS) for measuring aggregate shape characteristics (Figure 1). The work involved development of both software and hardware systems. The software incorporated several image analysis procedures and its application to measure the texture of a wide range of fine and coarse aggregates. The hardware for the image analysis system incorporated a computer-controlled mechanism to allow capturing different projections of aggregate particles and describing their shape properties rapidly and accurately. Further software refinement produced a user-friendly version of the original software that facilitated data presentation and manipulation. The hardware and software were then integrated to produce a prototype of the automated aggregate analysis system. The system was tested on a range of fine and coarse aggregates and the results were compared with hot mix asphalt performance data. The image analysis procedure provided detailed information on shape properties of aggregates in a relatively short time. The shape measurements also showed a good correlation with the resistance of asphalt mixes to permanent deformation measured in the laboratory using different wheel tracking devices. AIMS was further evaluated and refined with support from FHWA's Highways for LIFE Program. The system is now commercially available and is being used by FHWA in its mobile laboratory for demonstration and training. Two test procedures based on AIMS have been adopted by AASHTO for determining aggregate shape properties (TP 81 and PP 64). (NTIS Report # PB2003-102870).

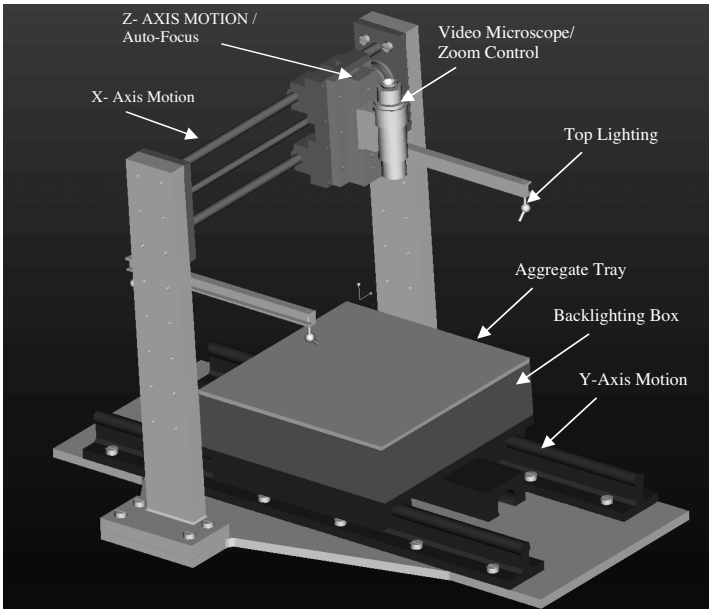


Figure 1

3-D graphical model of AIMS.

AGGREGATE SHAPE CHARACTERIZATION USING DIGITAL IMAGE PROCESSING

NCHRP-IDEA Project 78

Norbert H. Maerz [Tel.: (573) 341-6714, Fax: (573) 341-4368] and David N. Richardson, University of Missouri, Rolla, Missouri

This project developed and tested a rapid method based on automated digital imaging technology to characterize aggregate shapes. A prototype automated imager analyzer (Figure 1) was developed and evaluated. Over 150 aggregate samples procured from the Missouri DOT and a private quarry were used for evaluation. The imaging hardware was modified to use backlighting to reduce errors from dark aggregates and upgraded to allow rapid and accurate measurements. The software was also modified to enable particle angularity measurements in terms of curve radius. Control samples of various configurations with known or uniform characteristics were prepared and tested. Image-measured flat and elongation ratios were found to be fairly close to matching caliper results, and the repeatability of measurements was found to be better than with manual tests. Results also show that image-measured angularity can be correlated with void tests. Analysis of flat and elongation measurements as a function of crusher type showed that impact type crushers tended to produce more cubical particles even when rock type is not accounted for. The equipment needs additional development, refinement, and testing for its implementation. The final report is available from the National Technical Information Service (NTIS # PB2004-105016).

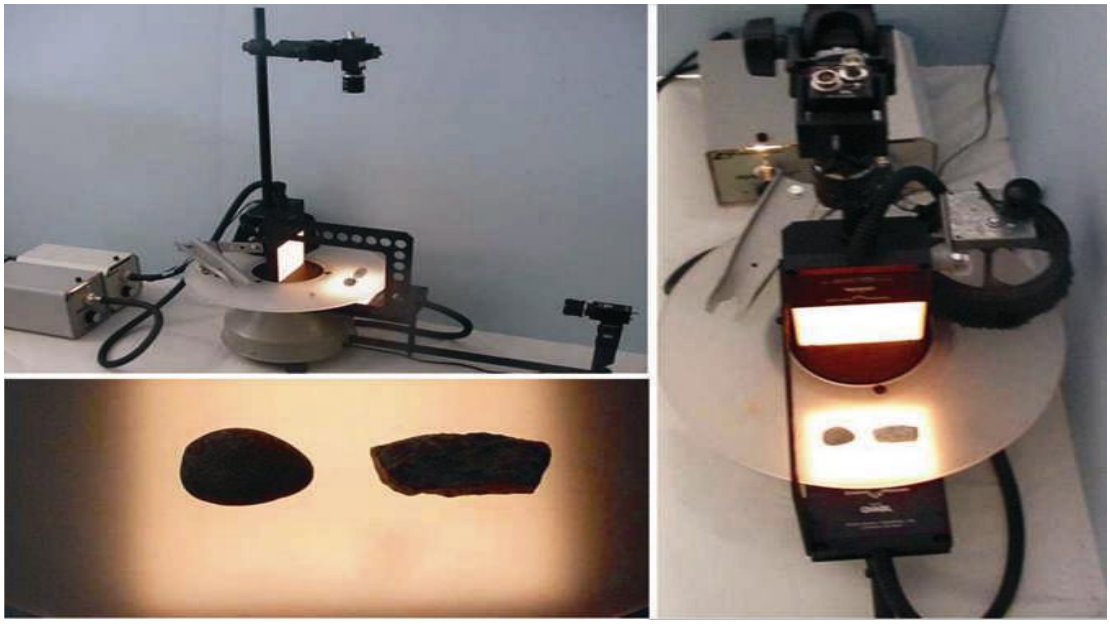


Figure 1

New flat and elongated image analyzer.

CONCRETE ROAD RECYCLER—HAMMER-ANVIL TEST RIG

NCHRP-IDEA Project 79

Deems Pfaff [Tel.: (970) 476-6577, Fax: (970) 476-0504]
Road Processing Resources, Inc., Vail, Colorado, and

Robert Burggren [Tel.: (651) 388-6179, Fax: (651) 388-6179]
Red Wing, Minnesota

This project involves designing, building, and demonstrating the practical feasibility of a mechanical system based on the anvil-hammer concept for removing, fragmenting, and recycling concrete pavement. Figure 1 shows the schematic diagram of the system. The designs of the hammer, anvil, feed system, and other components of the prototype system were developed and evaluated and various technical and operational issues were identified and resolved. A trailer test rig was fabricated for mounting and using the prototype road recycler system. The prototype system was integrated and mounted on the trailer at a test facility in Iowa. The present set-up uses a gravity-drop hammer but can be adapted to pneumatic hammers. The tests to-date show a capacity to separate concrete from steel to satisfy useable and saleable scrap. The aggregate composition will require more testing with feed bite, hammer stroke, and hammer face variables to suit the nature of the material being processed. After in-house tests, the system will be further improved and demonstrated in the field on actual pavement slabs. The contractor is working with several heavy equipment manufacturers in the design and assembly of the final prototype system. Kansas and Iowa DOTs have collaborated in testing of the prototype system.

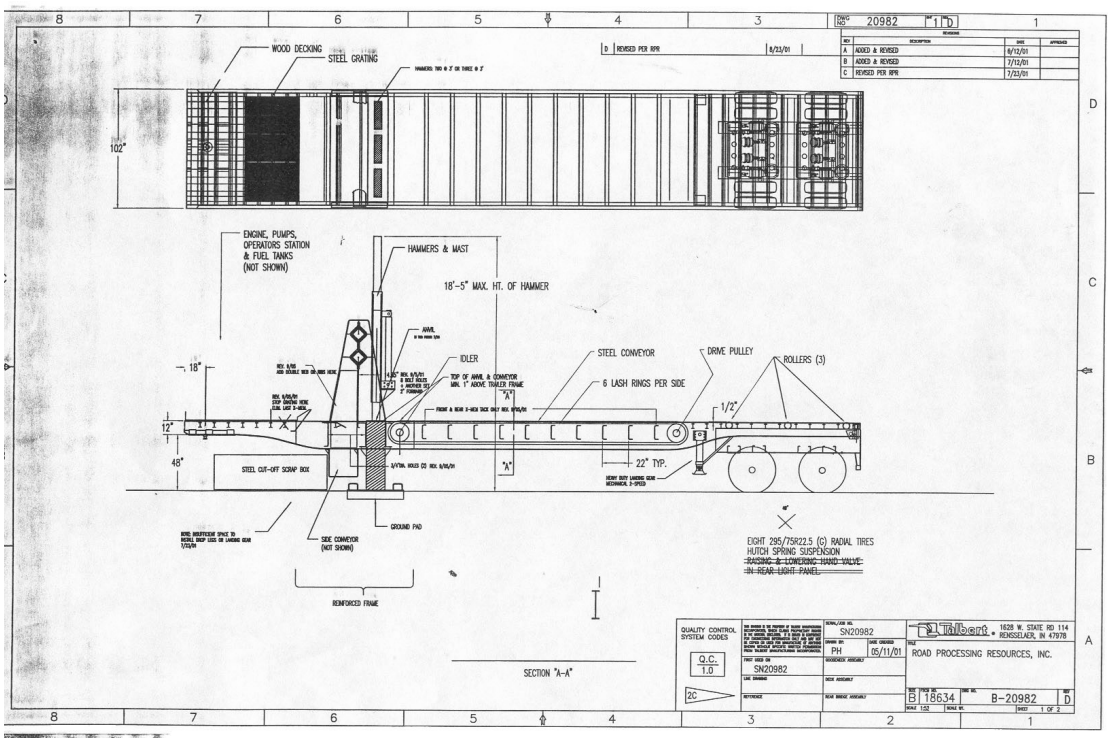


Figure 1

Schematic diagram of road recycling machine.

DEVELOPMENT OF A GENERIC CONNECTOR SYSTEM FOR ATTACHING CONVENTIONAL BRIDGE RAILS TO FIBER-REINFORCED POLYMER COMPOSITE BRIDGE DECKS

NCHRP-IDEA Project 80

Jerry D. Plunkett [Tel.: (303) 773-7790, Fax: (303) 733-2901, Email: <vrlp@earthlink.net>], Kansas Structural Composites Inc., Russell, Kansas

This project developed and tested a generic attachment system that permits the use of standard steel railings and posts on commercial fiber-reinforced polymer (FRP) composite bridge decks. Following analysis and connector design for both steel bridge railings and concrete barriers, static tests were performed that indicated a high probability of the connector system successfully passing the mandatory crash test. Based on test results, a multi-bolt design for the plate system was developed. In static tests using 12-bolt plate, the post failed in plastic bending, but no damage occurred to the deck and no serious strain in the area of the connector plates. In tests using 6-bolt plate, the railing post failed similarly, and there was some strain on the deck. Tests with a concrete barrier connected to the deck with 6 bolts showed no strain and no failure in the deck panel. The project achieved its goal of developing and testing a connector system that allows the attachment of standard steel post and rail, as well as standard concrete barrier systems, to most currently manufactured FRP composite bridge decks and superstructures. Two bridges with FRP superstructures in the states of Missouri and New York were built. Both successfully passed the required TL-2 static test and have been performing satisfactorily with no evidence of any failure or any serious loading in the superstructure. The project team also installed bridge decks for two detour bridges in Kansas in 2004 that continue to perform satisfactorily.

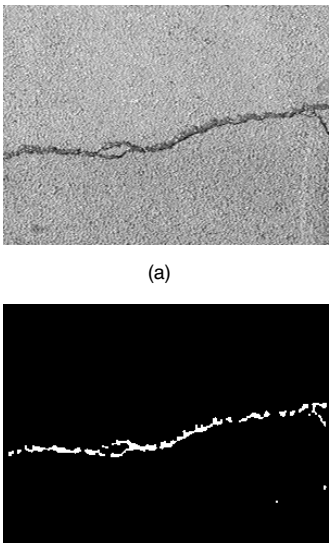
AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION SYSTEM

NCHRP-IDEA Project 81

Heng-Da Cheng [Tel.: (435) 797-2054,
Fax: (435) 797-3265]
Utah State University, Logan, Utah, and

Chris Glazier [Tel.: (801) 965-4551],
Utah Department of Transportation,
Salt Lake City, Utah

This project developed an automated real-time crack detection and analysis system based on image processing and computer vision techniques. The system consists of a personal computer, a frame grabber with two on-board processors, a distance sensor and a video camera mounted on top of a van. The images from the video camera are captured and converted to digital images by the frame grabber, while the images are recorded by the video camera for future reference. Over 20,000 images were obtained under different vehicle speeds and light conditions and digitized. Processing algorithms were developed and applied to the collected images. The effectiveness and speed of the algorithms were improved for features such as segmentation, enhancement, noise removal, Hugh transformation and morphology, and so forth for crack detection and classification applications. Three evaluation criteria were used: performance for different pavement types, including cracks, sealed cracks and shadows, performance under different light conditions and circumstances, and performance when there are some tars (bleeding) or other non-crack scenes on the images. Pavement images were obtained with vehicle speeds of 35 mph to 75 mph under different lighting conditions, including both cloudy and sunny days. The results demonstrate that the proposed system can accurately process the images of different types of pavements and under different lighting conditions, including the shadows (Figures 1 and 2). The final report is available from the National Technical Information Service (NTIS # PB2003-101350).

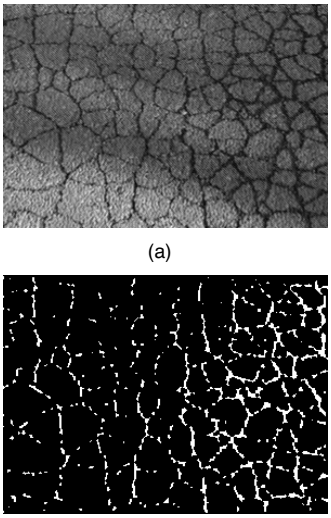


(a)

(b)

Figure 1

(a) The original image with a transverse crack. (b) The resulting image.



(a)

(b)

Figure 2

(a) The original image with an alligator crack. (b) The resulting image.

DEVELOPMENT AND FIELD VERIFICATION OF TORSIONAL CYLINDRICAL IMPULSE SHEAR TEST

NCHRP-IDEA Project 82

Wanda Henke [Tel.: (410) 252-4474, Fax: (410) 252-4474] and Robert Henke
Dynamic In Situ Geotechnical Testing Inc. Lutherville, Maryland

This project developed and tested an in situ torsional cylindrical impulse shear test for shearing deformation characteristics for geotechnical earthquake engineering analysis applications (Figure 1). The work involved rebuilding and improving an existing FHWA impulse shear testing system. All main components of the FHWA probe were assembled or reassembled and bench tested. These components included the testing module, the hydraulic module (containing a new sensing system for measuring the advance of the probe cylinder into the test soil), and a newly devised axial load cell. The bench tests indicated satisfactory performance of all the components and equipment. The components of the accessory equipment were also repaired, reassembled and bench tested. These components included a manually operated simple probe bed, a hydraulic pump, an electric generator, and a hydraulic system control panel. Bench tests indicated satisfactory performance of each of the components. Work is now underway on the consolidation of the data acquisition and control systems. This IDEA project was being complemented by a FHWA/State DOT-sponsored pooled-fund study for further development and implementation of the impulse shear test. The final report is available from the National Technical Information Service (NTIS # PB2004-100132).

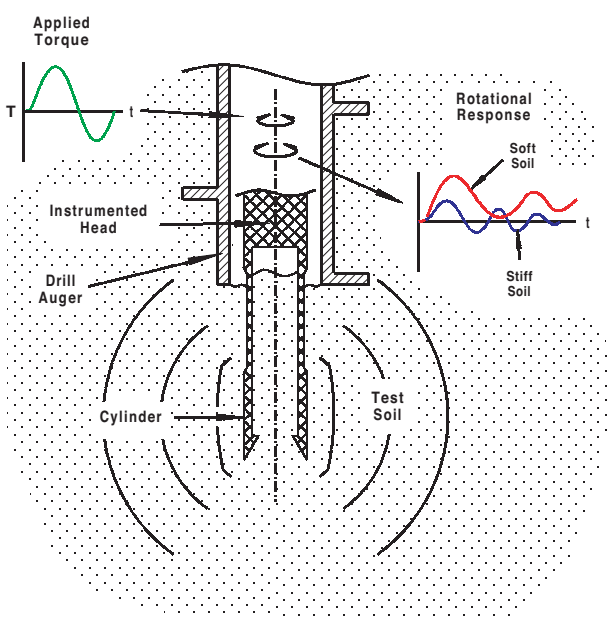


Figure 1

Basic idea of impulse shear test.

TESTING OF A WIDE AREA OPTICAL SURFACE CONTAMINATION DETECTION SYSTEM FOR PUBLIC TRANSPORTATION APPLICATIONS

NCHRP-IDEA Project 83

Paul Schmokel [Tel.: (952) 892-4888, Fax: (952) 892-4430]
Sensor Systems, Goodrich Corporation, Burnsville, Minnesota

This project developed a laser-based remote sensing technology for detecting ice on road surfaces. The system is an adaptation of a wide area ice detection system (IceHawk) that utilizes laser polarization properties and has been applied successfully to detect ice on typical aircraft surfaces (Figure 1). The work involved analysis of target materials, improvement of range performance, and detection of wet surfaces. The existing IceHawk system was modified to allow for stationary mount and remote operation. Target materials (concrete, asphalt, etc.) were evaluated for polarization reflection behavior, and test data collected during winter was used to improve and refine the system. A station pole-mounted IceHawk system was found adaptable to detect ice and snow on roadway surfaces. Test results showed a distinguishable difference between a clean surface and one covered with snow or ice. Data to determine the minimum thickness threshold settings for ice, snow, and wet roadway conditions was collected and a pixel-filtering technique was evaluated to determine the ice, snow, and wet area criteria necessary to alert the operator of unacceptable conditions. Work on range improvement enhanced the signal-to-noise ratio and led to an increase of 25 percent in the detection range for ice, snow, and wet surface. Additional improvements involved creating larger collecting optics and increasing the amount of light energy delivered to the photodetector. Further research, development, and testing, however, will be needed before the technology can be applied to the highways. The final report is available from the National Technical Information Service (NTIS # PB2004-105015).

Figure 1

Prototype ice detection system.

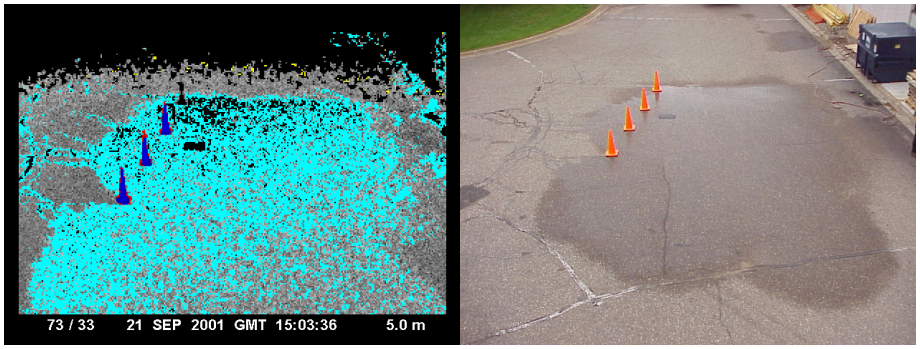


Figure 2

Areas of wet and dry pavement can be detected by the system.

DEVELOPMENT OF A FRACTURE MECHANICS-BASED ASPHALT BINDER TEST METHOD FOR LOW-TEMPERATURE PERFORMANCE GRADING

NCHRP-IDEA Project 84

Simon A.M. Hesp [Tel.: (613) 533-2615, Fax: (613) 533-6669,
Email: simon@chem.queensu.ca]
Queen's University, Kingston, Ontario, Canada, and

Mihai O. Marasteanu
University of Minnesota, Minneapolis, Minnesota

This project developed a test method based on fracture mechanics for predicting low temperature performance of asphalt binders. A low-temperature yield test was developed and validated using asphalt binders modified with commercial polymer modifiers. A simple and accurate low-temperature fracture toughness test for asphalt binders was also developed. The test measures fracture toughness and fracture energy values on three-point bend specimens with aluminum inserts. The use of inserts significantly reduced the sample amount requirement (less than 3 grams) and showed an improvement over the current SHRP procedures. The effect of sample width on fracture toughness was investigated to ascertain the plane strain condition. A survey of Highways 118 and 17 test section data on pavement cracking for use in establishing tests and asphalt binder performance in the field was conducted, and fracture tests on unaged binders and aged binders from these highways were performed. Results indicated a significant improvement of the IDEA test over SHRP tests for fracture and cracking predictions. The final report is available from the National Technical Information Service (NTIS # PB2004-103344).

WATERPROOFING CONCRETE HIGHWAYS

NCHRP-IDEA Project 85

John L. Massingill, Jr. [Tel.: (512) 245-9618, Fax: (512) 245-1892,
Email: john.massingill@txstate.edu]
Texas State University, San Marcos, Texas, and

David W. Fowler
International Center for Aggregates Research, The University of Texas, Austin, Texas

This project evaluated the concept of waterproofing concrete using soybean oil-based phosphate ester polyol (SOPEP) formulations and the effect of these additives on the physico-mechanical properties of fresh and hardened concrete. A number of SOPEP formulations and concentrations for optimum performance in concrete were evaluated through a series of laboratory tests. The different formulations affected mixing and dispersion in concrete differently. They also exhibited the properties of air entraining, water reducing, set retarding, and workability additives, producing reduced slump, reduced water requirement, and increased strength of concrete. Water absorption tests using 2 percent SOPEP showed a decrease of only about 7 percent in water absorption by the concrete indicating the need for higher dosages for waterproofing concrete. The effect of phosphate on oil absorption and dispersion in concrete was also investigated. Results showed the potential of SOPEP dispersions as suitable concrete curing compounds and that of polymerized SOPEP as inexpensive polymers for polymer modified concrete. However, additional research is needed to improve the concrete waterproofing ability of SOPEP formulations. The final report is available from the National Technical Information Service (NTIS # PB2004-103339).

ADVANCED CONCEPT CONCRETE USING BASALT FIBER/BF COMPOSITE REBAR REINFORCEMENT

NCHRP-IDEA Project 86

Dr. Vladimir Brik [Tel.: (608) 244-1349, Fax: (608) 244-9071, Email: v_brik@hotmail.com]
Research & Technology Corp., Madison, Wisconsin

This project evaluated basalt fiber composite rebars as an alternative to steel rebars as concrete reinforcement. Work in the initial stage focused on fabricating basalt fiber composite rebars using U.S. basalt and evaluating and optimizing the properties of rebars for use as concrete reinforcement. Initial tests for concrete-rebar bond strength were conducted with plain, 4-slot, and 8-slot basalt fiber rebars, as well as single-, double-, and triple-twisted cables using ASTM C-234 procedure. The results showed improved bond and no slippage between concrete and rebars with slots. Similar results were obtained for twisted cables. The concrete failure was not caused by bond failure or slippage. Additional laboratory testing of concrete beams and slabs reinforced with basalt fiber composite rebars verified the initial results and provided specifications for rebar parameters for use as concrete reinforcement. The final report is available from the National Technical Information Service (NTIS # PB2003-102862).

AN IN SITU SHEAR TEST FACILITY FOR ASPHALT CONCRETE PAVEMENTS

NCHRP-IDEA Project 87

A. O. Abd El Halim [Tel.: (613) 520-2600 ext.5789, Fax: (613) 520-3951,
Email: ahalim@ccs.carlton.ca]
Carleton University, Ottawa, Canada

This project, a follow-on activity for an earlier IDEA Project (NCHRP-55), focused on the application of an in situ shear strength testing (InSiSST™) facility through theoretical development, field testing, and laboratory verification (Figure 1). The InSiSST™ facility was upgraded to add a rotary displacement transducer to directly measure the angular displacement during field testing to avoid problems due to strain rate variation during testing. A special set up of blanket heaters was devised to control pavement temperature to allow field testing in all types of weather conditions. To avoid epoxy bond failure between pavement surface and steel plate, the system was modified using steel plates with vertical blades that were driven into the pavement surface, thus eliminating the need for the epoxy. This modification also shortened the testing time since waiting time is required for epoxy to harden. The upgraded InSiSST™ facility was tested on several sites along with laboratory tests to confirm the correlation between field and laboratory results. Work on a finite element analysis was completed to establish the optimum evaluation criteria based on the theoretical analysis of the InSiSST™ loading condition. This analytical study included the effects of viscoelasticity, plasticity, and large displacements. The successful completion of these tasks provided correlations between shear parameters measured by the InSiSST™ and field performance of asphalt pavements. The final report is available from the National Technical Information Service (NTIS # PB2004-106776).

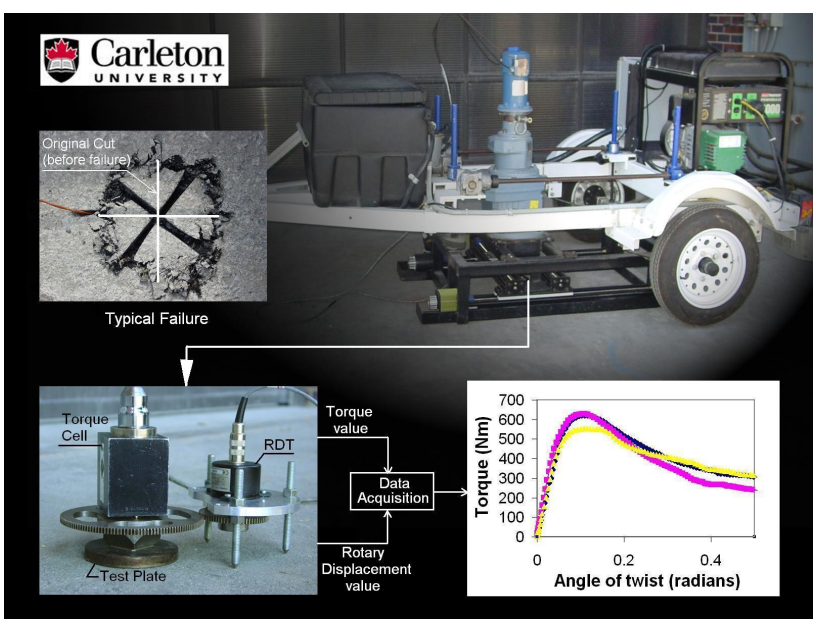


Figure 1

The InSiSST™ system.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION

NCHRP-IDEA Project 88

Kelvin C.P. Wang [Tel.: (470) 575-8425, Fax: (479) 575-7168]
University of Arkansas, Fayetteville, Arkansas

This project developed an automated and mobile high-speed and high-resolution pavement distress survey system for detecting cracks, rutting, and roughness in three dimensions (Figures 1 and 2). Images of pavement surface were obtained through the simultaneous use of two cameras, each with a resolution of 1300 by 1024, and then combined to potentially achieve higher accuracy. Algorithms for 3-D pavement surface were developed. A computer code was written that included a calibration program, distortion adjust program, matching program, and some user interface. The algorithms needed further improvement to enhance accuracy. Initial tests showed accuracy to be within 5 mm. After establishing 3-D geometric mode and necessary image resolution, algorithms for pavement cracks, rutting, and roughness were implemented. Issues with accuracy of the pavement survey parameters and the hardware and software requirements for a real-time pavement survey system capable of traveling and collecting data at highway speeds still need to be fully addressed for the successful field implementation of this technology. The final report is available from the National Technical Information Service (NTIS # PB2004-106775).

Figure 1

The dual-camera subsystem.

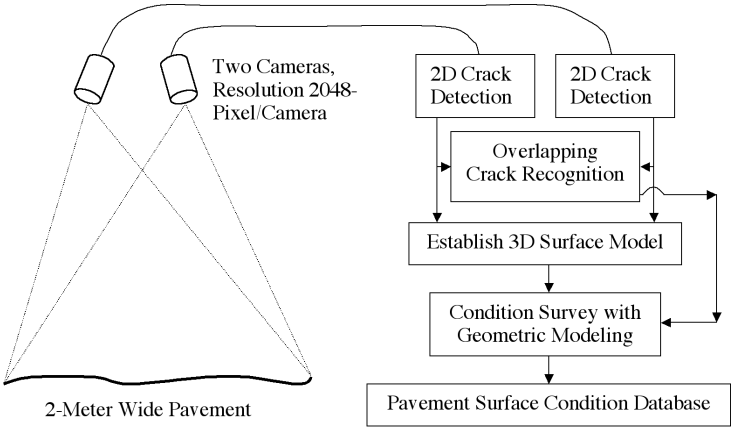


Figure 2

General procedures for automated condition survey with stereovision.

U.S.-SPECIFIC SELF-CONSOLIDATING CONCRETE FOR BRIDGES

NCHRP-IDEA Project 89

Andrzej S. Nowak [Tel.: (734) 764-9299, Fax: (734) 764-4292, Email: nowak@umich.edu]
University of Michigan, Ann Arbor, Michigan

This project was aimed at adapting the self-compacting concrete technology for the U.S. market using domestic concrete materials and practice for use in highway structures. The experimental work focused on designing self-compacting concrete mix formulations with desired workability, segregation resistance, and deformability, as well as testing for standard mechanical properties of the hardened concrete. Following a literature review, materials and equipment were selected and laboratory tests were performed to determine formulations that satisfied the filling and passing requirements for self-compacted concrete. All selected formulations contained fly ash and a superplasticizer. Tests on fresh mixes confirmed the flowability required for self-compacting concrete (Figure 1). However, the concrete mixes showed sensitivity to the mixing sequence. Consequently, tests were conducted to establish a mixing sequence for producing the most reliable and consistent results. Compressive strength tests showed rapid gain in strength: 3-day strengths approximated 80 percent of the 28-day strengths. The 28-day compressive strengths were almost 100 percent higher than those for conventional concrete. The modulus of elasticity tests showed an increase of about 30-45 percent over conventional concrete. The freeze-thaw resistance tests showed durability factors in the range of 87-98 percent. The segregation tendency of self consolidating concrete can be controlled by controlling the amount of superplasticizers. The higher unit cost of self-consolidating concrete (about 50 percent higher than conventional concrete) is largely offset by the use of less material and increased durability. The final report is available from the National Technical Information Service (NTIS # PB2005-109494).

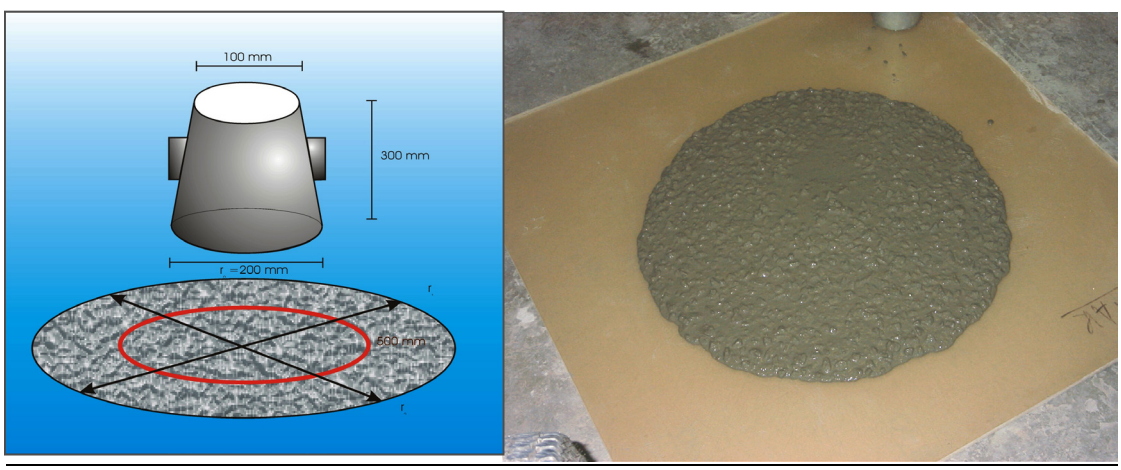


Figure 1

Slump flow test, typical range of diameters for SCC is 26-32 inches and the time to reach 20 inches is 2-5 seconds.

ROBOTIC HIGHWAY SAFETY MARKERS

NCHRP-IDEA Project 90

Shane Farritor [Tel.: (402) 472-5805, Fax: (402) 472-1465
Email: sfarritor@unl.edu, Web: Http://robots.unl.edu]
University of Nebraska, Lincoln, Nebraska

This project was aimed at developing a robotic safety marker system consisting of mobile signs, cones, and other safety devices to provide safety to workers in the work zone (Figure 1). A robotic safety marker system was designed along with a global laser-based sensor system capable of locating barrels up to 80 meters away with an accuracy of a few centimeters. Software was developed to integrate the sensor with the system, and a mathematical-matching algorithm was developed to determine the location of the barrel robot relative to the global sensor. Following the design and fabrication of a robot safety sign to complement the safety barrel robots, a functional system was produced by full integration of the global planning, sensing and communication systems. Both the global and local control schemes were tested without involving a human in the loop. The desired and actual paths for each robot showed good agreement and the tests took less than two minutes to complete (Figure 2). The control algorithm was successfully used for the relative movements of the robots and the global sensor. A new tracking system software was created to allow the global sensor to track the location of the barrels in real time, and an initial test successfully tracked a group of five robots in a realistic environment. The new tracking software should help develop a new control algorithm that will allow continuous motion of the barrel robots. Movies on project results showing moving safety robots can be viewed at http://robots.unl.edu/projects/current/barrelrobots/index.html. The project has received considerable national and international media attention. The final report is available from the National Technical Information Service (NTIS # PB2005-106347).

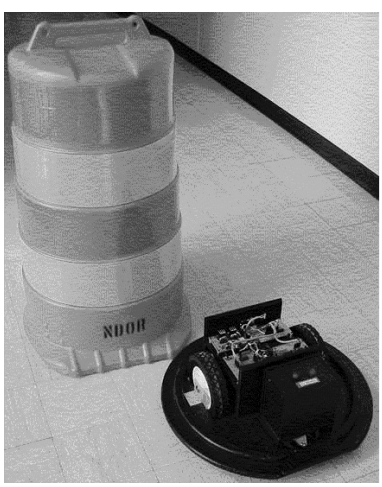


Figure 1

A robotic highway safety marker.

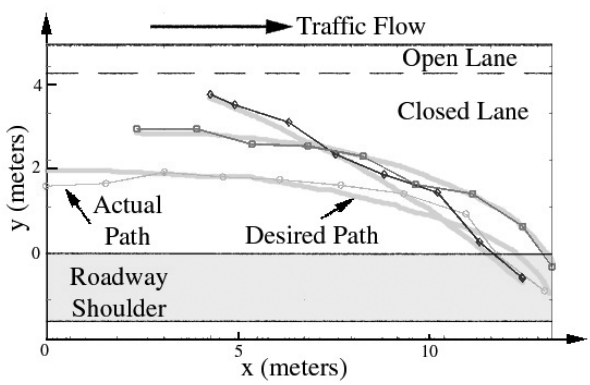


Figure 2

Desired and actual paths during field test.

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 91

Reginald DesRoches [Tel.: (404) 385-0826, Fax: (404) 894-0211]
Georgia Institute of Technology, Atlanta, Georgia

This project, a follow-on activity of an earlier IDEA project (NCHRP-65), focused on the application of shape memory alloy (SMA) restrainers to improve the resistance of highway bridges to seismic damage. Work in the initial stage involved developing cost-effective and mechanically stable SMAs for bridge rehabilitation that included ternary alloys of Ni and Ti doped with Fe or Cr. The results show that the binary form of SMAs (NiTi) exhibited superior performance as compared with the ternary NiTiCr or NiTiFe alloys. The performance of SMAs was optimized by thermo-mechanical processing. The effect of temperature on the superelastic cyclic properties of selected alloys was also evaluated in order to establish the optimum performance temperature range.

SMA-based prototype restrainers were fabricated and evaluated in dynamic laboratory and shake table tests. The restrainers were found to be superior to steel restrainers in limiting relative hinge displacements, with maximum hinge displacement being about half of steel restrainers (Figure 1). The restrainers also showed minimal residual strain after repeated cycling and, unlike steel, could undergo many loading cycles with little degradation of properties. Further, with equivalent restrainers under identical earthquake motion, the SMA restrainers produced lower block acceleration as compared to steel restrainers and reached only their yield level while the steel restrainers failed. Full-scale tests on bridges are needed to demonstrate the applicability of the technology in the field. The final report is available from the National Technical Information Service (NTIS # PB2005-109518).

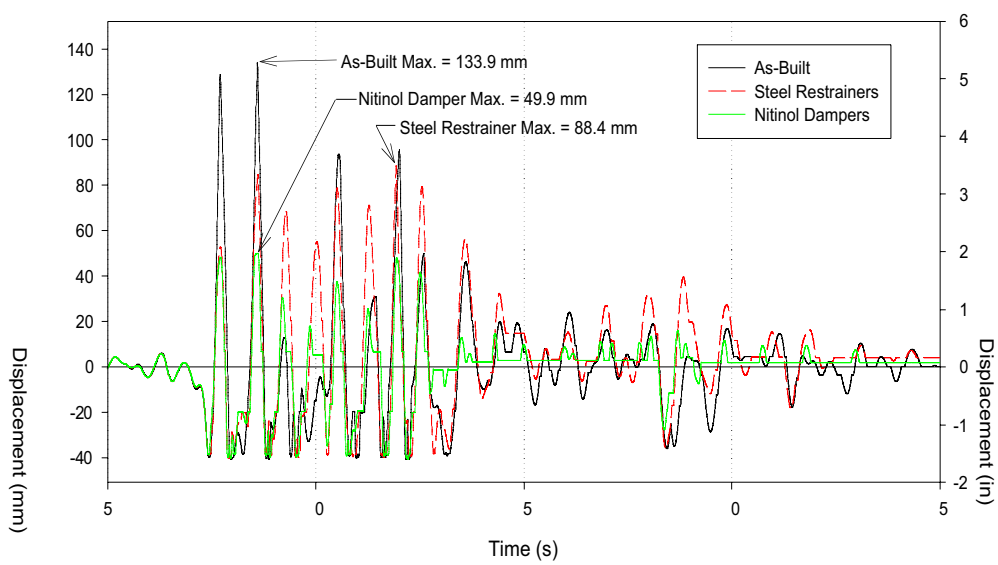


Figure 1

Results of analysis showing relative hinge opening with steel cable restrainers and SMA restrainers.

DEVELOPMENT OF AN ADAPTIVE DAMPER FOR CABLE VIBRATION CONTROL

NCHRP-IDEA Project 92

Steve C. S. Cai [Tel.: (225) 578-8898, Fax: (225) 578-8652, Email: cscai@lsu.edu]
Louisiana State University, Baton Rouge, Louisiana

This project developed and tested a tuned mass damper (TMD) system capable of adapting automatically to control cable vibrations in stayed-cable bridges. Figure 1 illustrates the proposed concept. Following a review of background information on TMD system and evaluating the performance of the magnetorheological (MR) fluids, a cable system was built to test the concept feasibility using parameters developed for a preliminary model that was based on the scaling theory. Data from laboratory experiments showed that the MR damper effectively reduced cable vibration by adding supplementary damping to the cable system with or without current and that there was an optimal current for producing optimal damping. This optimal current value depended on the properties of the cable system and the MR damper. The reduction in cable vibration showed dependence on the closeness between the TMD system frequency and the cable natural frequency and on the nature of the dissipative liquid. The closer the two frequency values, the easier the transfer of cable vibration energy to the TMD. Also, the more viscous the dissipative liquid, the easier the dissipation of TMD vibration energy. The results indicate that an adaptive TMD-MR damper system can be developed by choosing appropriate stiffness, mass, and MR damper. After the design and fabrication of dampers on the scaled prototype, testing and evaluation of both single and multi MR-TMD systems was carried out with promising results. The best effect of the TMD-MR damper on cable vibration reduction was shown when the natural frequency of TMD-MR is closer to that of the cable. The final report is available from the National Technical Information Service (NTIS # PB2005-106346).

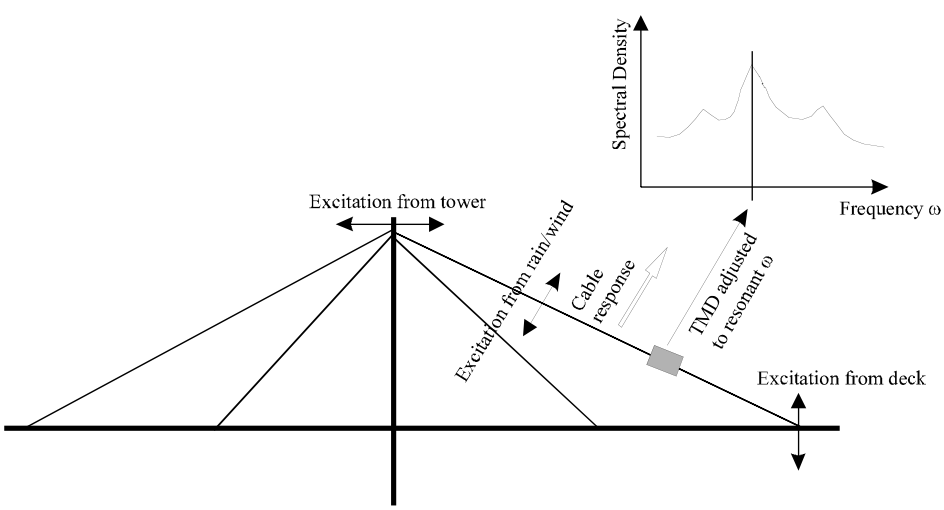


Figure 1

Sketch of cable vibration control strategy.

ADVANCED RELOCATABLE TRAFFIC SENSOR SYSTEM (ARTS)

NCHRP-IDEA Project 93

Eddie Neal [Tel.: (703) 276-3377, Fax: (703) 276-0996, Email: eddieneal@scientextcorp.com]
The Scientex Corporation, Alexandria, Virginia

This project developed and tested a portable advanced relocatable traffic sensor (ARTS) system based on microwave radar technology and wireless communication for improving the accuracy and effectiveness of work zone ITS systems (Figure 1). The system components included Doppler microwave radar, digital compass, solar portable power system, GPS positioning subsystem, satellite packet data terminal, palm-size single board computer, and electronic interface board. The components were designed or purchased and integrated into a compact prototype system that satisfied the requirements for portability, low cost, self-power, built-in satellite communication links, self-diagnostics, self-configuring, modularity, and ability to provide accurate measures of traffic counts, speed, volume, and headway. Laboratory tests using a tuning fork to simulate vehicle speeds were performed that validated the satellite communications and speed data acquisition aspects of the system. Limited field tests were performed to test the satellite communications and speed acquisition in actual traffic. Observed data accuracy and communications transmission durations of a few seconds provided encouraging indication of the potential for using ARTS in real time applications for work zone safety and incident management applications. However, further improvements, such as using ultraband radar instead of Doppler microwave transceiver, and hardware enhancement to reduce the system's size and additional field tests are needed before it can be implemented by highway agencies. The final report is available from the National Technical Information Service (NTIS # PB2005-109517).

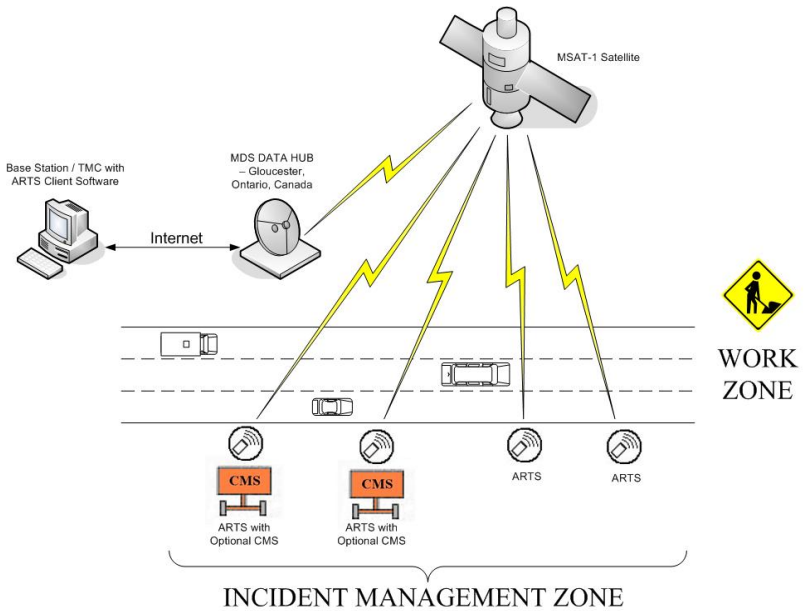


Figure 1

Advanced relocatable traffic sensor for work zone and incident management systems.

LIQUEFACTION MITIGATION USING VERTICAL DRAINAGE: FULL-SCALE TESTING

NCHRP-IDEA Project 94

Kyle M. Rollins [Tel.: (801) 422-6334, Fax: (801) 422-0159, Email: rollinsk@byu.edu]
Brigham Young University, Provo, Utah

In this project, full-scale field tests were performed to investigate the use of vertical composite drains (EQ-Drains) in dissipating pore pressure to prevent liquefaction during an earthquake. The EQ-Drains were evaluated at a test site in Vancouver, British Columbia, using controlled blasting technique to liquefy loose sand. Installing EQ-Drains using high vibration typically increased relative density by about 10 percent and produced volumetric strains of 2.5 percent. This effectively reduced the amount of settlement and increased the rate of pore pressure dissipation relative to untreated sites. Controlled blasting also showed the potential to produce significant densification of liquefiable soils. Settlements of 2 to 4 percent of volume were produced for small charge masses and relative density was typically increased by 7-10 percent. The presence of EQ-Drains significantly increased the rate of excess pore water pressure dissipation relative to untreated areas (Figure 1). Even though drains did not prevent liquefaction for the high stress levels imposed by the blast tests, settlements in areas where drains were installed using conventional procedures was reduced to only about 60 percent of the settlement measured in untreated areas. With minor input parameters modifications, computer analyses were successful in matching measured pore pressure and settlement response during blasting. Results of the computer model analysis indicate that the drains can prevent liquefaction and excessive settlement when drain diameter and spacing are properly designed for the expected earthquake. The committee approved a follow-on project for additional field tests at the Treasure Island site in California. The final report is available from the National Technical Information Service (NTIS # PB2004-103340).

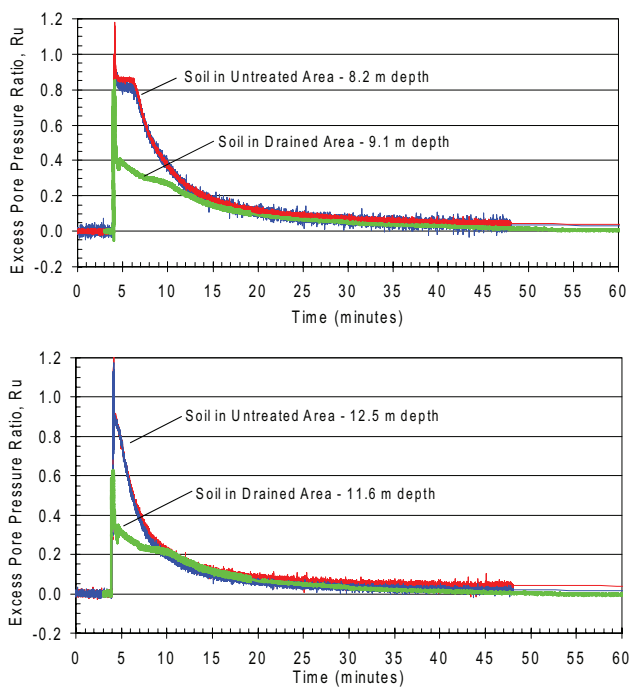


Figure 1

Comparison of time histories of excess pore pressure for areas with and without drains.

CONCRETE ROAD RECYCLER—HAMMER-ANVIL TEST

NCHRP-IDEA Project 95

Deems Pfaff [Tel.: (970) 476-6577, Fax: (970) 476-0504]
Road Processing Resources Inc., Vail, Colorado

This project upgraded and tested a gravity drop hammer of a prototype mechanical system developed in NCHRP-79 project for removing, fragmenting, and recycling concrete pavement (Figure 1). A detailed engineering study was conducted to develop the final configuration of the power hammer. The hammer retaining guides were redesigned using high-density plastics to provide longer life than the presently used metal-to-metal system. The gravity drop control system was evaluated for multi-hammer operational sequencing. Following system analysis and refinement, the design of a pneumatic power hammer was finalized to operate in a 6-hammer sequence on a 12-foot wide lane. A prototype pneumatic hammer system was built for testing including controls that can perform in a group of six hammers. The gravity drop hammers were installed on a mobile rig and tested. The process successfully worked on concrete slabs of thickness up to 8 inches thick, producing a 40 percent recyclable aggregate mix for use in concrete. A commercial version of the stationary machine is now available. Further development and improvement of the system with private industry support has continued with a goal to produce the final mobile version of the road-recycling machine.

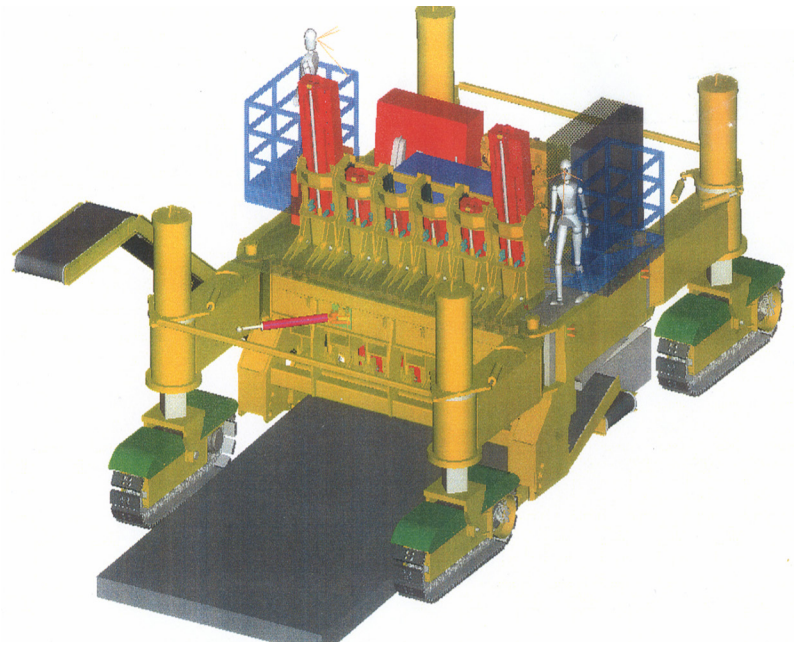


Figure 1

USING ULTRASOUND OF MHZ FREQUENCY FOR TESTING CONCRETE

NCHRP-IDEA Project 96

Sandor Popovics [Tel.: (610) 623-0116 and (215) 895-2345, Email: popovics@coe.drexel.edu]
OPTIMUM Engineering Research, Lansdowne, Pennsylvania

This project developed and demonstrated the feasibility of a nondestructive ultrasonic technique based on modified split spectrum processing (SSP) and its rationalization using a statistical spectral histogram technique (SHT) for field evaluation of highway concrete structures. SSP enhances the signal-to-noise ratio by reducing the intensive background noise accompanying high-frequency ultrasound in concrete, and SSP rationalization eliminates the time-consuming trial and error approach, greatly improving the method for practical applications. Following the selection, evaluation and optimization of the initial instrumentation, a new algorithm was developed that allowed automatic selection of optimum or near optimum parameters for split spectrum processing and performing the split spectrum processing using the selected parameters. A software system was developed that allowed spectral histogram analysis for the direct determination of the frequency region without trial and error. The software was successfully tested for several cases, including the determination of thickness and internal defects of a concrete slab. The combination of SSP with SHT reduced the noise, thereby significantly improving the interpretation of the received high frequency ultrasound. Also, the computerized form made the application simple and rapid. The improved process can further be extended to produce two-dimensional images for improved diagnosis of concrete structures. The researcher collaborated with Pennsylvania and Delaware DOTs for field testing and implementation. The researcher also worked with the American Concrete Institute's Committee 228 on Nondestructive Testing of Concrete to publicize the innovation. The final report is available from the National Technical Information Service (NTIS # PB2005-100682).

FIBER-REINFORCED PLASTICS FOR SEISMIC BRIDGE RESTRAINERS

NCHRP-IDEA Project 97

M. Saiid Saiidi and E. Manos Maragakis [Tel.: (775) 784-4839, Fax: (775) 784-1390,
Email: saiidi@unr.edu]
University of Nevada, Reno, Nevada

This project evaluated the use of fiber-reinforced plastic (FRP) fabrics as restrainers in the seismic rehabilitation of highway bridges as an alternative to steel for restrainer construction to reduce bridge hinge movement during earthquakes. Glass, carbon, and glass/carbon hybrid restrainers were constructed and evaluated in large-scale dynamic laboratory tests. The research effort included (i) tensile tests on FRP strips and on FRP/concrete bond at various loading rates, (ii) FRP restrainer development and dynamic testing, (iii) shake table tests, data analysis, performance comparison for FRP, steel, SMA restrainers, and (iv) development of a FRP restrainer design method.

The results showed that the FRP strength was insensitive to strain rate and that the FRP/concrete bond was a function of concrete shear strength but insensitive to strain rate. The results also demonstrated methods for flexible restrainer construction and restrainer/concrete bonding. A simplified FRP restrainer design method, considered more realistic than that of AASHTO was proposed (Figure 1) that takes into account the dynamic characteristics of a bridge structure. The final report is available from the National Technical Information Service (NTIS # PB2007-100047).

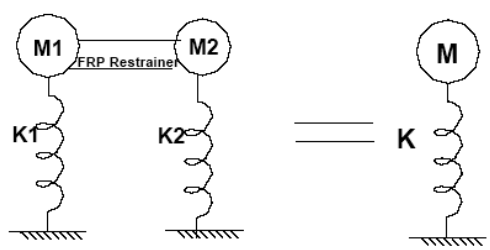


Figure 1

New restrainer design method.

VOID DETECTION IN POST-TENSIONING DUCTS USING TIME-DOMAIN REFLECTOMETRY

NCHRP-IDEA Project 98

Robert Hunsperger [Tel.: (302) 831-8031,
Email: robert_hunsperger@usa.net or hunsperg@eecis.udel.edu]

Michael Chajes [Tel.: (302) 831-2442, Email: chajes@ce.udel.edu]
University of Delaware, Newark, Delaware

This project developed and evaluated a nondestructive method, based on time domain reflectometry (TDR), to determine the presence of voids in post-tensioned ducts in highway structures. Figure 1 shows the TDR measurement apparatus setup. The voids were detectable using a single sensor wire in conjunction with an existing tensioning cable to form the two-wire transmission line. The voids could also be detected by using commercially available transmission lines, such as lamp cord or 300 ohm TV cable. Factors affecting the void detection signal were identified, and their effects quantified. The presence of sand, water, or moisture tended to decrease the positive amplitude of the reflected TDR signal but the void was still detectable. Work on using external sensors for void detection showed much weaker signals as compared to internal sensors, indicating a need for a more powerful pulse generator and pulses of high magnitude and short rise time. While higher output voltage with high rise time did not lead to any improvement, a rise time of 40-100 ps appeared satisfactory. Parameters for TDR meters for field application with external sensor detection were identified and several commercial portable TDR meters were evaluated. Further refinement and evaluation of the technique is necessary before it can be implemented for field applications. The final report is available from the National Technical Information Service (NTIS # PB2007-105524).

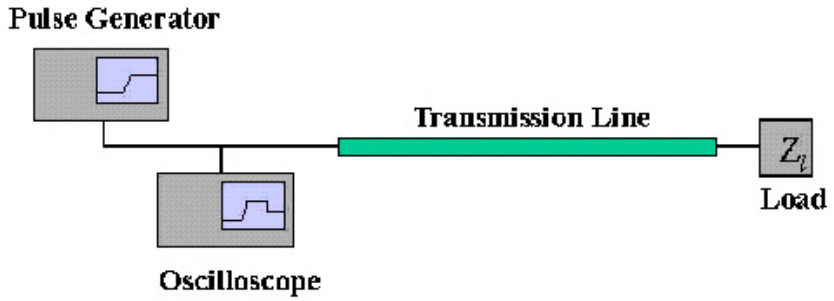


Figure 1

Time domain reflectometry measurement apparatus.

DEVELOPMENT OF ASPHALT BINDER CRACKING DEVICE

NCHRP-IDEA Project 99

Sang-Soo Kim [Tel.: (740) 593-1463, Fax: (740) 593-0625,
Email: skim@bobcat.ent.ohiou.edu] Ohio University, Athens, Ohio

This project developed a simple asphalt binder cracking device (ABCD) to determine the thermal cracking temperature of asphalt binders. In initial experiments, cracking temperatures determined by using ABCD with aluminum molds and rings appeared much lower than those determined by Superpave procedures (MP1 and 1a). Consequently, the ABCD setup was modified using silicone molds and invar and steel rings that produced more accurate and repeatable results (Figure 1). A computer program was developed to calculate theoretical thermal stress developed during ABCD tests. When appropriate coefficients of thermal expansion (CTEs) of ABCD ring and binders were used, the theoretical and experimental values of thermal stress agreed satisfactorily. When compared with AASHTO MP1 and 1a tests, the ABCD test showed best correlation with the thermal stress restrained specimen test (TSRST) for cracking temperature. The test also revealed a significant effect of polymer content on cracking temperature and fracture strength as compared to AASHTO M320 test. Additional work was carried out to improve the ABCD ring design and the data acquisition system. A ring with a biaxial strain gauge, a temperature sensor, and a Ni-chrome spot-welded connector bracket significantly improved the accuracy. The test method was further refined and evaluated with support from FHWA's Highways for LIFE Program. A test procedure based on ABCD for determining the thermal cracking temperature of asphalt binders has been adopted by AASHTO as a provisional standard (TP 92). (NTIS Report # PB2008-106867).

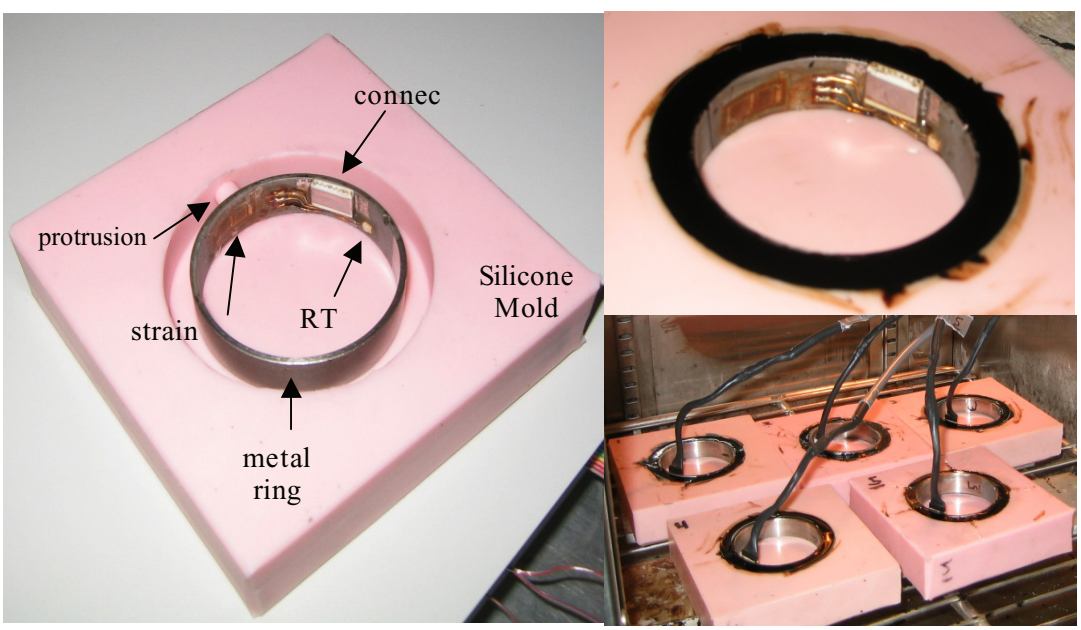


Figure 1

ABCD ring in a silicone mold (left); binder specimens prepared for ABCD test (right).

EVALUATION OF AL-ZN-IN ALLOY FOR GALVANIC CATHODIC PROTECTION OF BRIDGE DECKS

NCHRP-IDEA Project 100

W. Young [Tel.: 610-344-7002, Fax: 610-344-7092, Email: wyoung@corrpro.com]
Corrpro Companies Inc., West Chester, Pennsylvania

An alloy was developed under FHWA Project FHWA-RD-96-171 for use as a galvanic anode for the protection of steel-reinforced concrete bridge substructures. The alloy consists of 20 percent zinc, 0.2 percent indium, with the balance aluminum. Indium, the key component, keeps the anode active even in dry environments. The anode is applied to concrete substructures using thermal spray technology, typically electric arc spray. The objective of project NCHRP-100 was to develop a galvanic anode mesh for bridge deck application. The concept was to develop an expanded mesh or perforated sheet that meets the following criteria:

1. The galvanic anode material is sufficient to last a minimum of 25 years.
2. The anode mesh is durable for construction application.
3. The mesh openings are sufficiently large not to hinder the concrete overlay bonding.
4. The sheet size is practical for transportation and field installation.

An anode consisting of aluminum mesh with the Al-Zn-In alloy thermally sprayed onto an aluminum mesh was successfully applied to a bridge deck on Interstate 44 in Cuba, Missouri, in July 2005. This anode was tested periodically since then and found to be effective in protecting the rebar in the area it was installed. A further test installation using aluminum mesh with a thermally sprayed Al-Zn-In alloy coating is planned. Difficulties were encountered in obtaining the correct alloy to produce the anode. Some disbonding of the anode on the Cuba, Missouri bridge deck was noted at the last inspection. Localized delamination of the anode on the bridge deck has been observed. Testing in October 2008 revealed additional delamination and a significant reduction in anode current output. Material supply problems and the implementation of this task have delayed the installation of additional test installations. While this does not preclude the use of this technology, further work is needed to evaluate and resolve these issues. If this galvanic anode is successfully developed, a virtually maintenance-free CP system for bridge decks is expected to be developed. As a result, hundreds of millions of dollars could be saved repairing damage caused by corrosion of the nation's bridge decks (NTIS # PB2010-101385).

ACTIVE HEATING INFRARED THERMOGRAPHY FOR DETECTION OF SUBSURFACE BRIDGE DECK DETERIORATION

NCHRP-IDEA Project 101

Kenneth R. Maser [Tel.: (781) 648-0440, Fax: (781) 648-1778, Email: kmaser@infrasens.com]
Infrasense Inc., Arlington, Massachusetts

This project developed a method based on the technique of active heating infrared thermography for detecting delamination and deterioration in bridge decks. The method involves briefly heating the deck with high-intensity pavement heaters and then detecting the temperature differentials at delaminations using infrared thermography. Analytical studies employing a thermal/mechanical model showed that detectable differentials can be produced using the output of a standard pavement heater with 5-10 seconds of heating application. Laboratory studies on slabs with simulated delaminations incorporated at different locations and depths with 10-second heating confirmed detectable temperature differentials at the delaminated locations (Figure 1).

A cost analysis estimate shows that for a standard overpass bridge, the infrared method is less than half the cost of the conventional chain dragging method and occupies the structure for one tenth of the time. For a four-lane bridge, 180 ft long and with a surface area of about 8,600 sq ft, the chain drag method cost over $7,200, required 42 hours of the field technician's time and 21 hours of lane closure. The infrared heating method cost about $3,600, requiring only four hours of the technician's time and two hours of moving lane closure. Further field testing and demonstration is needed to implement this technology for highway application. The final report is available from the National Technical Information Service (NTIS # PB2005-100681).

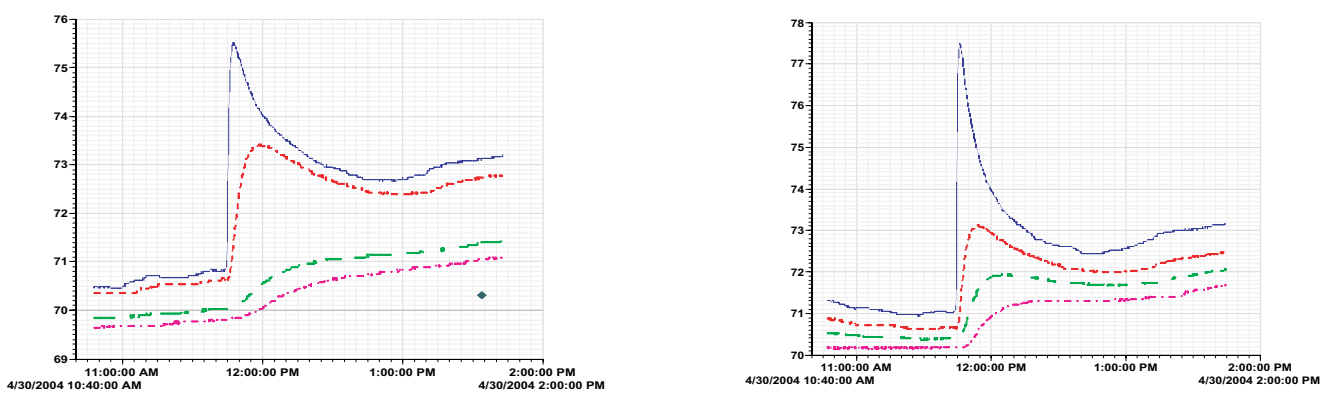


Figure 1

Temperature profiles: (left) at delamination and (right) in sound area at various sensor depths.

NONDESTRUCTIVE EVALUATION METHOD FOR DETERMINATION OF INTERNAL GROUT CONDITIONS INSIDE BRIDGE POST-TENSIONING DUCTS USING ROLLING STRESS WAVES FOR CONTINUOUS SCANNING

NCHRP-IDEA Project 102

Yajai Tinkey and Larry D. Olson [Tel.: (303) 423-1212, Fax: (303) 423-6071,
Email: yajai@olsonengineering.com, ldolson@olsonengineering.com]
Olson Engineering Inc., Wheat Ridge, Colorado

This project developed a nondestructive method based on impact-echo technique with continuous scanning features (Figure 1) and spectral analysis of surface waves for determining the grout condition inside post-tensioned bridge ducts. Work in the first phase focused on evaluating and establishing the accuracy/reliability of the impact echo scanning test. The impact echo scanner hardware was modified by incorporating a rolling transducer into the prototype to overcome the problem of variable thickness. The scanner software was also improved to provide three-dimensional display of impact echo results. Data on a mock-up slab fabricated with defects of different types and sizes and collected using the modified instrument was analyzed. Visualization from three-dimensional surface plots helped interpret the data. The presence of a tendon duct and grouting discontinuities appeared to cause an increase in the apparent slab thickness. The contractor procured two U-shaped precast bridge girders with four ducts on each wall from Colorado Department of Transportation for a full-scale test. Impact echo tests using a rolling scanner at different times after the grouting process were performed on the walls of the girders. The results showed good agreement with the actual defect design. The clearest indication of the presence of grouting defect was given by the apparent increase in slab thickness due to a reduction in the impact echo resonant frequency (caused by a decrease in stiffness associated with a defect). Work in the second and final stage focused on building and refining a prototype. The equipment is now ready for implementation and is commercially available. The final report is available from the National Technical Information Service (NTIS # PB2007-107314).

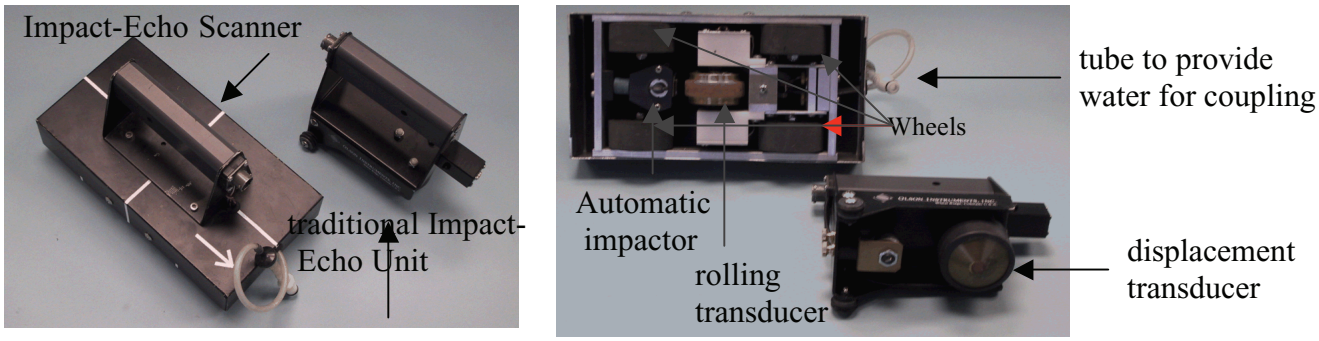


Figure 1

Impact Echo Scanning Unit and Traditional Impact Echo Unit.

LIQUEFACTION MITIGATION USING VERTICAL COMPOSITE DRAINS: FULL-SCALE TESTING FOR PILE APPLICATIONS

NCHRP-IDEA Project 103

Kyle M. Rollins [Tel.: (801) 422-6334, Fax: (801) 422-0159, Email: rollinsk@byu.edu]
Brigham Young University, Provo, Utah

This follow-on project to an earlier IDEA project (NCHRP-94) involved full-scale field tests to evaluate the liquefaction mitigating effect of vertical composite drains for pile applications (Figure 1). Work in the first phase focused on site characterization and blast testing in an untreated area. A pattern of small explosive charges was established for detonation to simulate the liquefaction process produced by an earthquake, and pilot tests were performed with various charge weights and delays to better simulate the duration and intensity of an earthquake and to determine the energy required to induce liquefaction. The contractor had to change the location of the field test because California withdrew permission for the initially approved Treasure Island site. The new test site is near Vancouver, British Columbia. Beginning with the pilot blast liquefaction testing, all tests were completed by the end of summer 2006. The tests also included pile-load testing before and after blast testing in areas treated and untreated with drains. The field test results were complemented with modeling analysis to determine likely pore pressure response in the area treated with drains. The test results and modeling analysis verified the effectiveness of the proposed approach. The final report is available from the National Technical Information Service (NTIS # PB2007-109590).

Figure 1

Installation of slotted drain pipe within vibrating mandrel.

IMPROVED LOW-TEMPERATURE AND FATIGUE-PERFORMANCE GRADING OF ASPHALT BINDERS

NCHRP-IDEA Project 104

Simon Hesp [Tel.: (613) 533-2615, Fax: (613) 533-6669, Email: simon@chem.queensu.ca]
Queen's University, Kingston, Ontario, Canada

This project refined and evaluated a test method developed in an earlier IDEA project (NCHRP-84) based on fracture mechanics for predicting the low temperature performance of asphalt binders. Fracture performance properties of selected asphalt binders from various pavement trial sections in Canada (particularly from Highway 655), along with additional commercial materials were determined using the developed tests. The ductile fracture properties varied by a significant amount; the mixture that showed the highest essential work of fracture performed well in the field, while those with lower works of fracture performed poorly. In contrast, the mixture that performed best in the repeated compression tests at both 25°C and 40°C, performed worst in service, suggesting that this test measures properties that show little relevance for fracture performance. Failure properties at low temperatures in both creep tests and in controlled-crack-opening displacement tests were determined. Based on research results, the Ontario Ministry of Transportation has approved two additional pavement trials, one on Highway 417 and the other on a new section of Highway 655. These and other test sections are being used in the validation tests for the laboratory standards developed under the two IDEA projects. Several other agencies (Ontario Ministry of Transportation, Imperial Oil of Canada, and the Science and Engineering Research Council of Canada) have collaborated in this IDEA effort. The key deliverables from the proposed effort are as follows:

- LS-296 (draft)–Asphalt Cement Grading for Fracture Performance using Single-Edge-Notched Bend Procedure;
- LS-298 (draft)–Asphalt Cement Grading for Fracture Performance using Compact Tension Procedure;
- LS-299 (draft)–Asphalt Cement Grading for Fracture Performance using Double-Edge-Notched Tension Procedure; and
- LS-308–Determination of Performance Grade of Physically Aged Asphalt Cement using Extended Bending Beam Rheometer (BBR) Method.

These four methods provide practical and improved low-temperature and fatigue binder specification tests. The research team is working closely with the Materials Engineering and Research Office of the Ministry of Transportation of Ontario and with users and producers in the Canadian asphalt industry to get the specification test method included in all future hot mix contracts. The final report is available from the National Technical Information Service (NTIS # PB2007-107317).

EVALUATION OF NEW METHODS TO MEASURE WATER-TO-CEMENT RATIO OF FRESH CONCRETE

NCHRP-IDEA Project 105

Art Crotzer [Tel.: (405) 372-9595, Fax: (405) 372-9537, Email: acrotzer@nomadics.com]
Nomadics Inc., Stillwater, Oklahoma

Steve Trost [Tel.: (405) 412-7879, Email: steve@ssi.us]
Strategic Solutions International, LLC, Stillwater, Oklahoma

Michael Fox [Tel.: (405) 533-3770, Email: mfox@engius.com]
Engius, LLC, Stillwater, Oklahoma

This project explored new methods to determine the water-to-cement ratio of fresh concrete. Several new approaches for measuring the water/cement ratio of fresh concrete based on the principles of turbidity and unit-weight/specific-gravity, fluorescence, and radiographic attenuation were initially evaluated. Of all these methods, the approach based on unit weight/specific gravity measurements appeared to be most promising provided certain physical properties of concrete were known in advance. Consequently, work focused on the design, fabrication, and testing of a prototype water/cement meter based on unit weight measurements.

Two systems were developed that involved the measurements of the specific gravities of fresh concrete, cement, flyash as well as the ratios of flyash to cementitious materials and sand, and mathematical equations were derived to calculate the water-to-cement ratio based on these ratios. Results showed good predictive capability of water/cementitious materials ratio with a coefficient of determination of 99.89% and a standard error of 0.77%. A modified microwave oven drying method provided results with a coefficient of determination of 98.7% and a standard error of 2.2%. Efforts have been initiated for marketing, manufacturing, and commercialization of the results of this research and licensing and intellectual property agreements with all involved parties are already in place, which will allow a smooth transition from development and validation to commercialization. The final report is available from the National Technical Information Service (NTIS # PB2008-106868).

AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION

NCHRP-IDEA Project 106

Heng-Da Cheng [Tel.: (435) 797-2054, Fax: (435) 797-3265, Email:_hengda.cheng@ usu.edu]
Utah State University, Logan, Utah

This follow-on project to an earlier IDEA project (NCHRP-81) refined and evaluated in the field an automated high resolution imaging system to detect and classify pavement cracks in real time at highway speeds. The integrated pavement crack analysis and detection system with camera and accessories was installed on a vehicle (Figure 1). While field tests demonstrated the system's capability of recording and processing of images at speeds up to 80 miles per hour, the camera performed unsatisfactorily for the desired resolution. Consequently, a line camera with necessary specifications was procured and used to collect additional data. However, the line camera showed problems with synchronization, white light calibration, and interruption in image capture with change in scan rate. Use of wide angle lens with area cameras produced distortion in the captured images. While an interpolation method appeared to help correct the distortion, it greatly increased the processing time. A satisfactory solution was to use two cameras without the wide-angle lens. This approach was used in field testing by the Utah Department of Transportation (DOT). The testing program used five descriptive statistics (accuracy, sensitivity, specificity, positive predictive value, and negative predictive value) to objectively evaluate the system's performance. The tests results and feedback from Utah DOT were used to refine and upgrade the system. The final integrated system is ready to survey pavement distress on highways. The detailed list of test images and results can be downloaded from the website http://cvprip.cs.usu.edu/idea. The final report is available from the National Technical Information Service (NTIS # PB2007-107318).

Figure 1

Integrated pavement crack analysis system installed on a vehicle.

MOBILE GEOPHYSICAL TECHNOLOGY: A SUBSURFACE SCOPING TOOL FOR REDUCING UNFORESEEN ROADBLOCKS IN PROJECT DELIVERY

NCHRP-IDEA Project 107

John A. Lopez [Tel.: (707) 678-2330, Fax: (707) 471-6502, Email: johnlopez@ argustec.com]
Argus Technologies Inc., Dixon, California

This project demonstrated the application of a new mobile geophysical technology, based on electromagnetic induction technology, to detect subsurface features and objects for highway-related projects (Figure 1). Two highway projects were identified in collaboration with Caltrans for evaluating the mobile geophysical technology. The first project was a road-widening Donner Road Rehabilitation Project along highway I-80 (Nevada County). The IDEA work in this project investigated the geological composition of the soils beneath I-80. The second project was a bypass Cherry Avenue Project between Taft and Bakersfield (Western Kern County). The IDEA work determined soil texture density differences, identified plumes, and selected geotechnical boring locations. The electromagnetic signatures were correlated with soil conditions and used to identify differences in geology, landform, and roadbed materials. In both projects, the data obtained by the geophysical equipment provided a more complete understanding of the subsurface conditions and allowed construction plans to be updated and their accuracy improved. The final report is available from the National Technical Information Service (NTIS # PB2007-109638).

Figure 1

Mobile geophysical subsurface scoping equipment.

PILOT STUDY OF 3D-CENTRIC MODELING PROCESSES FOR INTEGRATED DESIGN AND CONSTRUCTION OF HIGHWAY BRIDGES

NCHRP-IDEA Project 108

Stuart S. Chen [Tel.: (716) 645-2114, Fax: (716) 645-3733, Email: Stuartschen@hotmail.com]
State University of New York (SUNY), Buffalo, New York

This project developed and tested a 3D-centric model for an integrated design and construction process for highway bridges. An integrated design of the 3D-centric model was developed. Workflow aspects that were addressed include the following: parametric data entry and management, line girder analysis under AASHTO LRFD (Load and Resistance Factor Design) loadings, AASHTO LRFD design checks, database maintenance and augmentation as the work progresses, 3D CAD modeling, selected contract plan and "shop drawing" generation, extraction of quantity takeoffs for cost estimating, material procurement and shop material management, and export of Computer Numerical Control instructions for automated fabrication by suitably configured shop equipment. Examples of bridge models that were generated are shown in Figure 1. From the single central 3D model current project information relevant to a given project stakeholder (e.g., owner, designer, contractor, fabricator, detailer, precaster, erector) can be extracted at any given time. A pre-stressed concrete bridge provided by Pennsylvania Department of Transportation was modeled parametrically in 3D and was evaluated to record lessons learned about how parametric 3D modeling should be conducted for a real bridge design and construction project. The final report documents the requirements for needed standards and "best practices" pragmatics for 3D-centric approaches and accompanying electronic data interchange for streamlining construction and design processes. The final report is available from the National Technical Information Service (NTIS # PB 2007-107319).

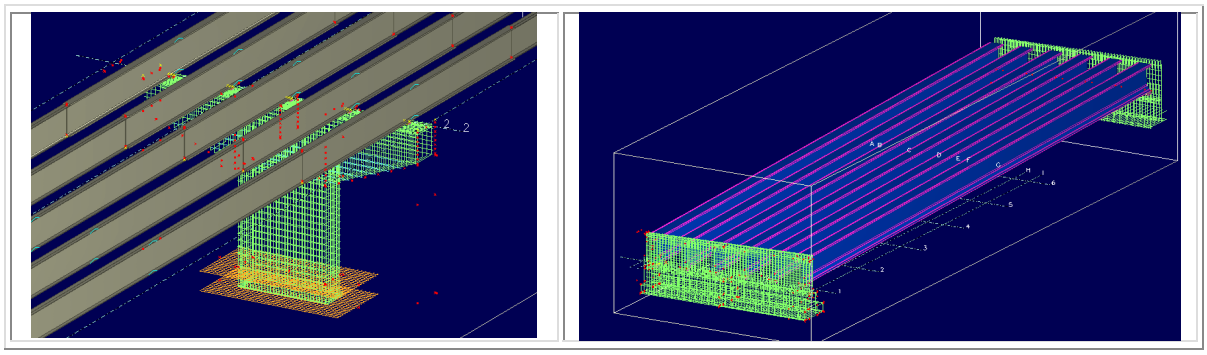


Figure 1

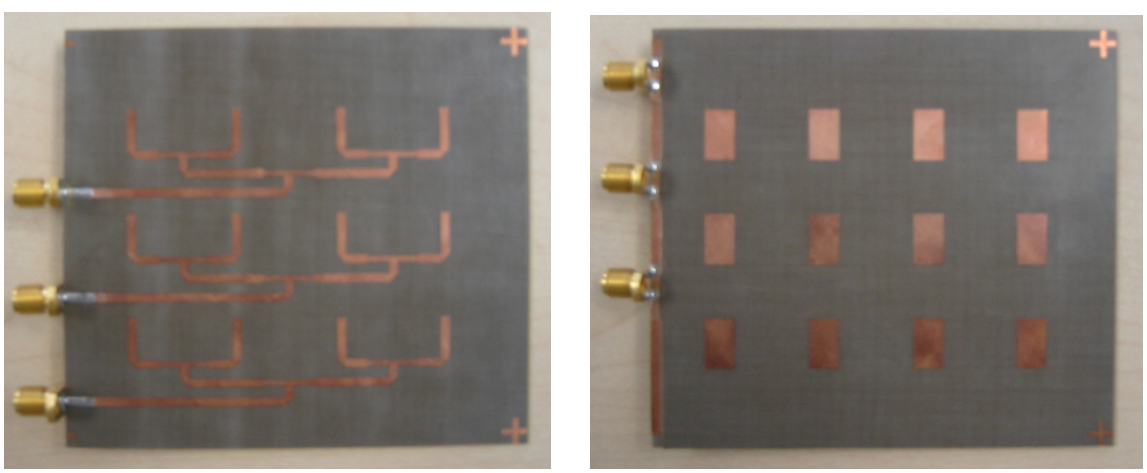
Portions of steel and concrete bridge models.

SMART ARRAY ANTENNA FOR NONDESTRUCTIVE EVALUATION OF FIBER-REINFORCED POLYMER-WRAPPED CONCRETE BRIDGE MEMBERS

NCHRP-IDEA Project 109

Maria Feng [Tel.: (949) 378-8666, Fax: (949) 824-0187, Email: mfeng@newport sensors.com]
Newport Sensors Inc., Irvine, California

This project developed a nondestructive method for the condition evaluation of fiber-reinforced polymer (FRP) concrete bridge members using a smart antenna array to detect microwave signals (Figure 1). The system consisted of three modules: a controller and a power supplier, a transceiver, and array antennas with a feed network. The system was subjected to several modifications and refinements. An embedded single board computer with a data acquisition board was used as the controller. The power supply design was modified to minimize its size. The housing was also redesigned and a transceiver with several RF parts was assembled. Software for system operation and real-time data processing and image visualization was developed and integrated with the hardware. The software verified that the feed network was working well and the control parameters were correct. The software program controlled the parameters for the transceiver operation and beam scanning and could also diagnose the status of the system. The performance of the prototype was evaluated on a variety of concrete-FRP specimens. Debonds of various areas and gaps were artificially created between the FRP and concrete. The prototype was shown to be effective in detecting and even quantifying debonding at the concrete-FRP interface. Based on evaluation results, a final design of the smart antenna system was developed. The final report is available from the National Technical Information Service (NTIS # PB2007-107337).



Microstrip feed *Patch*

Figure 1

One of the six array antennas.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION

NCHRP IDEA Project 111

Kelvin C.P. Wang [Tel.: (479) 575-87425, Fax: (479) 575-7168, Email: kcw@uark.edu]
University of Arkansas, Fayetteville, Arkansas

This follow-on project was aimed at refining and field testing a computer vision technique that was investigated in an earlier IDEA project (NCHRP-88) using multiple cameras for automated condition survey of highway pavements. A new vehicle for collecting digital highway data was procured, and four cameras were mounted in the rear of the vehicle to collect pavement surface images across a 4-m wide pavement. However, calibration work to correct camera distortion for 3D surface reconstruction showed the inadequacy of the Direct Linear Transformation (DLT) method for the purpose, and further work indicated that the Tsai method provided better accuracy than the DLT method. The space relationship between the two cameras also affected the calibration accuracy. While efforts were directed at improving the accuracy by adjusting each camera's angle and the space between the cameras, a new laser-based illumination imaging system was also investigated with promising results. Figure 1 demonstrates the working principles of the laser imaging system. The system allows image acquisition without the influence of sunlight or shadows, providing a 1-mm resolution of both longitudinal and transverse cracks at speeds up to 60 miles per hour. However, with the line-scan camera, the stereovision technology is not directly applicable and additional work is needed to establish the 1-mm level resolution of 3D pavement surface models with multiple laser imaging devices. The final report is available from the National Technical Information Service (NTIS # PB2008-106866).

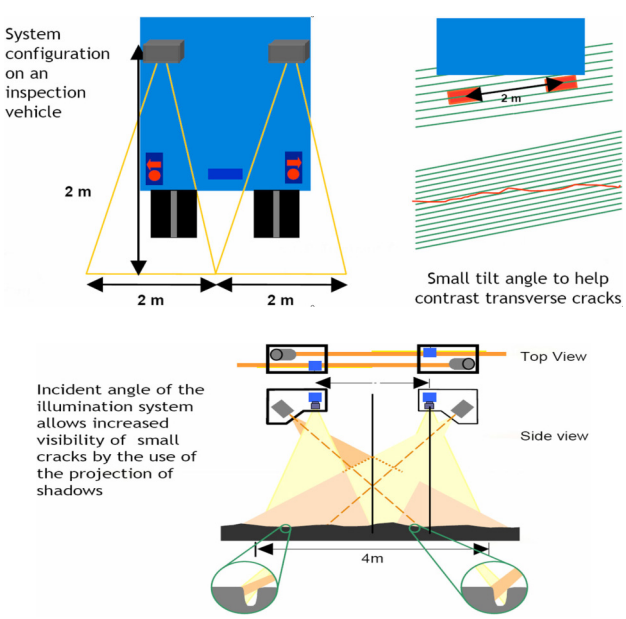


Figure 1

Working principle of the Laser Road Imaging System.

CONE PENETROMETER EQUIPPED WITH PIEZOELECTRIC SENSORS FOR MEASUREMENT OF SOIL PROPERTIES IN HIGHWAY PAVEMENT

NCHRP-IDEA Project 112

Xiangwu (David) Zeng [Tel.: (216) 368-2923, Fax: (216) 368-5229, Email: xxz16@cwru.edu]
Case Western Reserve University, Cleveland, Ohio

This project developed a mobile and robust cone penetrometer prototype with piezoelectric sensors (Figure 1) to measure soil properties in highway pavement. Sensors for the cone penetrometer were procured and tested, and the instrument design was modified to enhance its ruggedness and sensitivity. Software based on the theory of wave propagation in granular materials was developed for field data analysis. Laboratory tests on the system using two different types of soils, one fine-grained and the other coarse-grained, showed good results and repeatability for resilient modulus, shear modulus, and Poisson's ratio. The shear modulii of the soils agree well with that which was calculated by Hardin and Richard's equation. Work in the second stage focused on design improvement and field testing of the prototype equipment. Final design modifications to the prototype were made, and the equipment was fabricated. The modifications were aimed at making the equipment lightweight for easy handling and making the sensors waterproof to allow its use in wet soils. A vibration system was also introduced to help drive the penetrometer in the ground smoothly. The Ohio Department of Transportation provided a test site in Delaware County for field evaluation of the equipment. An equipment manufacturer is exploring commercialization of the instrument. The final report is available from the National Technical Information Service (NTIS # PB2007-107339).

Figure 1

The cone penetrometer equipped with piezoelectric sensors.

GEOCOMPOSITE CAPILLARY BARRIER DRAIN FOR LIMITING MOISTURE CHANGES IN PAVEMENTS

NCHRP-IDEA Project 113

John Stormont [Tel.: (505) 277-6063, Fax: (505) 277-1988, Email: jcstorm@unm.edu]
University of New Mexico, Albuquerque, New Mexico

Karen Henry [Tel.: (603) 646-4188, Fax: (603) 646-4640,
Email: karen.s.henry@erdc.usace.army.mil]
US Army Cold Regions and Research Engineering Laboratory, Hanover, New Hampshire

Andrew Eller [Tel.: (651) 366-5524, Fax: (651) 366-5461, Email: andrew.eller@dot.state.mn.us]
Minnesota Department of Transportation, Minneapolis, Minnesota

This follow-on project evaluated and demonstrated the field application of a geocomposite capillary barrier drain (GCBD) technology developed in an earlier IDEA project (NCHRP-68) to improve pavement subsurface drainage. When placed between a base and subgrade, the GBCD can drain the unsaturated base and reduce its water content as well as prevent water from reaching the subgrade. In contrast to the GCBD, conventional drainage is designed for saturated flow, even though the positive pore water pressures required for saturated flow reduce strength and lead to rutting, heaving, and failure. The GCBD comprises three layers from top to bottom: a transport layer (a specially designed geotextile), a capillary barrier (a geonet), and a separator (geotextile). Figure 1 illustrates the principal function of the GCBD.

After selecting materials for the field test, developing a method for terminating the GCBD in an edge drain trench, and establishing specifications for field installation, a prototype GCBD was installed in a full-scale test section of MnRoad project. The MnRoad test data showed the pavement section with GCBD to be considerably drier compared to a control section. Falling weight deflectometer data from the section with the GCBD and the control section were compared, and design calculations for the performance of the GCBD in specific climate, geometry, and material properties were made. A geosynthetic manufacturing company in Atlanta, Georgia, has developed a new material that may work well as a transport layer in the GCBD configuration. (NTIS Report # PB2009-113226)

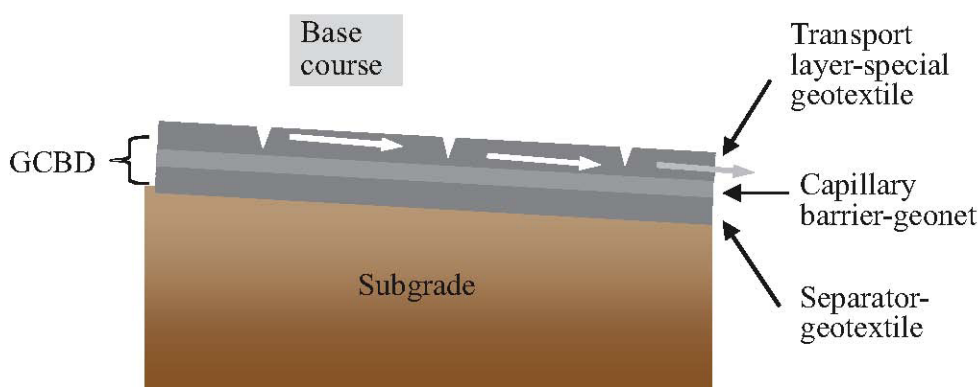


Figure 1

GCBD between base course and subgrade illustrating how waer laterally drains in transport layer.

RELATIONSHIP OF ASPHALT PAVEMENT MICROTEXTURE USING IMAGE ANALYSIS OF AGGREGATE SHAPE

NCHRP-IDEA Project 114

Eyad Masad, Texas A&M University [Tel.: (979) 845-8308, Fax: (979) 845-0278,
Email: emasad@civil.tamu.edu]
Department of Civil Engineering, Texas A&M University, College Station, Texas

This follow-on project further evaluated and refined a methodology based on the Aggregate Imaging System (AIMS), an image analysis technique developed in an earlier NCHRP-IDEA project (NCHRP-77) to measure and differentiate multiscale components of aggregate shape characteristics and to relate these characteristics to asphalt pavement microtexture and skid resistance. Initial efforts were focused on improving the image analysis methodology and identifying the shape scales that best correlated with aggregate resistance to polishing. The AIMS was used in conjunction with the Micro-Deval abrasion test to evaluate the aggregates' characteristics after different levels of polishing. Based on results, an empirical equation relating texture to time in the Micro-Deval was proposed. As a general trend, the texture and angularity of the aggregate decreased with an increase in time in the Micro-Deval machine. An evaluation of available skid data on Texas DOT test sections also showed a trend between aggregate type, mix type, and skid resistance. The asphalt pavement skid resistance also appeared to be related to aggregate average texture and the variability of texture within the aggregate source. A testing protocol for aggregate shape characteristics was also developed for aggregates commonly used in pavements.

As part of technology transfer efforts, the method developed under the NCHRP-IDEA project 144 was used to analyze more than 100 aggregate samples in Texas. The results were used to revise the Texas DOT classification of aggregates in order to improve the frictional resistance of asphalt pavements. The work is based on measuring the skid resistance of many asphalt pavements and measuring the texture of aggregates used in these pavements. Consequently, a large database will be available to classify aggregates based on their contribution to asphalt pavement skid resistance. AIMS was further evaluated and refined with support from FHWA's Highways for LIFE Program. The imaging system is now commercially available and is being used by FHWA for demonstration and training in its mobile laboratory. Two test procedures based on AIMS have been adopted by AASHTO for determining aggregate shape properties (TP 81 and PP 64). The final report is available from the National Technical Information Service (NTIS # PB2008 109819).

DEVELOPMENT OF A SECOND GENERATION DETECTION-CONTROL SYSTEM FOR SAFER OPERATION OF HIGH-SPEED SIGNALIZED INTERSECTIONS

NCHRP-IDEA Project 115

Karl Zimmerman [Tel.: (979) 458-2835, Email: k-zimmerman@ttimail.tamu.edu]
Texas Transportation Institute, College Station, Texas

This project improved and evaluated a detection-control system (D-CS) for enhanced traffic safety at high speed signalized intersections. Drivers approaching a traffic signal at high speed must decide whether to proceed or stop when presented with a yellow indication. This decision is based on each driver's perception of whether it is safe (or possible) to stop prior to entering the intersection. This decision is illustrated in Figure 1. A driver in the shaded area in Figure 1 is said to be in the "dilemma zone," where there is a range of driver reactions to the yellow indication. The Detection-Control System (D-CS), developed at the Texas Transportation Institute (TTI), was designed to reduce the likelihood of vehicles being in the dilemma zone. A literature review was conducted to identify potential enhancements to D-CS control algorithm required to create the "second generation" D-CS algorithm. The needed enhancements included dilemma zone protection based on vehicle size, real-time dilemma zone changes, coordination, and real-time measures of effectiveness reporting. After selecting the most feasible enhancements, the control algorithm was modified and tested in the laboratory. Based on laboratory test results, a "second generation" D-CS control algorithm was developed capable of providing dilemma zone protection specific to vehicle type using a modified system to prevent max out during "Stage 2" operation. The new algorithm showed improvement over the original algorithm and could provide real time information to engineers about intersection operation. The software was downloaded to intersections where D-CS had been installed during earlier field trials. At the first installation, it was discovered that shortening the D-CS protection zone to improve efficiency (the third installment) caused increased red light violation by vehicles. Therefore, prior to the second field trial, the third enhancement was removed from the enhanced control algorithm. The second trial was more successful as a result, indicating that the enhanced algorithm is successful at improving safety at isolated high-speed intersections. The final report is available from the National Technical Information Service (NTIS # PB2007-107338).

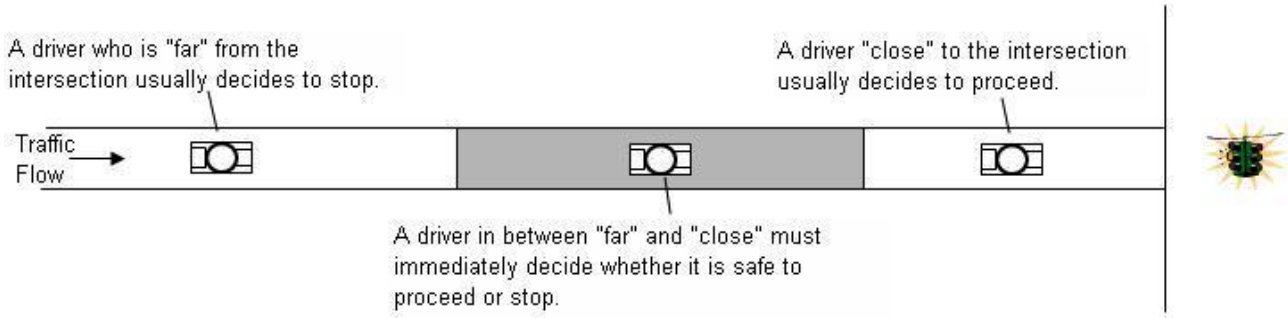


Figure 1

Driver decisions approaching an intersection.

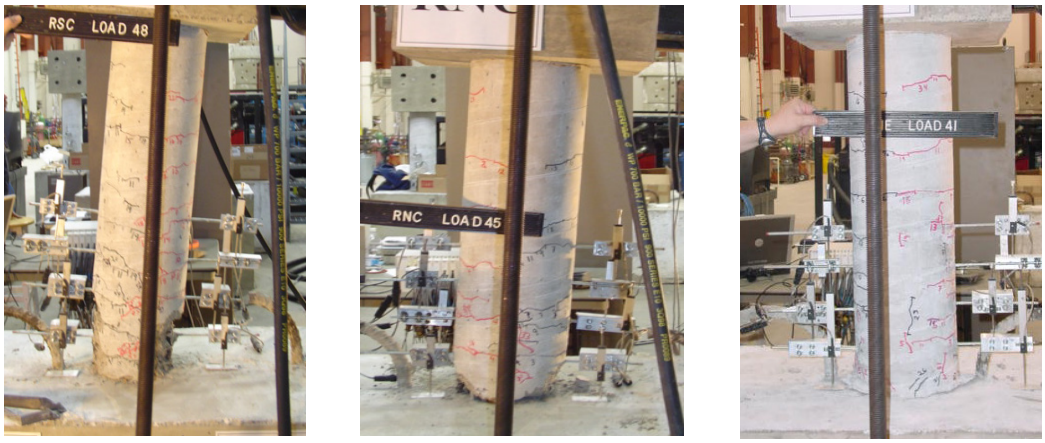
SEISMIC RESPONSE OF BRIDGE COLUMNS WITH ENGINEERED CEMENTITIOUS COMPOSITES AND SHAPE MEMORY ALLOYS IN PLASTIC HINGE ZONE

NCHRP-IDEA Project 116

S. M. Sadrossadat-Zadeh [Tel.: (775) 784-4482, Fax: (775) 784-1390, Email: smsz@unr.edu], and

M. Saiid Saiidi [Tel.: (775) 784-4839, Fax: (775) 784-1390, Email: saiidi@unr.edu]
University of Nevada, Reno, Nevada

This project evaluated the application of superelastic shape memory alloy (SMA) reinforcement in combination with engineered cementitious composites (ECC) in bridge columns to minimize earthquake damage. Based on initial evaluation, Nitinol SMA and ECC compositions were selected for application in bridge columns. An analytical study was performed to determine optimum material properties and configuration for the concrete column. Bridge columns incorporating a combination of SMA and ECC or conventional concrete were constructed and subjected to quasi-static cyclic tests. The first column (RSC) used conventional concrete and steel reinforcement; the other two, RNC and RNE, respectively, used conventional concreare with Ninitol and engineered cementitious composites (ECC) with Ninitol in the plastic hinge (Figure 1). The average ratios of residual to maximum displacement in RSC, RNC, and RNE were 0.82, 0.27, and 0.14, respectively, indicating the substantial benefits of using innovative materials. RNE experienced the least damage and highest drift capacity among the three columns. The test results showed the promise of SMA and EEC in improving serviceability of bridges after earthquakes. The final report includes important experimental and analytical data and provides design guidelines for improving the seismic response of bridge columns using SMA and ECC materials. The final report is available from the National Technical Information Service (NTIS # PB2007-109640).



(a) RSC (b) RNC (c) RNE

Figure 1

Residual displacement and damage after 10 percent maximum drift.

SELF-POWERED SENSORS AND ACTUATORS FOR BRIDGES

NCHRP-IDEA Project 117

Edward Sazonov [Tel.: (315) 268-3914, Email: esazonov@ieee.org or esazonov@clarkson.edu]

Pragasen Pillay [Tel.: (315) 268-6509, Email: pillayp@clarkson.edu]
Clarkson University, Potsdam, New York

Life-cycle monitoring of civil infrastructure, such as bridges, is critical to the long-term operational cost and safety of aging structures. Localized monitoring of bridge structural elements may require placement of a dense sensor array on the structure that would also require power. This project developed a micro-power electromechanical energy harvester and energy conversion unit for generation of electrical power from ambient vibration of bridges. Energy generated by the harvesting device powers wireless sensors that measure and wirelessly transmit bridge information, such as temperature and vibration, to a central location for analysis. A prototype linear generator was assembled, characterized, and tested in the laboratory and on a bridge (Figure 1). The prototype utilized a spring-mass approach. The stator was attached to a vibrating structure while spring stiffness was tuned to a resonant frequency of the bridge structure. An adaptive tracking algorithm to allow harvesting energy at the maximum power point was also developed. The electromagnetic energy harvester was integrated with energy conversion and storage circuitry and wireless sensor for testing on an actual bridge. The generator successfully harvested the bridge vibration energy to power the sensor. The self-powered wireless sensor technology was licensed to startup company AmbioSystems, LCC (www.ambiosystems.com). The research team is working in conjunction with AmbioSystems, New York State DOT, and other companies to bring self-powered sensors into practice. (NTIS Report # PB2008-113777).

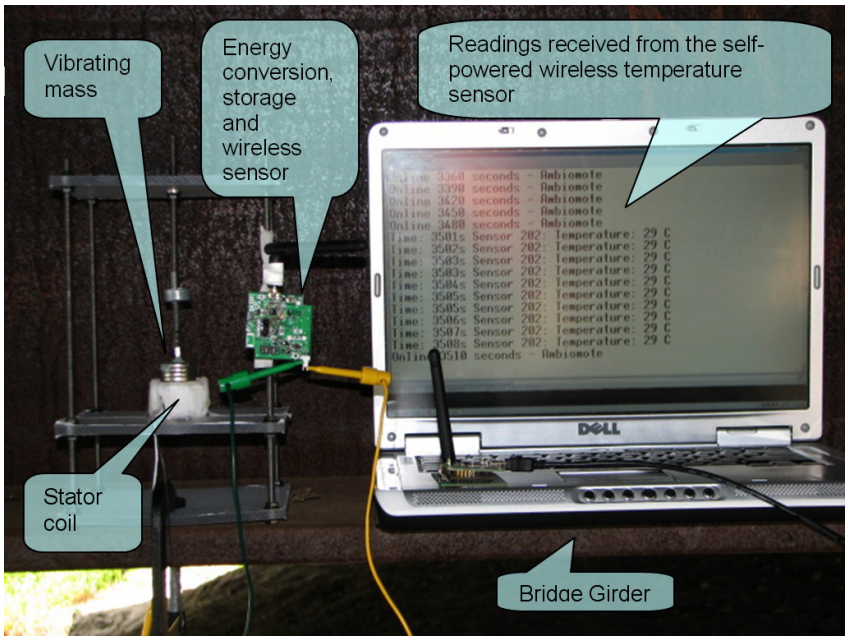


Figure 1

Prototype of the self-powered wireless sensor.

THE BCD: A NEW INSTRUMENT FOR COMPACTION CONTROL

NCHRP-IDEA Project 118

Jean-Louis Briaud and Keunyoung Rhee [Tel.: (979) 845-3795, Fax: (979) 845-6554, Email: briaud@tamu.edu] Texas A&M University, College Station, Texas

This project developed and tested the Briaud Compaction Device (BCD), a portable device for measuring the soil modulus for compaction control in the field and establishing a target value in the laboratory (Figures 1 and 2). The BCD consists of a thin steel plate, 6 inches in diameter, at the bottom of a rod. When the operator leans on the rod handle, the plate bends and the strain produced in the plate is recorded. Use of a wet sand cushion between the plate and the soil significantly reduced the effect of an uneven surface and minimized variation in field test readings. Based on numerical simulations, the BCD can measure the modulus of soils in the range of 3 to 300 MPa and measure the modulus within a depth of influence of about 6 inches for a soil with a modulus between 5 and 100 MPa. Tests using a rubber block showed a linear relationship between the load applied on the BCD and the hoop strain recorded on the steel plate. Repeated testing on the same block showed very good repeatability of the test. Plate tests, performed in parallel with the BCD tests, showed good correlation between the plate and the BCD moduli. The diameter of the rod connecting to the plate was reduced to 1 inch to extend the range of the BCD to harder soils. A calibration procedure was developed using calibrated rubber blocks of known moduli; this allowed each BCD unit to be calibrated independently of the manufacturing variables. Resilient modulus tests and parallel BCD tests were performed in the laboratory on silty clay samples, 6 inches in diameter and 8 inches high, at various water contents. The data show a good correlation between the resilient modulus and the BCD modulus for different water contents for a given soil. The product is now commercially available, and several DOTs have already purchased it for further evaluation and implementation. The final report is available from the National Technical Information Service (NTIS # PB2009-113227).

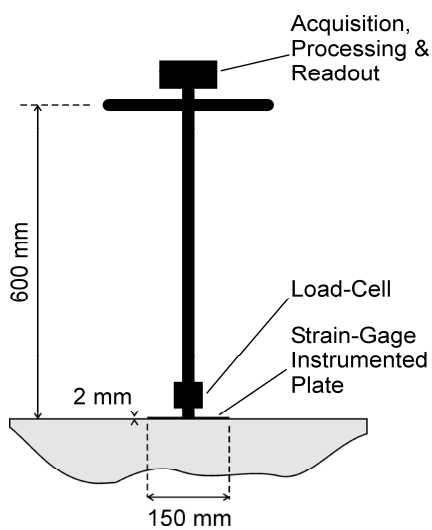


Figure 1

Conceptual Sketch of a BCD.

Figure 2

BCD-4.

THREE-DIMENSIONAL DIGITAL IMAGING FOR THE IDENTIFICATION, EVALUATION, AND MANAGEMENT OF UNUSABLE HIGHWAY SLOPES

NCHRP-IDEA Project 119

John Kemeny [Tel.: (520) 621-4448, Email: kemeny@spliteng.com, Web: www.spliteng.com]
Split Engineering LLC, Tucson, Arizona

James Donovan [Tel.: (801) 585-3029, Email: james.donovan@mines.utah.edu]
University of Utah, Salt Lake City, Utah

This project developed and field tested software for using ground-based LIDAR (also called 3D laser scanners) and digital imaging to analyze rockfall. This includes assessing rock faces for the likelihood of rockfall (rockfall ratings) and determining information on rockfalls that actually occur (rockfall locations, rate, and volume). Software development will be made through improvements to Split Engineering's Split-FX software for processing point clouds and associated digital images. Several sites were identified for field testing of the software, and LIDAR scans were conducted at locations where rock fall was likely to occur. The most important field site was a site chosen along Interstate 70 near Georgetown, Colorado where fatalities due to rockfall are known to occur (Figure 1). Further improvements to the software were made along with the incorporation of major features to the Split-FX program, including photo draping and the ability to extract fracture orientations from the 3-D photos, a change detection algorithm to detect and analyze the size and volume of rockfall, and a built-in rockfall hazard rating system to quickly and accurately evaluate rockfall and slope stability hazards. Additionally, Georgetown and Utah sites were rescanned to determine rockfall locations and volumes and the rockfall rating using the newly developed software. Also, a 'rolling rock' field test was conducted on Mount Lemmon, Arizona, to determine the smallest rockfall that could be detected and the overall accuracy and usefulness of the rockfall detection software. The product of this project is being further evaluated for implementation in a pooled-fund study supported by FHWA and eight state highway agencies (NTIS # PB2010-101386).

(a) (b)

Figure 1

LIDAR field site along Interstate 70 near Georgetown, Colorado, (a) rocky, steep rockfall source area above Interstate 70 and (b) Lidar scanning using an Optech scanner.

ACTIVE SENSING FOR ONLINE HIGHWAY BRIDGE MONITORING

NCHRP-IDEA Project 120

Hoon Sohn [Tel.: (412) 268-2077, Fax: (412) 268-7813, Email: hsohn@cmu.edu]
Carnegie Mellon University, Pittsburgh, Pennsylvania

This project developed a sensor-based nondestructive testing (NDT) method for online monitoring of highway bridges without using any past baseline data. The concept is illustrated in Figure 1. A theoretical framework of the proposed technique was developed along with a time reversal process (TRP) and an NDT methodology for detecting cracks in bridge steel girders. To prove concept feasibility, the following key questions were addressed: What is the practical sensing range of TRP for damage detection? Can different types of defects be selectively detected and quantified? Do sensor conditions affect damage detection? Do undesirable operational and environmental conditions affect damage detection? Is the proposed TRP applicable to more complex structural geometries? The sensing range of TRP was found to be significantly larger than that achieved by conventional NDT methods, and the active sensing device was able to propagate up to 40 m. Results also indicated that different types of defects could be distinguished, and adverse conditions, such as debonding and cracking of the sensing device, did not severely affect the TRP used for structural damage detection. Experiments also demonstrated that the technique was not significantly affected by (i) ambient temperature variations, (ii) imperfect sizing and positioning of the active sensing device, (iii) ambient background vibration of test specimens, (iv) changes in test specimen's boundary conditions, and (v) surface debris or additional paint layer on steel girders. Field tests at a steel bridge near Pittsburgh further established the robustness of the proposed approach against operational and environmental variations of the bridge. Further refinement of the technique is needed to address issues with automating data collection and interpretation and with hardware and transducer devices for long term continuous monitoring. The final report is available from the National Technical Information Service (NTIS # PB2007-109637).

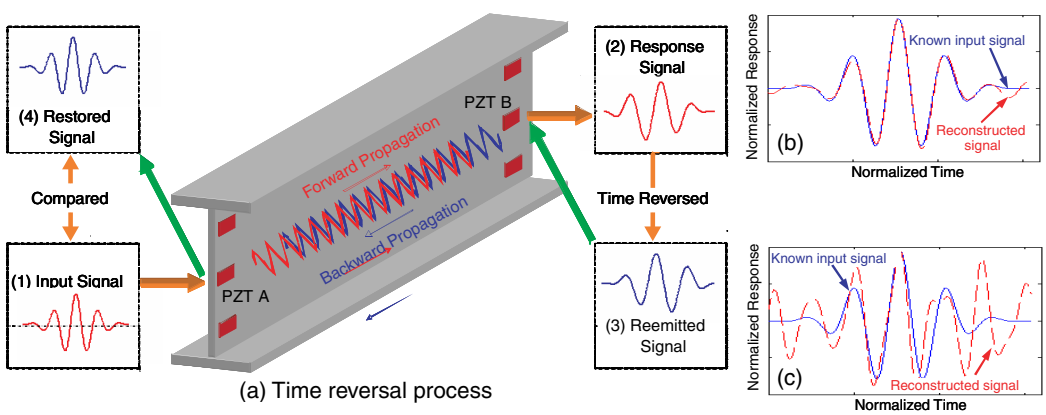


Figure 1

In the proposed baseline-free NDT, a time reversal process will be applied to crack detection within a steel girder: (a) a schematic sketch of time reversal process; (b) comparison between the original input signal (solid line) and the reconstructed signal (dotted line) before crack; (c) comparison between the original input (solid line) and the reconstructed signal (dotted line) after damage. Note that this method does not require any past baseline signals.

USING IMAGE PATTERN RECOGNITION ALGORITHMS FOR PROCESSING VIDEO LOG IMAGES TO ENHANCE ROADWAY INFRASTRUCTURE DATA COLLECTION

NCHRP-IDEA Project 121

Yichang (James) Tsai [Tel.: (912) 963-6977, Email: james.tsai@ce.gatech.edu]
Georgia Institute of Technology, Atlanta, Georgia

Collecting roadway infrastructure data, including roadway signs at each location is essential for asset management and for state departments of transportation (DOTs) to submit highway performance monitoring system data annually. Currently, this data collection is a manual process that is costly, time-consuming, and dangerous. This project developed an algorithm to automate sign inventory data collection and to make sign image recognition algorithms applicable for real-world video log images under different lighting, sign, and roadway conditions. The development was done in two parts: sign detection and sign recognition. A robust algorithm based on multifeature fusion was proposed for detecting signs. The algorithm performed both training and testing. In the training step, characteristics of MUTCD signs (including shape, color distribution, location distribution, and width-height ratios) in video log images were analyzed. For each feature, one or more sign detectors were designed, and their parameters (such as threshold values) were adjusted. Next, a sign recognition algorithm capable of classifying a variety of sign images was developed. This algorithm also consisted of training and testing steps and was tested with video log images collected on I-75 from Macon to Atlanta, Georgia, covering 140 km of rural and urban roadways. The algorithm successfully recognized 28 of 31 speed limit signs (a 90.3% recognition rate) and had only 5 false positives out of 136 speed limit sign images. With sufficient image training data sets, the proposed algorithm should also be applicable to other types of signs. The algorithms show a high promise for developing an intelligent sign inventory system that would help reduce the cost and time spent by state DOTs to acquire roadway infrastructure data through the use of video images. Louisiana and Georgia DOTs and the city of Nashville collaborated in this work and provided needed data for testing. Implementation of the IDEA product is under way through an FHWA-funded national demonstration project. The U.S. Coast Guard is exploring the technology for maritime applications. (NTIS Report # PB 2010-101387).

(a) Image containing speed limit sign

(b) Processed binary image after color segmentation

(c) Extracted speed limit digits

Figure 1

Speed limit sign extraction.

DIGITAL SPECIMEN AND MULTI-FUNCTION DIGITAL TESTER TECHNIQUE FOR PERFORMANCE EVALUATION OF ASPHALT MIXES

NCHRP-IDEA Project 122

Linbing Wang [Tel.: (540) 231-5262, Fax: (540) 231-7532, Email: wangl@vt.edu]
Virginia Polytechnic Institute & State University, Blacksburg, Virginia

Recent developments in x-ray computerized tomography (XCT) imaging and computational simulation have made it possible to characterize the properties of asphalt concrete through reconstruction of its three-dimensional (3-D) microstructure and computational simulation based on the 3-D microstructure. This project developed a 3-D digital representation of the microstructure of asphalt concrete and evaluated the performance of the 'digital specimen' using modeling and simulation techniques. A computer program to represent the microstructure of cylindrical specimens of asphalt concrete in digital format (digital specimen) was created, and modules to link the microstructure to a finite element code for simulating the indirect tensile test and dynamic modulus test (digital test) were developed (Figure 1). The simulation used elastic and viscoplastic material models for aggregate and asphalt respectively.

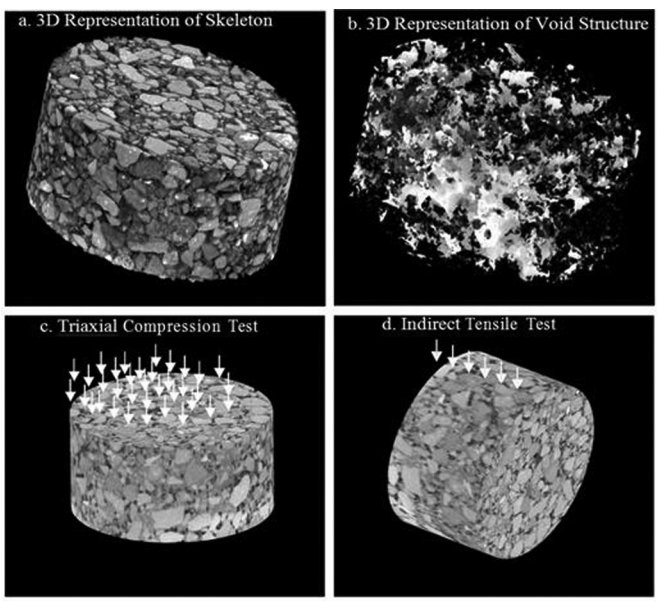


Figure 1

Illustration of the concepts of digital specimen and digital test.

By using rate dependent material model for asphalt binder, the numerical simulation of the indirect tensile test provided realistic response for asphalt mixture when compared qualitatively with experimental results. The model successfully captured stress variations due to both aggregates and voids, and the test was able to distinguish performance differences of different mixes. In addition, a set of compression tests on asphalt mixture specimens with different aggregate contents were conducted together with their digital counterparts. The actual and digital test results were in agreement at both microscopic and macroscopic levels. Additional development is needed before the digital specimen and digital test techniques can be implemented by highway agencies. (NTIS Report # PB2009-102139).

LONG-TERM REMOTE SENSING SYSTEM FOR BRIDGE PIERS

NCHRP-IDEA Project 123

Glenn Washer [Tel.: (573) 884-0320, Fax: (573) 882-4784, Email: washerg@missouri.edu]
University of Missouri, Columbia, Missouri

Paul Fuchs [Tel.: (703) 737-3871, Fax: (703) 737-6381,
Email: paul.fuchs@fuchsconsultinginc.com] Fuchs Consulting Inc., Leesburg, Virginia

Scour and other natural hazards have the potential to undermine the structural stability of highway bridges and the piers that support them. However, there remains a lack of reliable, cost-effective, long-term monitoring devices capable of determining the structural stability of bridge piers. This IDEA project developed a prototype tilt and displacement sensor (TDS) system for long-term remote monitoring of bridge piers. The system utilizes arrays of tilt sensors located on the pier and superstructure of a bridge to monitor long-term movements including tilt and vertical displacements (Figure 1). The system measures both changes in rotations (tilt) and vertical displacement of a pier, allowing for a more complete understanding of the behavior of the pier than is possible using currently available technologies. Following successful laboratory testing on a model pier, a fieldable system was developed and installed on an in-service bridge in upstate New York. Low-cost sensor arrays were installed on a central pier and on the superstructure of the bridge to evaluate tilt and vertical displacement of the pier over time. The online system is monitoring long-term motions of the pier and providing summarized, processed data over the web. The system results are being monitored to evaluate its performance and to assess the long-term displacements at the bridge. The system of sensors, data acquisition, and data processing algorithms comprise a commercial-ready product for monitoring bridge piers and other transportation structures. (NTIS Report# PB2011-105275).

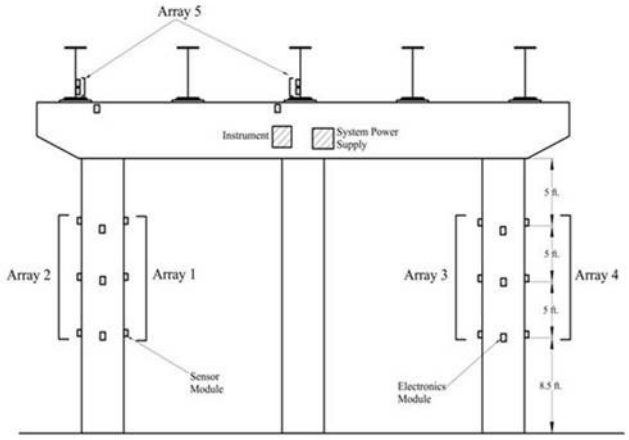


Figure 1

Schematic diagram of the tiltmeter system on a bridge in New York.

NOVEL OPTICAL FIBER SENSORS FOR MONITORING BRIDGE STRUCTURAL INTEGRITY

NCHRP-IDEA Project 124

Maria Feng [Tel.: (949) 378-8666, Fax: (949) 856-2082, Email: info@newportsensors.com]
Newport Sensors Inc., Irvine, California

This project developed a robust sensor system with high sensitivity based on novel integration of the moiré phenomena and fiber optics for monitoring bridge structural integrity. The system is easy to install and immune to electromagnetic interference and lightning strikes. With simple modification, the sensor can measure how a bridge responds to dynamic loads such as traffic acceleration, traffic displacement, and earthquakes. The measured structural vibration data then can be used to enhance the safety of highway bridges in real time by identifying structural damage and evaluating remaining capacity. The system's sensor head consisted of a pair of parallel grating panels, a pendulum, and two pairs of fibers with collimators (Figure 1). A special signal processing algorithm was developed to further broaden the dynamic bandwidth and enhance the measurement sensitivity of the accelerometer. A portable prototype multi-channel accelerometer system was also developed that included multiple sensor heads, a low-cost signal box (for sensor interrogation), and a PC (for signal processing). The system was tested in the laboratory and the field under a variety of dynamic excitations (including earthquakes). Two of the field tests were conducted at highway bridge sites under traffic excitations. The tests demonstrated superior performance of the new sensor system over its conventional electrical counterparts, including (1) total immunity to electromagnetic interference and lightning strikes, (2) high sensitivity and accuracy, (3) a large measuring range with particularly high performance in low frequencies, (4) a small sensor head with a lightweight optical fiber cable facilitating installation on long-span bridges, (5) robustness against environmental changes, and (6) a much lower cost than most optical fiber sensors. When integrated with the software system developed by the IDEA researchers, this sensor system can be easily installed on highway bridges for real-time structural health monitoring, post-event damage assessment, and capacity estimation. (NTIS Report # PB 2009-102139).

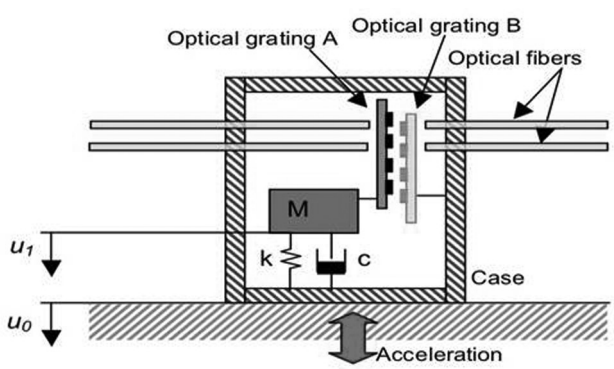


Figure 1

Design of fiber optic accelerometer.

AN AUTONOMOUS AND SELF-SUSTAINED SENSING SYSTEM TO MONITOR WATER QUALITY NEAR HIGHWAYS

NCHRP-IDEA Project 125

Xianming Shi [Tel.: (406) 994-6486, Fax: (406) 994-1697, Email: xianming_s@coe.montana.edu]
Western Transportation Institute, Bozeman, Montana

Monitoring water quality on a continuous basis is necessary for assessing the impact of highway runoff on bodies of water adjacent to highways. This project developed an autonomous and self-sustained sensing system for in-situ monitoring of environmental parameters (such as chloride, pH, dissolved oxygen, and temperature) in water bodies near highways (Figure 1). The system uses a novel microbial fuel cell (MFC) with a safe type of bacteria from the environment (*L. discophora*). After selecting sensors, communication devices, and a microcontroller and analyzing their voltage, current, and power requirements, an MFC was designed and tested under various conditions. Subsequently, an array of MFCs was built for preliminary testing, and improvements to the design of both the single MFC and the array of MFCs were made based on test results.

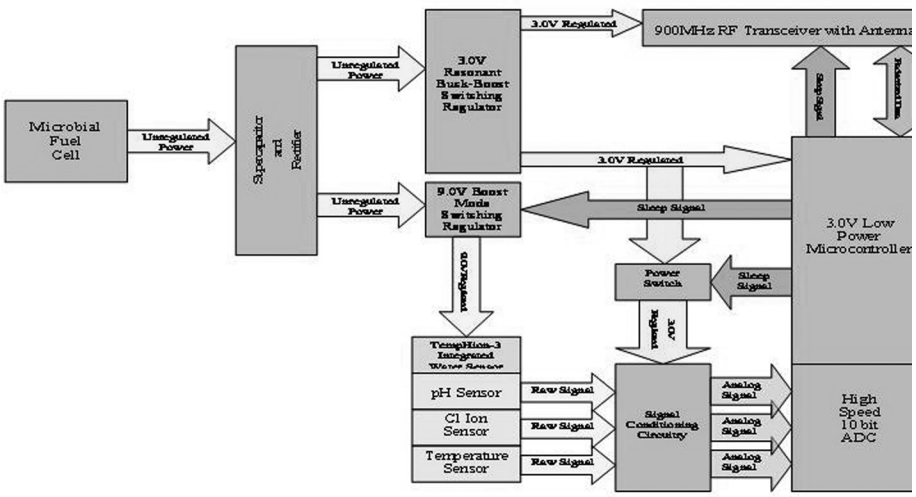


Figure 1

System block diagram

The system was tested in a local stream during varied weather conditions. The MFC array provided enough power to sustain circuitry function over a test period that included both temperature and sunlight fluctuations. The microcontroller successfully executed proper system functions based upon the measured output power of the MFC array. The data was transmitted on a 60 second interval over a period of several hours and was within acceptable tolerances for the chosen sensors. The system can save highway agencies time and labor by providing an efficient self-sustained tool to identify seasonal trends in real time for water quality parameters along highways, to assess the impact of various highway activities on water quality, and to evaluate the performance of various highway-runoff management practices over time. A patent for the technology was filed by Montana State University. (NTIS Report # PB 2010-112450).

DEVELOPING A TIME DOMAIN REFLECTOMETRY INSTRUMENT FOR FRESH CONCRETE AND EARLY-STAGE CONCRETE

NCHRP-IDEA Project 126

Xiong (Bill) Yu [Tel.: (216) 368-6247, Fax: (216) 368-5229, Email: xxy21@cwru.edu]
Case Western Reserve University, Cleveland, Ohio

This project developed a new instrument based on time domain reflectometry (TDR) for measuring properties of fresh and early-stage concrete as an alternative to traditional quality control methods that rely on slump value and compressive strength and do not always produce durable concrete. A prototype sensor system was designed (Figure 1) and tested on several concrete specimens used in highway construction. TDR signals were collected on concrete specimens subjected to different curing conditions, including early freezing, and the results were correlated with data obtained by standard test methods. The results indicated that the TDR sensor system could reliably measure or estimate concrete properties, such as free water content, density, air void content, initial and final setting times, and mechanical strength. New test results also showed promise of advancing this technology to estimate the thermal properties of concrete, such as the thermal conductivity and heat capacity. Experiments conducted on several soil types to verify the testing methodology provided promising results. The technology was found not only suitable to measure the physical and thermal properties of materials, but it also worked nondestructively under freeze-thaw cycles. Consequently, the system was refined to measure the thermal properties in nonintrusive fashion. The researchers received U.S. patents on the technology and on the flat strip design in addition to submitting several invention disclosures to the University. Durham Geo Slope Indicator, a manufacturer and distributor of engineering testing instruments, is interested in commercializing the developed TDR technology. (NTIS Report # PB 2010-112451).

(a) *(b)*

Figure 1

(a) TDR package for field use (courtesy Durham Geo Enterprises);
(b) Example of laboratory experiment.

INSTRUMENTATION TO AID IN STEEL BRIDGE FABRICATION

NCHRP-IDEA Project 127

Paul Fuchs [Tel.: (703) 737-3871, Fax: (703) 737-6381,
Email: paul.fuchs@fuchsconsultinginc.com] Fuchs Consulting Inc., Leesburg, Virginia

The goal of this project was to develop a complete laser measurement system that would eventually eliminate the shop assembly process of steel bridges and provide a complete permanent record of the as-built condition of each girder. This system is built around an established commercial laser scanner and can provide features not found using any other commercial instrument or collection of instruments. The system measures girders in a fabrication shop, produces documentation, and can provide data to virtually assemble girders (Figure 1). The project work began with testing the proposed laser-based system in laboratory conditions. A three-week testing program was successfully completed at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center (TFHRC). These tests helped prepare the laser system and develop measurement algorithms for testing at a steel bridge fabricator. The system was then tested at a steel bridge fabricator's facility in Lancaster, Pennsylvania, where it was used to measure a pair of straight girders for a bridge job for the Maryland State Highway Administration. Data was taken on separate girder sections, fit virtually together, and compared to CAD shop drawings. Other curved girders and more complex structural shapes were also measured. The testing demonstrated the laser system's ability to work in a typical bridge fabrication shop environment. Several improvements in measurement algorithms and system configurations were identified. The research team is collaborating with the steel bridge fabrication industry to promote implementation of the system. A pooled-fund study involving several state DOTs is being planned to evaluate and implement the IDEA product. The final report is available from the National Technical Information Service (NTIS # PB2009-109001).

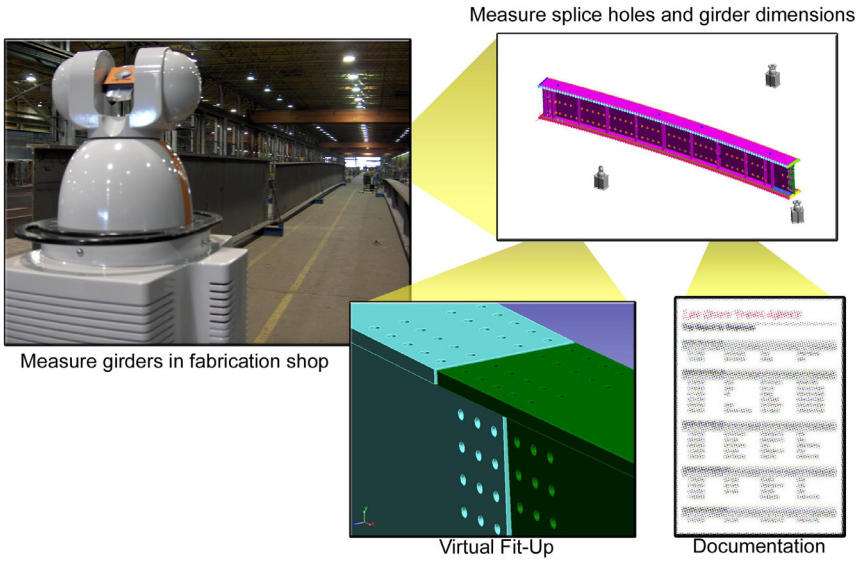


Figure 1

System concept for laser measurements of steel bridge girders.

UNDERWATER FIBER-REINFORCED POLYMER REPAIR OF CORRODING PILES INCORPORATING CATHODIC PROTECTION

NCHRP-IDEA Project 128

Rajan Sen [Tel.: (813) 974-5820, Fax: (813) 974-2957, Email: sen@eng.usf.edu]
University of South Florida, Tampa, Florida

Cathodic protection (CP) is a proven corrosion protection method for chloride-contaminated concrete; and the light weight, high strength, and corrosion resistance of fiber-reinforced polymer (FRP) make it the ideal repair material. This study incorporates CP within a bonded FRP repair to develop a new system that takes advantage of both technologies. This project developed and tested a hybrid FRP-CP system for the repair and corrosion protection of underwater piles. Initially, tests were performed on new systems that were developed to allow several partially submerged piles to be simultaneously pressure/vacuum bagged. Results from over 400 pullout tests showed that these new systems led to significant improvement in the FRP-concrete bond both above and below the waterline. Subsequently, the systems developed in the laboratory were implemented in the field. An embedded anode system was installed in four piles supporting the Friendship Trail Bridge in Tampa Bay in which the FRP wrap was pressure bagged (Figure 1). Preliminary results were found encouraging. However, several data loggers damaged by water intrusion were replaced and installed in a specially designed waterproof enclosure. Field monitoring of the CP system continues. The final report documents all data and developments of the FRP-CP system along with an assessment of the technology for implementation and commercialization. The capital costs for using pressure bagging systems and implementing embedded anodes are relatively small and are unlikely to be an important factor. (NTIS Report # PB 2010-112452).

Figure 1

Pressure bagging for enhancing FRP-concrete bond.

DEVELOPING AN EMBEDDED WIRELESS STRAIN/STRESS/ TEMPERATURE SENSORS PLATFORM FOR HIGHWAY APPLICATIONS

NCHRP-IDEA Project 129

Kun Lian [Tel.: (225) 578-9341, Fax: (225) 578-6954, Email: klian@lsu.edu]
Louisiana State University, Baton Rouge, Louisiana

Zhongjie "Doc" Zhang [Tel.: (225) 767-9162, Fax: (225) 767-9108, Email: zzhang@dotd.la.gov]
Louisiana Transportation Research Center, Baton Rouge, Louisiana

This project developed and tested a radiofrequency (RF) wireless embedded sensor platform for monitoring material responses to traffic flow, such as deformation, pressure, temperature and acceleration inside asphalt, soil, and concrete structures. A prototype platform was designed that consisted of three main modules: sensor system, measurement/control/RF transmission, and Faraday/piezoelectric power harvesting devices (Figure 1). The sensor components were calibrated with the sensor control/RF data acquisition boards developed in the project and the calibration of strain sensors for asphalt and concrete material deformation was completed using MTS 810. The sensor was tested against measurements from a standard asphalt extensometer (Model 3910). The results showed that the strain sensor was able to measure accurately the asphalt strain level as a function of loading profile. It measured strain changes that matched results obtained from the conventional methods. Furthermore, the developed strain sensors met the asphalt strain measurement requirements with rapid enough response time. Similar strain calibration tests were also performed for concrete. The results showed that the embedded sensor had the same strain response behavior as the extensometer, suggesting that these sensors could reveal the true deformation behavior of concrete material under dynamic loading conditions. Additional work is needed before the system can be implemented in the field. (NTIS Report #PB 2011-114171).

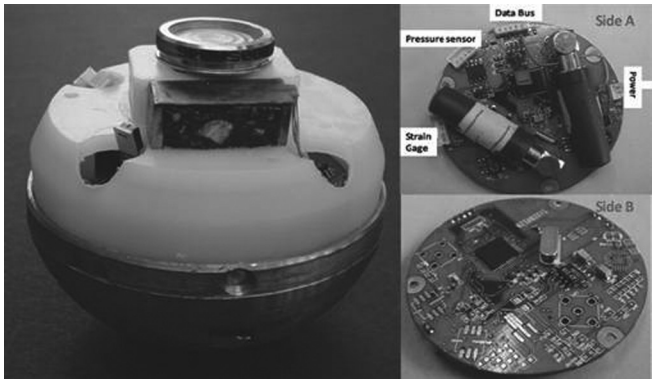


Figure 1

Prototype sensor platform with pressure, strain, acceleration, moisture, and temperature sensors integrated (left); the OEM RF control board (right).

RAPID, SELF-CONTAINED IN SITU PERMEAMETER FOR FIELD QC/QA OF PAVEMENT BASE/SUBBASE MATERIALS

NCHRP-IDEA Project 130

David J. White [Tel.: (515) 294-1463, Fax: (515) 294-8216,
Email: djwhite@iastate.edu] Iowa State University, Ames, Iowa

Recent studies show the coefficient of variation of in-situ permeability to be as high as 50 to 400 percent, making base/subbase permeability the most variable engineering parameter in the pavement system. This project developed an automated in situ permeability test (APT) based on a gas-pressurized system that takes less than 30 seconds per test location, allowing for statistical/spatial analysis of the results (Figure 1). Spatial maps of the in situ permeability can be used as field QC/QA criteria for pavement base/subbase to identify field problems such as segregation and particle degradation. Comparison permeability measurements demonstrated that the APT was within one order of magnitude of laboratory and another in-situ permeameter test device that use water. Measurements at test sites on US 63 in Iowa, I-94 in Michigan, and US 22 in Pennsylvania indicated strong correlations between APT measurements and fines content. The use of in situ permeability measurements will allow greater precision in the design, construction, and field QC/QA of pavement bases/subbases. It could also reduce over-design or improve long-term performance due to improved quality control of the drainage layer and, specifically, uniformity. Other applications of the device include measuring the permeability of pervious concrete materials and stabilizing open-graded drainage layers and hot-mix asphalt joints. (NTIS Report # PB2011-100029).

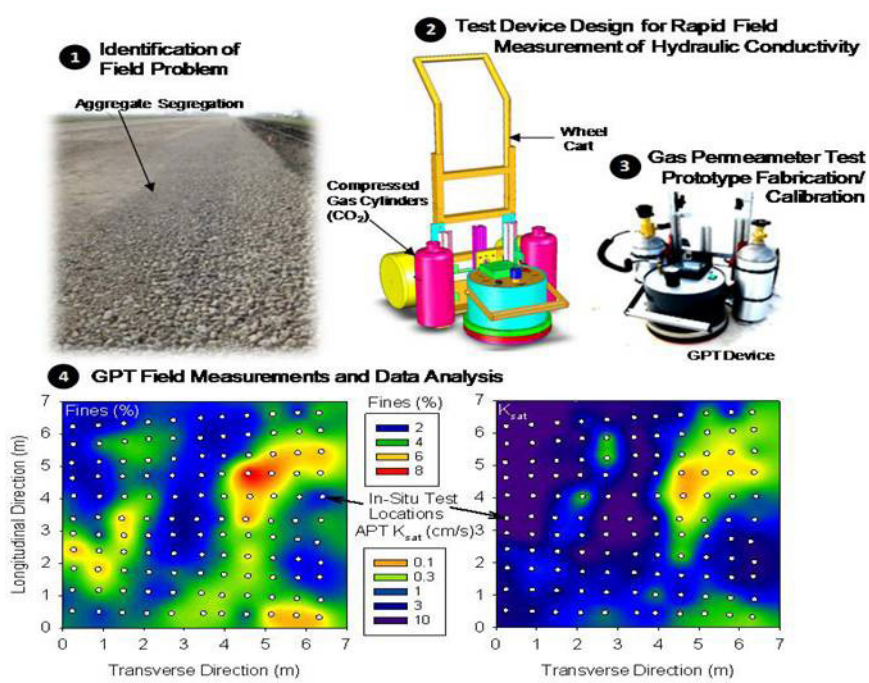


Figure 1

Primary steps involved in the development and validation of the gas permeameter test device.

SMART SENSOR FOR AUTONOMOUS NOISE MONITORING

NCHRP-IDEA Project 131

Douglas Meegan [Tel.: (303) 795-8106, Fax: (303) 795-8159, Email: dmeegan@ara.com]
Applied Research Associates Inc., Littleton, Colorado

This project developed a low-cost sensor system for autonomously monitoring and wirelessly reporting highway traffic noise data. The smart sensor for autonomous noise monitoring (SSAM) reports noise measurements periodically (for example, hourly, daily, or as desired) to a receiver located up to 1.2 miles away. The technology incorporates embedded processing software developed to provide capability to measure sound in averaging modes, apply frequency weightings, and compute octave band analyses consistent with ANSI standards for Type 1 ratings. The sensor enclosures are readily mounted to a simple post or tripod and wireless transmission ranges of more than 1 mile were demonstrated through controlled testing. Working with Ohio DOT, a total of 20 SSAM systems were tested. In field tests, 16 SSAM units operated simultaneously and transmitted noise data wirelessly. The field work included noise barrier testing for the Ohio DOT and wayside measurements (statistical pass-by) for California DOT. The developed prototype hardware was capable of performing low-cost noise monitoring at several locations simultaneously with wireless data transfer to a remote base station. The sensors are expected to cost less than $100 each (in large quantities), making them cost-effective to monitor many locations simultaneously (Figure 1). The SSAM is now available for demonstration or use in noise studies. (NTIS Report # PB 2010-115380).

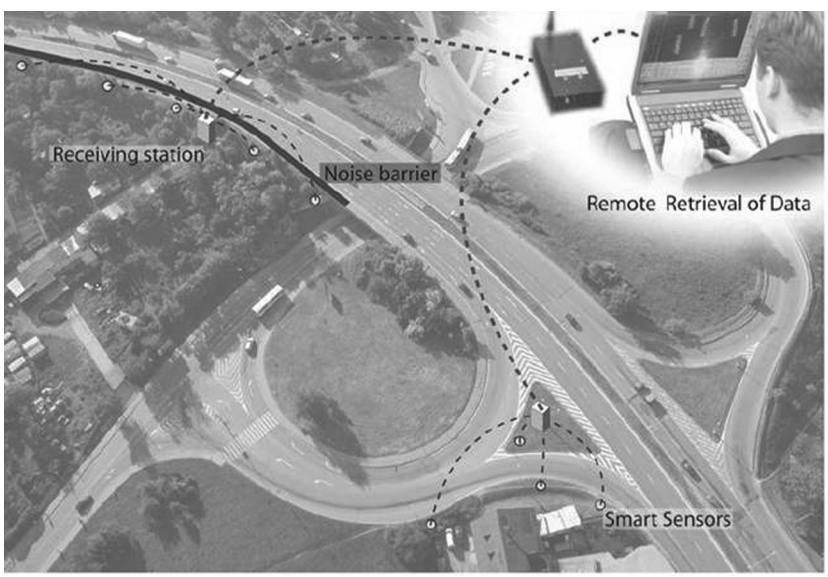


Figure 1

General concept of operation of a network of wireless smart sensors for autonomous noise monitoring.

VEHICLE-MOUNTED BRIDGE DECK SCANNER

NCHRP-IDEA Project 132

Yajai Tinkey and Larry D. Olson [Tel.: (303) 423-1212, Fax: (303) 423-6071, Email: yajai@olsonengineering.com] Olson Engineering Inc., Wheat Ridge, Colorado

This project developed a vehicle-mounted bridge deck scanner (BDS) system based on nondestructive evaluation (NDE) technologies for the rapid and quantitative internal evaluation of reinforced concrete bridge decks, using a combination of the impact echo (IE), automated acoustic sounding, spectral analysis of surface waves (SASW), and slab impulse response (SIR) methods. This research explored and implemented rolling contact and noncontact transducers used by all four test methods in the BDS. The final product was a vehicle-mounted prototype system with multiple rolling contact sensors and/or airborne noncontact transducers with different types of sources to perform IE, automated sounding, SASW, and SIR tests. The BDS system was easily attachable and detachable from any vehicle (e.g., from the ball on a truck hitch). Results from the four NDE test methods address different aspects of the internal conditions of concrete decks. Attaching the BDS system to a vehicle during scans expedites the field-testing process and allows near-continuous testing along the bridge deck by the BDS system. The prototype was tested in Wyoming on Douglas Bridge in Douglas and the bridge on First Street in Casper to determine bridge deck conditions along with other traditional evaluation methods, such as ground penetrating radar, impact echo (point by point) and infrared thermography, for comparison. The tests showed excellent results from the rolling IE component (the sensor and impactor wheel).The delamination map of the bridge deck obtained from the impact echo wheels and the chain drag results also showed good agreement. (NTIS Report # PB2011-100030).

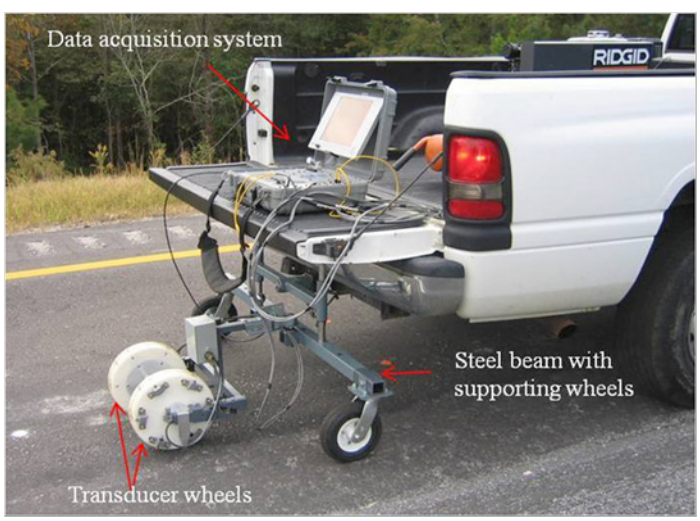


Figure 1

Bridge deck scanner (BDS) prototype.

DEVELOPMENT OF A SIMPLE TEST TO DETERMINE THE LOW-TEMPERATURE CREEP COMPLIANCE OF ASPHALT MIXTURES

NCHRP-IDEA Project 133

Mihai Marasteanu [Tel.: (612) 625-5558, Fax: (612) 626-7750, Email: maras002@umn.edu]
University of Minnesota, Minneapolis, Minnesota

Good fracture resistance is critical for asphalt pavements in cold regions where the predominant failure mode is low-temperature cracking. The current Superpave specifications for asphalt binders and mixtures address thermal cracking through the use of strength and creep tests. This IDEA project developed a simple bending creep test as a rapid, convenient, and versatile alternative to the tedious and time-consuming indirect tension test (IDT). The new test uses thin beams of asphalt mixtures and is performed on the bending beam rheometer (BBR) currently used as part of the asphalt binder performance grading specifications (Figure 1). A methodology for sample preparation and testing was developed. Thin mixture beams were cut using a simple tile saw. The loading protocol of the existing bending beam rheometer (BBR) device was modified to accommodate higher load levels. The simplest test method avoided testing at low temperature levels and predicted creep stiffness from data obtained at higher temperatures. The current AASHTO standard for IDT and the proposed BBR test method were followed to perform creep tests on laboratory prepared asphalt mixtures and cored field samples. The results indicated that IDT and BBR creep compliance are slightly different, but tests on homogenous polymer specimens showed no significant differences. Additional tests on asphalt mixture beams of different sizes gave similar creep stiffness results suggesting that the differences between IDT and BBR results are due to sample geometry effects and testing artifacts. Based on composite materials models and finite element method simulations, a back calculation procedure was developed to obtain asphalt binder creep compliance from mixture experimental data. Based on the IDEA work, a method for determining the flexural creep stiffness of asphalt mixtures using the bending beam rheometer was drafted for review by AASHTO. Utah and Minnesota DOTs have expressed interest in implementing the test method as part of their routine testing program. (NTIS Report # PB 2010-101388).

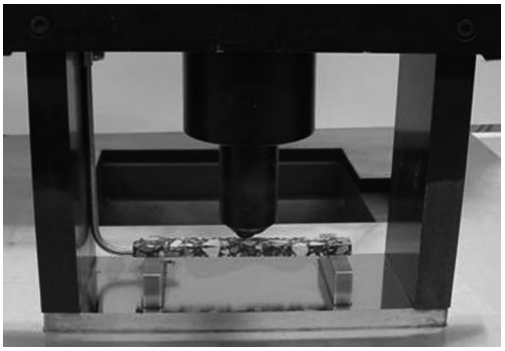


Figure 1

Bending Beam Rheometer (BBR) with thin asphalt mixture.

INVESTIGATION OF A FULL-LANE ACOUSTIC SCANNING METHOD FOR BRIDGE DECK NONDESTRUCTIVE EVALUATION

NCHRP-IDEA Project 134

John S. Popovics [Tel.: (217) 244-0843, Fax: (217) 265-8040,
Email: johnpop@illinois.edu] University of Illinois, Urbana-Champaign, Illinois

Alex Gibson [Tel.: (+61) 0437 159 774, Fax: (+61) 8 9467 9172,
Email: alex@chased.com.au] Chased Technologies Pty Ltd., Perth, Australia

Of the nearly 600,000 bridges in the United States, 27 percent were rated as structurally deficient or functionally obsolete in 2003. Timely renewal of service life is facilitated if rapid, accurate, and reliable nondestructive scanning technologies are applied to assess various transportation infrastructure components (such as bridge decks) with minimal disruption to structure service. This project developed an acoustic scanning method for nondestructive condition evaluation of bridge decks. The prototype included data acquisition and analysis hardware and noncontact sensors, and its design considered issues such as impact source type, trigger mechanism, background noise, rolling vibrations, spatial tracking and mapping, and self-contained power source, among others. The prototype was further optimized in terms of sensor type and source sensor configuration, and its performance was confirmed by preliminary experimental tests carried out on a controlled reinforced concrete slab that contained artificial delamination defects. Two sets of delaminations were cast at two different depths: approximately 1 in. and 2 in. in the test slabs. The delaminations varied in size to represent a wide range of delamination defects in terms of area, angle, and depth-to-size ratio. The delamination defects were simulated by a double-layer of polyethylene sheeting cut to appropriate size. Air-coupled impact-echo data collected across the test slab unambiguously and accurately identified the locations of all defects. Technical problems with the rolling impactor system were principally caused by the rough surface of the pavement site. This issue and the field robustness of the system need to be addressed before the system can be implemented in the field. (NTIS Final # PB2011-105276).

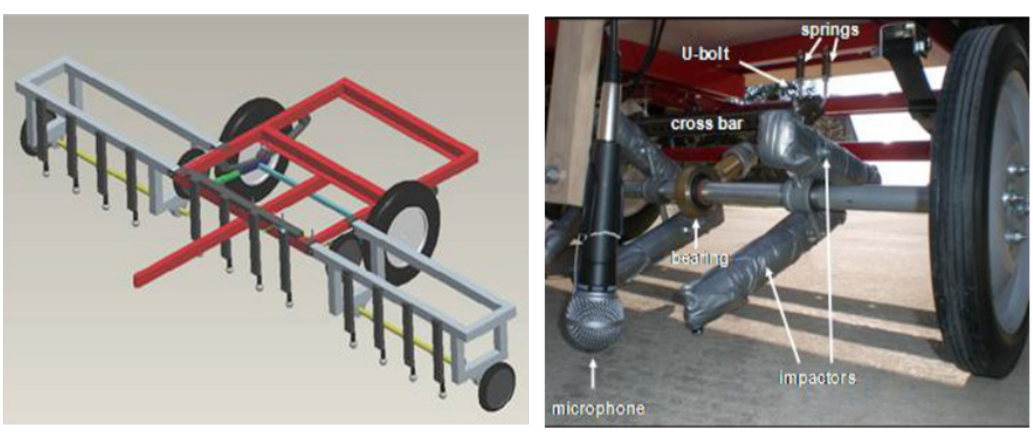


Figure 1

Area scan trailer prototype: concept of testing configuration (left) and photo showing detail of excitation axle and sensors (right).

ACTIVE CONFINEMENT OF BRIDGE PIERS USING SHAPE MEMORY ALLOYS

NCHRP-IDEA Project 135

Bassem Andrawes [Tel.: (217) 244-4178, Fax: (217) 265-8039,
Email: andrawes@illinois.edu] University of Illinois, Urbana-Champaign, Illinois

This project developed a system for the active confinement of reinforced concrete bridge piers using shape memory alloys (SMAs). A material testing program determined the stress-strain behavior of concrete cylinders actively confined with SMAs. Figure 1 illustrates the procedure for applying active confinement on bridge piers using SMAs and one of the SMA retrofitted columns that was tested in this project. The approach is expected to facilitate the application of active confinement and provide a more desirable retrofitting method, which would enhance the performance of reinforced concrete bridges during earthquakes. SMA spirals were evaluated for their thermo-mechanical characteristics and effectiveness in enhancing the concrete compressive strength and ductility. Recovery stress of the SMA wires and its stability at various ambient temperatures was also examined. The tests revealed a reliable behavior for the SMA wires, which were able to develop a recovery stress of 75 kip per square inch that was stable at room temperature. A series of concrete compression tests were conducted to compare the effectiveness of the SMA spirals with glass fiber-reinforced plastic (GFRP) wraps. Results showed that the SMA spirals increased the concrete ultimate strain (ductility) by 24 times as much as unconfined concrete. The behavior of the SMA-confined concrete was much superior to GFRP-confined concrete. In quasi-static lateral cyclic tests on reduced-scale reinforced concrete circular bridge columns, SMA spiral-wrapped columns were able to sustain 12 percent drift ratio with no significant signs of damage, while the GFRP wrapped column started experiencing major damage starting at 4 percent drift ratio. The new SMA spirals/wraps product could be easily installed and removed in bridges without the need for adhesive material between the columns and the spirals and with minimal labor and hardware. Using active confinement will increase the ductility capacity and shear strength of bridge piers and hence reduce the extent of damage sustained by the piers during strong earthquakes. This would make bridges more resilient to earthquakes and enhance their functionality after major seismic events. (NTIS Report # PB2011-105277).

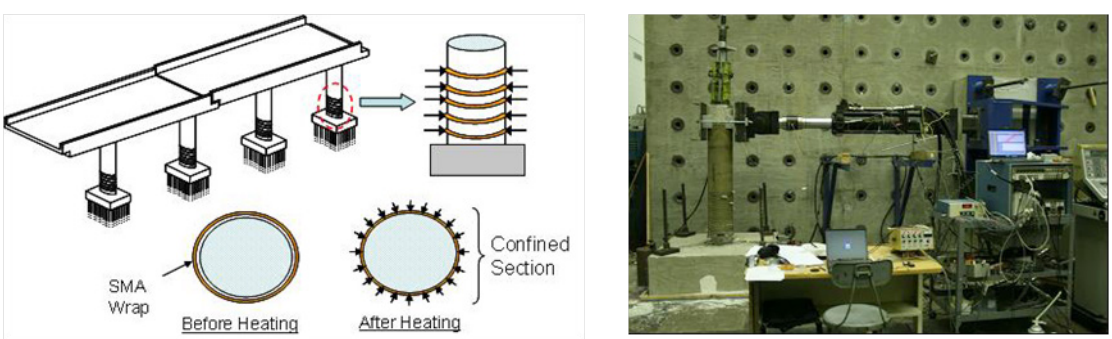


Figure 1

Schematic illustrating the concept of using SMA wraps for the retrofitting of bridge columns (left) and a picture of SMA wrapped concrete column during testing (right).

DEVELOPMENT OF A SECOND GENERATION NEUTRON-BASED DETECTOR FOR CHLORIDE IN CONCRETE

NCHRP-IDEA Project 136

Mohamad Al-Sheikhly [Tel.: (301) 405-5214, Fax: (301) 314-2029;
Email: mohamad@umd.edu] University of Maryland, College Park, Maryland

The project was undertaken to develop and test a neutron-based detector system for detecting and measuring chloride in in-service concrete (Figure 1). The nondestructive test method is based on prompt gamma neutron activation (PGNA). Neutrons from a portable source are used to irradiate the concrete structure. The neutrons are captured by atoms in the material, and in this process gamma rays are emitted with characteristic energies. The gamma rays travel out of the concrete and are then counted by detectors. The size of each gamma ray peak in the spectrum is proportional to the concentration of the element in the concrete. The original work plan involved three stages: 1. Numerical modeling and simulations to optimize the design of the system; 2. Instrument assembly and calibration in the laboratory on test specimens with known chloride concentrations; and 3. Field testing on actual concrete bridges. Work on the design calculations (Stage 1) was satisfactorily completed. This consisted of specifying the dimensions of the planar gamma ray detector, selecting the type of neutron generator, and modeling the moderator using the Monte Carlo N-Particle (MCNP) software. However, a major obstacle to the completion of Stages 2 and 3 was the lack of a thermal neutron source in the timeframe of this project. The nuclear reactors at the University of Maryland and at the National Institute of Standards and Technology (NIST) were not operable. Consequently, most of the work proposed in Stage 2 of the original work plan, which involved calibration of the system in the laboratory, could not be accomplished. Still, some experimental investigations were carried out using radio-isotope gamma ray sources, which confirmed the principle of electronic collimation and verified the improved directionality of the system. In addition, experiments using the cold neutron PGNA station at NIST provided data that can be used to estimate the performance of a portable field PGNA system. A number of state departments of transportation have expressed interest in using the PGNA system when it becomes available. Current plans are to continue the research on laboratory testing of the system using the portable neutron generator at NIST.

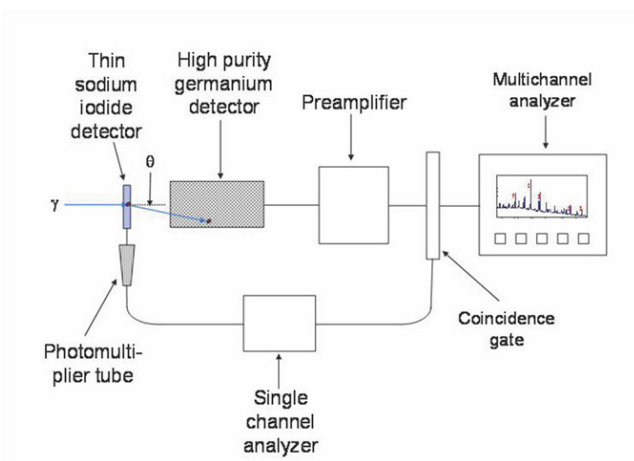


Figure 1

Schematic diagram of the HPGe gamma-ray detector in the electronic collimation configuration.

REAL-TIME REMOTE EVALUATION OF POST-EVENT RESIDUAL CAPACITY OF HIGHWAY BRIDGES

NCHRP-IDEA Project 137

Maria Feng [Tel.: (949) 378-8666, Fax: (949) 856-2082, Email: info@newportsensors.com]
Newport Sensors Inc., Irvine, California

Lack of rapid information about the post-event structural integrity of bridges can cause safety hazards to the traveling public, halt mobility of the transportation network, and disrupt emergency response. The current practice relies mainly on visual inspection for damage detection, which is time consuming and requires physical presence of inspection crews on a structure that is potentially hazardous after events such as earthquakes, hurricanes, and terrorist attacks. This project developed and demonstrated the application of a baseline-free monitoring methodology for real-time assessment of post-event integrity and safety of highway bridges. The method is illustrated in Figure 1. Four different methods were developed for post-event bridge structural damage assessment based on vibration responses measured during the event and structural stiffness and damping identification and validated through seismic shaking table tests of a large multi-span concrete bridge model. One of the methods was based on nonlinear damping and the others on structural stiffness identification. The damping method performs quick damage screening. If damage is detected, a more detailed assessment is carried out based on structural stiffness analysis, which identifies damage locations and extents. Based on measured bridge dynamic responses, changes in structural stiffness were identified and the occurrence, locations, and extents of structural damage assessed. These damage assessment results were used to develop a method to estimate the post-event remaining capacity of a bridge. The identified post-event structural stiffness was used to update the structural model for push-over analysis to allow determination of the remaining capacity of the bridge. The methods for post-event damage assessment and capacity estimation were packaged into efficient computer algorithms and into an exploratory software package named "Bridge Doctor." The software was integrated with an instrumented test bed bridge in California for long-term performance evaluation and demonstration. The software is capable of rapid damage screening, detailed damage assessment, and remaining capacity estimation, and it can serve as a useful tool to assist decision making in post-event bridge operations and repair/retrofit. (NTIS Report # PB2011-105278).

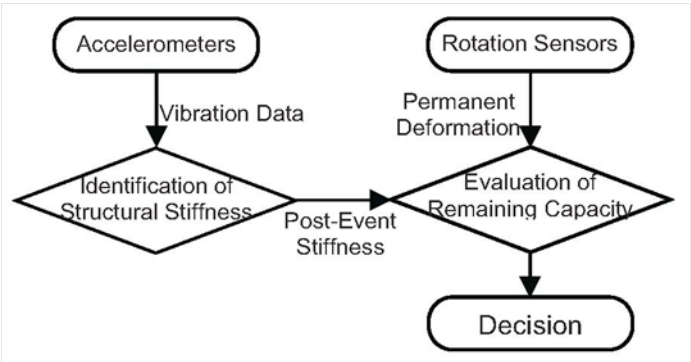


Figure 1

Proposed damage assessment and capacity estimation method.

SCANNING CAPACITIVE ARRAYS FOR REAL-TIME, IN-SITU IMAGING OF DENSITY AND THICKNESS IN HMA ROADWAYS

NCHRP-IDEA Project 138

Yanko Sheiretov [Tel: (781) 642-9666 Fax: (781) 642-7525 E-mail: jentek@shore.net]
JENTEK Sensors, Inc., Waltham, Massachusetts

Hot-mix asphalt (HMA) density is one of the best predictors of pavement quality and durability. The goal of this project was to develop a method for measuring HMA density via an array of sensors capable of rapidly inspecting large areas (Figure 1). Research performed in the project demonstrated desired measurements with a working prototype. The prototype sensor was designed to be one element of the multiple-element sensor array. It was about 2.5 inches high, had an active element length of 12 inches, and was equipped with wheels. The active area of the sensor included electrodes for generating the electric field (drive electrodes) and four sets of sensing electrodes, sensitive to material properties at varying depths (patents issued and pending). In the demonstration, this prototype sensor was used to scan four 1.5 inch thick lab-produced Superpave HMA-lift specimens (two at about 86% density and two at about 91% density). Data from two sensing electrodes acquired at 10 MHz were used to estimate the effective dielectric permittivity of the HMA specimens, using Jentek multivariate inverse methods. The estimated permittivity exhibited strong correlation with the HMA density, and the measurements were repeatable. The prototype sensor is designed to be a part of a 19-sensor array—enabling rapid, wide, detailed, full coverage of a 10-foot-wide scan path. Jentek's parallel-architecture 39-channel instrument can simultaneously acquire single-frequency data from all sensors in the array at a rate higher than 100 measurements per second. Additional work is needed to transition this prototype to a commercial product. (NTIS Report # PB 2010-112453).

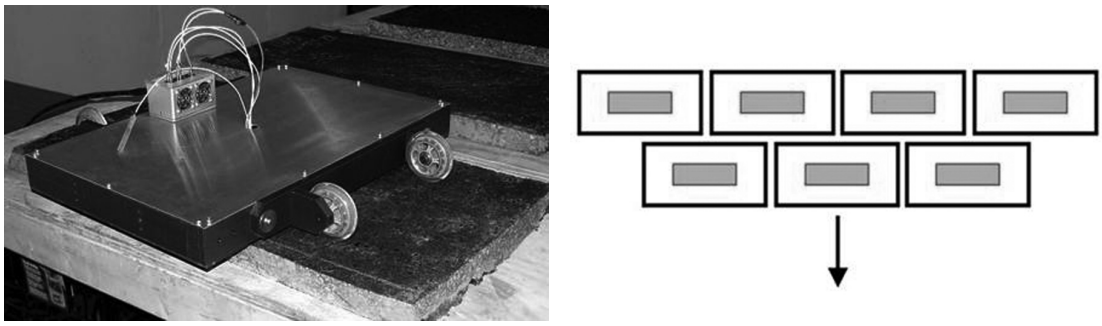


Figure 1

Prototype rolling capacitive HMA density sensor atop an HMA slab (left) and schematic of seven such sensors in a staggered array designed to be rolled down a roadway to generate a rapid image (right).

DEVELOPMENT OF A SENSING METHOLOGY FOR INTELLIGENT AND RELIABLE WORK-ZONE HAZARD AWARENESS

NCHRP-IDEA Project 139

Yichang (James) Tsai [Tel.: (912) 963-6977, Email: james.tsai@ce.gatech.edu]
Georgia Institute of Technology, Atlanta, Georgia

The project developed a vision-based sensing methodology that has two features: (1) It can detect a vehicle intruding into work-zone areas and provide early warning to improve safety of workers; and (2) it can detect missing work-zone channelization traffic control devices (e.g., cones) to ensure the safety of drivers and workers, and to prevent lawsuits against state departments of transportation. The objective was to maximize the detection of potential work-zone hazards without excessively triggering false alarms. Figure 1 shows how a protection zone with the proposed awareness system could be established by using an intelligent vision and sensing system. The system could be located behind the barrel taper or along the shoulder.

The system was developed in four steps. In the first step, a reliable vehicle detection, recognition, and tracking algorithm was developed. This algorithm provided accurate computation for minimizing false negative and false positive rates. In the second step, a vehicle trajectory and intrusion likelihood (e.g., safe, cautious, and dangerous) analysis algorithm was developed to track all approaching vehicles and their intrusion likelihood. In the third step, a work-zone hazard decision-support model was established, based on the vehicle intrusion likelihood for each approaching vehicle to determine the adequate timing to trigger an alarm. In the final step, a surveillance system, including a 30-ft surveillance tower and cameras, was developed and successfully tested on an actual pavement resurfacing work zone on I-95 near Savannah, Georgia. The final report is available from the National Technical Information Service (NTIS Report # PB2012-110781).

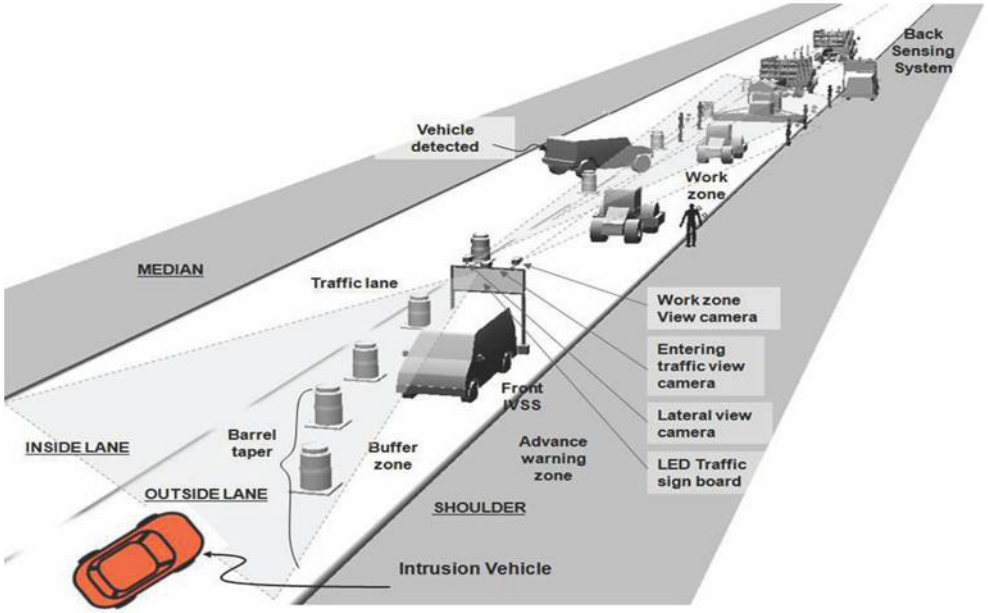


Figure 1

Intelligent vision and sensing system to detect hazard conditions in the work zone.

COMPUTER VISION TRAFFIC SENSOR FOR FIXED AND PAN-TILT-ZOOM CAMERAS

NCHRP-IDEA Project 140

Stan Birchfield [Tel.: (864) 656-5912, Fax: (864) 656-5910, Email: stb@clemson.edu]

Wayne Sarasua [Tel.: (864) 656-3318, Fax: (864) 656-2670, Email: sarasua@clemson.edu]
Clemson University, Clemson, South Carolina

This project developed and tested a next generation vision-based traffic sensor to collect traffic parameters such as volume, classification, and speed using both fixed and pan-tilt-zoom (PTZ) cameras. Figure 1 shows the system's versatility in a variety of camera configurations, road characteristics, lighting conditions, and weather conditions. The developed sensor is quick and easy to calibrate using just six clicks in the image. The sensor also has the ability to dynamically recalibrate itself when the camera undergoes PTZ changes. Two prototype sensors were tested at two locations (Maryland and New York) for more than 15 months. The sensor's accuracy in terms of vehicle count was comparable under various traffic, weather, and lighting conditions and often slightly better that that of the loop detectors present at the corresponding sites. The improvement was particularly noticeable in congested traffic conditions encountered at the New York test site. The project also helped make significant progress toward developing a Traffic Management Center solution using existing pan-tilt-zoom cameras. The architecture of the software was redesigned to enable the processing of multiple (up to 32) videostreams simultaneously on a single server. An automatic calibration algorithm to handle user pan and tilt was developed to further augment the system. A patent for the developed sensor technology has been filed, and the IDEA product has been commercialized with involvement of a local software company. (NTIS Report # PB2011-100031).

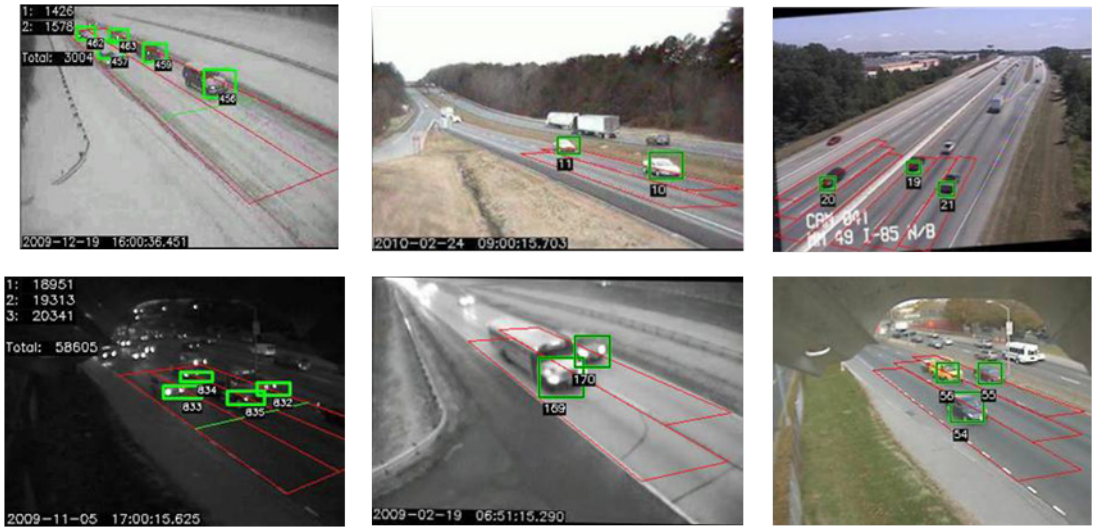


Figure 1

Detection and tracking of vehicles in a variety of scenarios, demonstrating the versatility of the system.

REDUCING FATIGUE IN WIND-EXCITED TRAFFIC SIGNAL SUPPORT STRUCTURES USING SMART DAMPING TECHNOLOGIES

NCHRP-IDEA Project 141

Richard Christenson [Tel.: (860) 486-2270, Fax: (860) 486-2298,
Email: rchriste@engr.uconn.edu] University of Connecticut, Storrs, Connecticut

This project developed a vibration absorbing system to reduce fatigue in traffic signal support structures exposed to excessive wind-induced vibration. A prototype smart vibration absorber was designed for installation onto a full-scale traffic signal support structure in the laboratory (Figure 1) and free and forced vibration tests were conducted. Three different damper types were tested including a magneto-rheological (MR) fluid damper, an air damper, and a permanent magnet damper. The final prototype design used the permanent magnet damper because of the linear viscous damping achieved and simplified mechanics of the device. The prototype was evaluated by measuring damping level in the structure from free vibration response and measured steady state accelerations from forced vibration tests. Damping in the traffic signal support structure increased from 0.1% to 10.1%, reducing free vibration time for the response to attenuate from over 5 minutes to just under 5 seconds. The system is expected to significantly reduce the wind-induced vibrations of traffic signal support structures, thereby reducing fatigue and increasing the safe life of the structure. For signal support owners, this means that fewer resources will need to be committed to replacing and repairing fatigued signal support structures. The retrofit would be applied to only those signal structures that exhibit vibration problems in the field, thus making the application and use of resources more efficient. The vibration absorber is relatively cheap, easy to install, and would provide savings in the form of increased life of the structure and supplemental information for signal support inspection. The monitoring capabilities would supplement visual inspections. Connecticut DOT's Technology Transfer Center will help in implementing the IDEA technology. (NTIS # PB2011-113455)

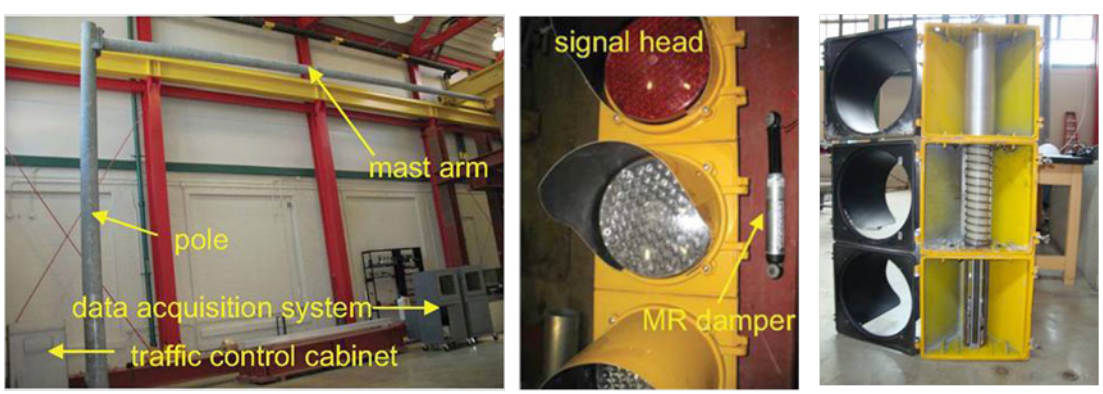


Figure 1

Traffic signal mast arm and pole in structures laboratory and signal head vibration absorber.

A SHAPE MEMORY POLYMER-BASED SELF-HEALING SEALANT FOR EXPANSION JOINTS

NCHRP-IDEA Project 142

Guoqiang Li [Tel.: (225) 578-5302, Fax: (225) 578-5924, Email: guoli@me.lsu.edu]
Louisiana State University, Baton Rouge, Louisiana

This project developed a shape memory polymer-based sealant for expansion joints in pavements and bridges that can help prevent adhesive and cohesive failures through a self-healing mechanism, thereby minimizing the need for replacing sealant. The proposed sealant was fabricated by dispersing glass microballoons into a thermosetting shape memory polymer. Through a programming or educating process, the foam sealant can be tailored to self-seal both adhesive and cohesive damage by a confined shape recovery process. Laboratory testing showed that shape memory polymer, after 2-D programming, can prevent the accumulation of excessive compressive stress in compression-sealed sealant and prevent sealant from being squeezed from a channel when concrete walls expand during the summer. Figure 1 shows the shape recovery process of the sealant after the 2-D programming. The tests also showed that the sealant had sufficient strength and stiffness under simulated traffic loading, thermal stress, and cyclic loading. The sealant was found to be functionally stable (i.e., maintaining its shape memory functionality when subjected to various combinations of environmental attacks) and showed negative Poisson's ratio at normal working temperature, which facilitates integrity of the sealant. The research also showed that the one-step 2-D programming can be replaced by a two-step 1-D programming and that thermosetting shape memory polymer can be cold-compression programmed. These findings lay a foundation for implementation of the smart sealant in practice. Shape memory polymer-based sealant was fabricated, programmed, and installed in two joints on a concrete pavement. Monitoring of the sealant's performance has continued beyond the IDEA project by the Louisiana Department of Transportation and Development. Extensive field testing is needed before the technology can be implemented in the field in actual highway environment. The final report is available from the National Technical Information Service (NTIS # PB2013-100223).

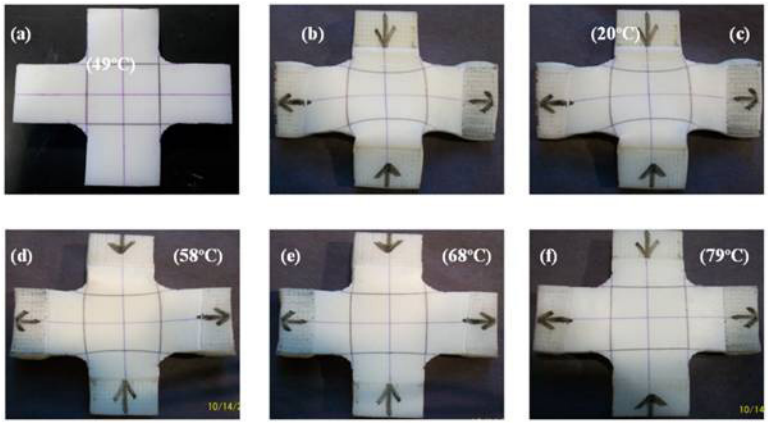


Figure 1

(a) Original and (b) programmed cruciform foam sealant specimen; and (c-f) its recovery process under various temperatures.

THE GUAYULE PLANT: A RENEWABLE, DOMESTIC SOURCE OF BINDER MATERIALS FOR FLEXIBLE PAVEMENT MIXTURES

NCHRP-IDEA Project 143

David N. Richardson [Tel.: (573) 341-4487, Fax: (573) 341-4729, Email: richardd@mst.edu]

Mike Lusher [Tel.: (573) 341-4457, Fax: (573) 341-4729, Email: smlush@mst.edu]
Missouri University of Science and Technology, Rolla, Missouri

This project explored the feasibility of using materials derived from the guayule (pronounced 'why-YOO-lee') plant in flexible pavement mixtures (FPMs). From several guayule-based materials, the most viable recycling (softening) agent in high-reclaimed asphalt pavement (RAP)/reclaimed asphalt shingles (RAS) content FPMs was an acetone-extractable resin that is present as a residue in the commercially produced, bulk guayule rubber. Binder-blends were evaluated for temperature-dependent stiffness parameters with different proportions of reclaimed RAP and RAS, and a virgin binder—either a petroleum-based recycling agent (CyclogenL or CycL) or the guayule rubber resin (RR). Tests showed that the RR-RAP/RAS blends performed similarly to the CycL-RAP/RAS blends in terms of high-temperature stiffness although slightly less effective in cold-temperature cracking resistance. The blend met all PG64-22 specifications, except mass change. For final testing, a high-reclaimed-binder-content FPM was designed according to Missouri DOT specifications. This FPM utilized only 5.5% (by weight) virgin petroleum-based binder and contained either the RR or the CycL. The results of Hamburg wheel-track testing on these two FPMs showed that the RR-based FPM performed as well as the CycL-based FPM in terms of rutting and stripping or moisture-susceptibility resistance. The results show that the RR can be used as a recycling agent in FPMs with high contents of RAP and/or RAS. The final report is available from the National Technical Information Service (NTIS # PB2013-104859).

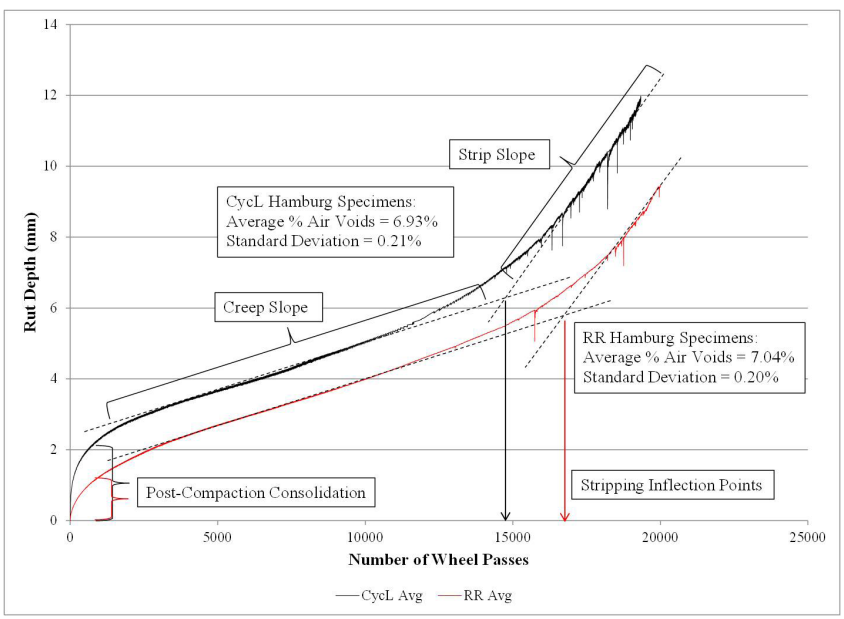


Figure 1

Hamburg Test: Rubber resin (RR) vs. Cyclogen L (CycL) flexible pavement mixture.

AN ACOUSTIC EMISSION-BASED TEST TO DETERMINE ASPHALT BINDER AND MIXTURE EMBRITTLEMENT TEMPERATURE

NCHRP-IDEA Project 144

William G. Buttlar [Tel.: (217) 333-5966, Fax: (217) 333-1924, Email: buttlar@illinois.edu]

Henrique M. Reis [Tel.: (217) 333-1228, Fax: (217) 244-5705, Email: h-reis@illinois.edu]

Behzad Behnia [Tel: (217) 721-4842, Email: bbehnia2@illinois.edu] University of Illinois, Urbana-Champaign, Illinois

This project developed an acoustic emission-based test method for characterizing the embrittlement temperature of asphalt binders and mixtures. An acoustic emission-based measurement system complete with signal processing and data analysis algorithms, along with a compact and low maintenance thermoelectric-based cooling device, was developed. Test results on asphalt concrete mixtures were very promising; microcracking of the asphalt mastic was easily detectable with the new method and highly correlated to binder test results. Figure 1 schematically shows the asphalt binder sample bonded to the granite substrate during the test. Testing of samples from the MnRoad Program also showed a good correlation between acoustic emission-based mixture embrittlement temperature and low temperature binder grade mixture fracture energy obtained from the Disk-shaped Compact Tension test, and field performance. The developed acoustic emission system was also successfully used to detect the presence and the effect of recycled asphalt pavement in asphalt mixtures. Further validation of the new testing system with field specimens was completed, including specimens obtained from the Asphalt Institute (airfield pavement durability study) and Michigan Technological University. Strong correlations between the results of acoustic emission tests and industry standard low temperature binder tests were obtained. The researcher is working with a local company, TE Technologies, Inc., to commercialize the IDEA product. The product is expected to yield significant payoff for both up-stream and down-stream suppliers and producers for material formulation, material compatibility assessment, mix design, assessment of warm-mix designs, quality assurance of binders and mixtures, optimization of mixtures using recycled asphalt pavement and assessment of pavement condition and scheduling of preventive maintenance and rehabilitation treatments. (NTIS Report # PB2012-104699).

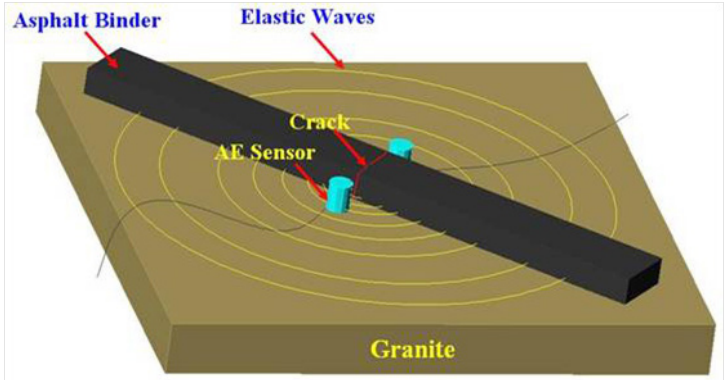


Figure 1

Schematic representation of AE asphalt binder sample during the test.

EXTRACTION OF LAYER PROPERTIES FROM INTELLIGENT COMPACTION DATA

NCHRP-IDEA Project 145

Mike Mooney [Tel.: (303) 384-2498, Fax: (303) 273-3602, Email: mooney@mines.edu]
Colorado School of Mines, Golden, Colorado

This project developed a methodology to extract layer elastic modulus/stiffness from composite soil stiffness and GPS-based position provided by currently available vibratory intelligent compaction (IC) rollers. The developed methodology combines two key components that were advanced in this investigation, namely, forward modeling and inverse analysis. Forward modeling efforts focused on finite element and boundary element method techniques to predict roller-measured composite stiffness values for ranges of layer elastic moduli and layer thickness expected in practice. Inverse analysis or back-calculation works in reverse and provides an estimate of individual layer elastic modulus using IC data. The investigation demonstrated that layered elastic modulus can be estimated from IC data over a wide range of layered earthwork configurations (layer thickness and ratio of layer moduli). The methodology can be implemented via software algorithms that can be integrated into any commercially available IC software offered by roller manufacturers, consultants, and third-party vendors (e.g., navigation system providers). The implementation of this latter approach could be performed by any interested party. The generated methodology is generic and can be applied to any currently available proprietary measures of ground stiffness from vibratory rollers. The final report is available from the National Technical Information Service (NTIS # PB2013-108441).

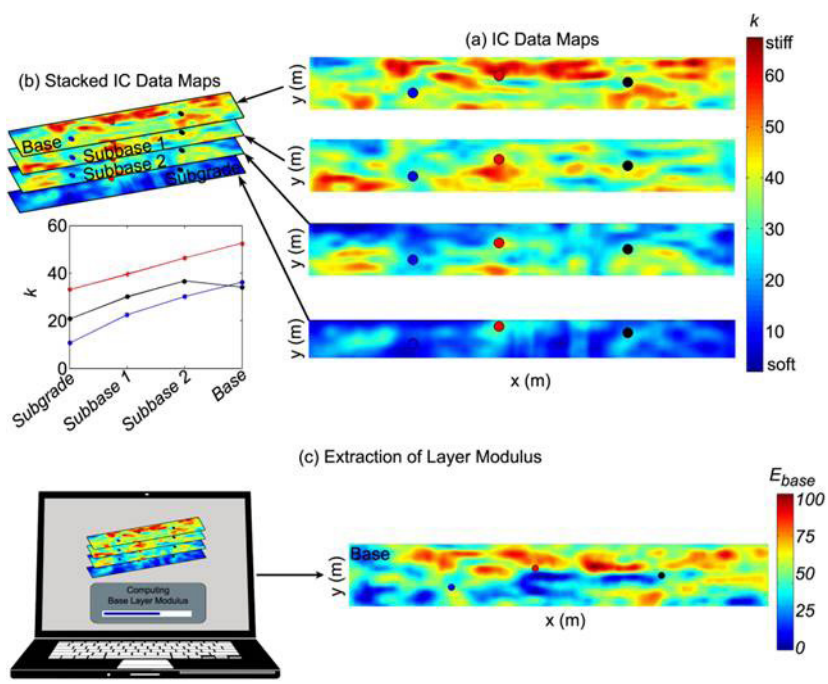


Figure 1

Conceptual illustration of the proposed process: extracting layer moduli from composite stiffness measured during construction of a pavement support structure.

ADVANCED METHODS FOR MOBILE RETROREFLECTIVITY MEASUREMENT ON PAVEMENT MARKING

NCHRP-IDEA Project 146

Terry Lee [Tel.: (603) 369-2785, Fax: (303) 600-4121, Email: leetronvision@gmail.com]
Leetronvision, Concord, New Hampshire

This project developed a prototype mobile unit for a rapid and reliable measurement of pavement marking retroreflectivity. The unit consisted of a retroreflectivity measurement system, tracking system, geometry measurement system, neural network system, and speed simulator system. The unit's repeatability of the measurement on a sample strip at simulated highway speeds was satisfactory, and tests showed close correlation between hand-held and mobile units under stationary conditions (Figure 1). Road tests indicated that the results are repeatable (Figure 2). After additional refinements were implemented on the tracking system, road test results achieved a repeatability error under 1.5%. Because of the success of the prototype, more engineering and financial resources are being applied toward commercializing the system. A beta production version of the system has been designed and built. Currently, the system is in the testing and refinement phase. The final report is available from the National Technical Information Service (NTIS # PB2012-110782).

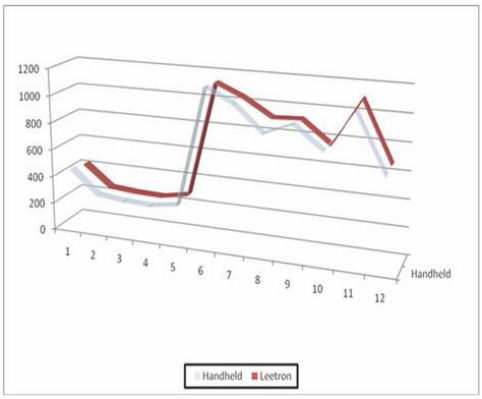


Figure 1

Measurement comparison between handheld unit and Leetron unit on 12 sample marking strips.

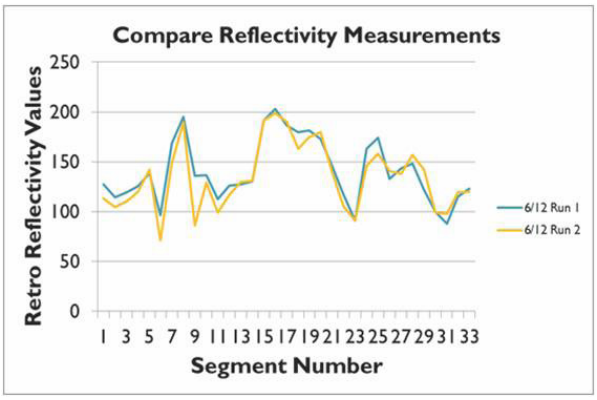


Figure 2

Repeatable road test at 60 mph.

SHAPE MEMORY ALLOY ENHANCED SMART BRIDGE EXPANSION JOINTS

NCHRP-IDEA Project 147

Jamie E. Padgett [Tel.: (713) 348-2325, Email: jp7@rice.edu] Rice University, Houston, Texas

Reginald DesRoches, Georgia Institute of Technology, Atlanta, Georgia

This project provides a new type of bridge expansion joint, referred to as a SMART joint using shape memory alloys (SMAs), that can accommodate not only service loads but also larger displacement demands required during extreme events like earthquakes. The system offers an intermediate alternative between commonly installed service level expansion joints and dedicated seismic expansion joints that generally add to costs and complexity. The SMART expansion joint integrates nickel titanium SMAs to modify a commonly installed modular bridge expansion joint. Through strategic placement within the bridge joint, advantageous and unique SMA behaviors are introduced into the expansion system, such as recentering and energy dissipating characteristics (improving seismic behavior) and corrosion resistance (alleviating joint maintenance costs). A full-scale SMART expansion joint prototype was developed and tested (Figure 1). Through limited alteration of the existing joint configuration, upfront costs are minimized (less than 15% increase over a basic service level joint).

The validity and benefits of this new expansion joint system were evaluated through a systematic research program including component and full-scale joint experimental testing, analytical modeling of the joint, reliability assessment of the joint within a bridge system, and subsequent life-cycle cost-benefit analyses. The SMART joint design preserves existing desirable service load behavior of the joint, but can accommodate significant increases in longitudinal displacement capacity under dynamic loads, while limiting internal load transfer that would otherwise lead to failure of joint components. These improvements translate into reduced joint repair and replacement costs and improved post-event functionality of bridges, offering systems that are capable of accommodating traffic passage after a hazard event. Furthermore, advanced performance and functionality were afforded without changing the field construction requirements in order to provide easy transfer of the technology. The minimal increase in cost makes the SMART joint a cost-effective solution even in regions of moderate seismicity, given the significant reduction in joint failure probability across a range of hazard levels. The coupled reduction of expected life-cycle costs and preservation of current field construction requirements eases future transfer of the smart joint technology into practice (NTIS Repot # PB2014-100623).

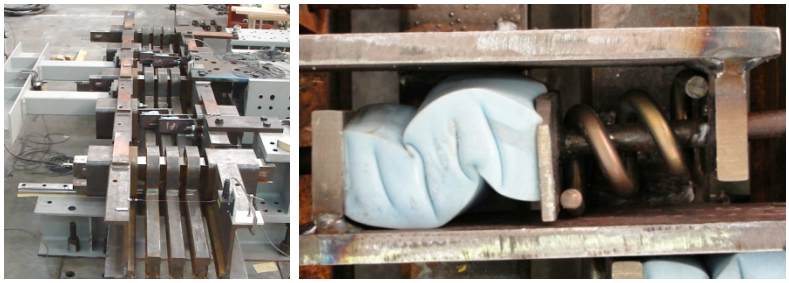


Figure 1

SMART expansion joint and close up of expansion system incorporating SMA spring.

CLEANING DEVICE TO REMOVE DEBRIS AND CHEMICALS FOR CRACK/JOINT SEALING

NCHRP-IDEA Project 148

Yong Cho [Tel.: (402) 554-3277, Fax: (402) 554-3850, Email: ycho2@unl.edu]
University of Nebraska, Lincoln, Nebraska

Debris and foreign materials left in a crack (resulting from sawing, routing, or pavement use) contaminate the sealing or filling material and reduce cohesion. Deicing chemicals left in cracks during winter present an especially critical problem related to early failure of sealed cracks. To avoid these contamination-related failures, cracks must be cleaned prior to being treated. This project developed a low-cost and effective mechanical tool to prepare random cracks and joints for sealing (Figure 1). The system incorporates two traditional crack cleaning methods (wire brushing and air blasting) into one device. The device uses a pneumatically driven rotary wire brush to clean cracks of mid- to large-sized debris and vegetation. Directly behind the rotary brush, variable direction air blasting nozzles are used to further expel fine grained particulate like concrete dust, fine sand, and—most importantly—winter deicing chemicals from the walls and surfaces of the pavement cracks. The prototype was evaluated in the laboratory for mechanical durability, brush effectiveness, air blast effectiveness, ergonomics, and equipment adaptability. Following necessary improvements, the prototype was further tested in the field at two highway crack sealing sites in collaboration with the Nebraska Department of Roads. The device was also successfully demonstrated to the City of Omaha street maintenance group in Nebraska. A pavement repair equipment company, Crafco, Inc., has expressed interest in further development of the device and in its commercialization. (NTIS Report # PB2011-114172).

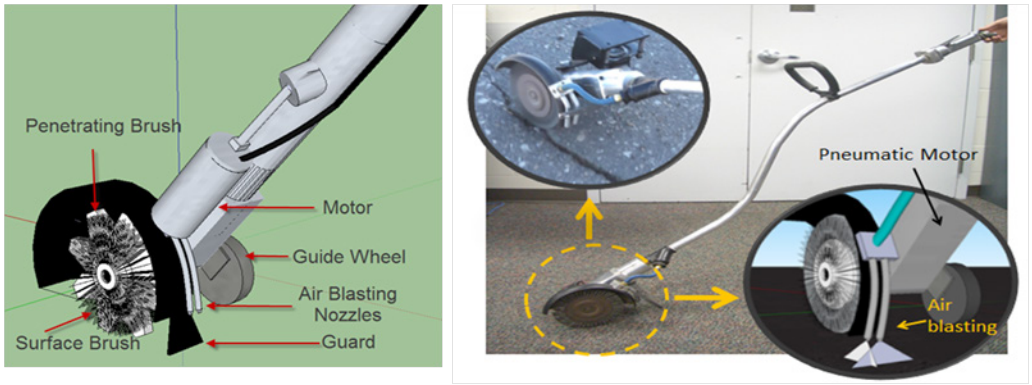


Figure 1

Crack cleaning device concept and product.

USE OF ENERGY-ABSORBING BREAKAWAY POSTS FOR W-BEAM GUARDRAILS IN FROZEN SOIL CONDITIONS

NCHRP-IDEA Project 149

King Mak [Tel./Fax: (210) 698-0556, Email: kingkmak@sbcglobal.net]
John Rohde [Tel.: (402) 554-3049, Fax: (402) 554-3288, Email: jrohde@unl.edu]
Safety by Design Co., Lincoln, Nebraska

The goal of this project was to develop, test, and demonstrate the application of breakaway posts with energy absorbing capability to enhance the safety performance of W-beam guardrails in frozen soil conditions. From the four initial concepts, two designs were selected for further evaluation based on potential impact performance, manufacturability, and cost. The bent-plate design (Figure 1) showed the desired failure mechanism, although the force level was lower than that required for proper impact performance. The bogie test was then simulated using the LS-DYNA computer simulation program. Based on the calibrated simulation model, the thickness of the bent plate was optimized to increase the force level while maintaining the manufacturability. Additional bogie tests were conducted on the optimized design, and the results showed acceptable force levels. Computer simulation of a guardrail system with breakaway posts was then conducted with satisfactory results indicating that implementation of this new guardrail post could potentially reduce the severity of guardrail crashes and the associated serious and fatal injuries. The next step was to conduct a full-scale crash test at the Midwest Roadside Safety Facility. The post manufacturer, Road Systems, Inc., had agreed on the finalized design and to contribute to the cost for the full-scale crash test. However, after reevaluating the potential market for the new posts, Road Systems, Inc. determined them to be not viable in the current market and withdrew support from the full-scale crash test. Implementation of the new posts requires fabrication and full-scale crash testing followed by field tests in collaboration with state Departments of Transportation.

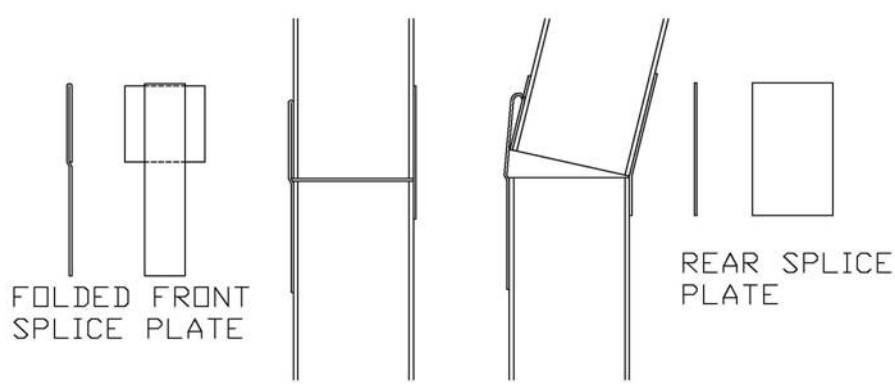


Figure 1

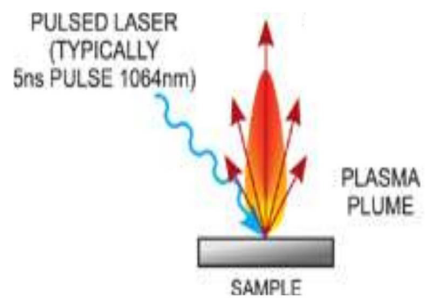
Schematic of bent plate design.

AUTOMATED LASER SPECTROGRAPHIC PATTERN MATCHING FOR AGGREGATE IDENTIFICATION

NCHRP-IDEA Project 150

Warren Chesner [Tel.: (516) 431-4031, Fax: (516) 717-2621, Email: wchesner@chesnerengineering.com] Chesner Engineering, P.C., Long Beach, New York

This project evaluated the feasibility of using laser-induced breakdown spectroscopy (LIBS) technology as a quality-control tool to conduct real-time scans of aggregates that are used in highway construction applications. LIBS is a rapid method laser-scanning technique in which a very quick pulse of energy from a high-powered laser is optically focused to a point, instantaneously heating the target sample to vaporize and atomize nanograms of material within a microplasma with a corresponding release of light. To identify the specific target material, the intensity of the wavelengths of light released in this process is spectrally and temporally resolved.



In this project, aggregates were targeted with a high-powered laser, and multivariate statistical modeling techniques were used to determine whether aggregates of interest exhibit definable spectral patterns that could be correlated with selected engineering properties of the target samples. In tests, mineral aggregates were found to exhibit unique spectral fingerprints or spectral patterns when subjected to a high irradiance, which was induced by focusing a high-powered laser onto very tiny spot on a target aggregate material. These spectral patterns were successfully correlated with engineering material properties of the targeted material. The acid insoluble residue content, the presence of D-cracking susceptibility, and alkali-silica reactivity were accurately predicted using multivariate determinant models on aggregates supplied by the New York, Kansas, and Texas departments of transportation (DOTs), respectively. A prototype system for field use in an actual quarry is being developed in NCHRP-IDEA Project 168, and a pooled-fund study involving several state DOTs with Kansas as the lead state will further evaluate the technology for implementation. (NTIS Report # PB2012-111107)

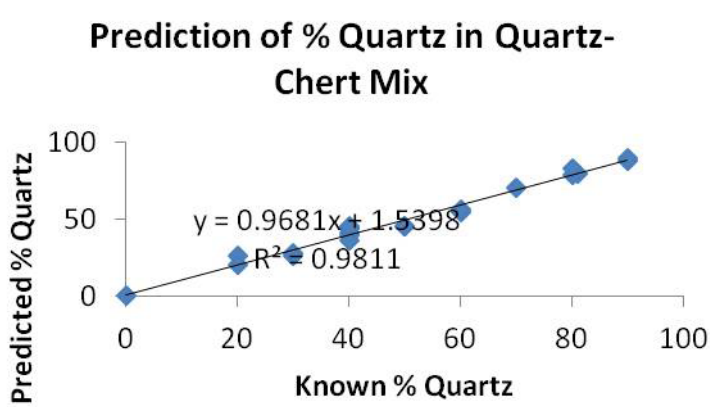


Figure 1

Calibration for percent quartz in quartz-chert mixtures of samples from Texas DOT.

DEVELOPMENT OF A SIMPLE TEST TO DETERMINE THE LOW-TEMPERATURE STRENGTH OF ASPHALT MIXTURES AND BINDERS

NCHRP-IDEA Project 151

Mihai Marasteanu [Tel.: (612) 625-5558, Fax: (612) 626-7750, Email: maras002@umn.edu]
University of Minnesota, Minneapolis, Minnesota

In NCHRP-IDEA Project 133, a simple bending creep test on thin beams of asphalt mixtures was developed. However, mixture creep compliance only represents one of the two parameters required to predict low-temperature performance; strength is the other critical parameter needed in the American Association of State Highway and Transportation Officials pavement design guide low temperature algorithm. This follow-on project developed a strength test for asphalt mixtures using the same bending beam rheometer (BBR) device from Project 133. The product is a BBR that can run low-temperature creep and strength tests for both asphalt binder and mixture specimens.

Using a modified BBR with a new proportional valve system and a heavier loading frame, beam replicates for asphalt binders and mixtures were tested. There was a significant difference between BBR and direct tension test (DTT) asphalt binder strength results. It was found that ethanol significantly reduced the strength values, most likely due to environmental stress cracking. Further investigation concluded that testing in air represented the best option for mixture testing, for which the results are less sensitive to small temperature fluctuations. Given the smaller dimension of the BBR beam compared to the RVE size of asphalt mixture, a mathematical model for reconstructing the material RVE was proposed. The RVE model was validated through histogram testing on larger specimens. The good agreement between the predicted strength obtained from the RVE model and the experimental results indicated that BBR could provide a simple alternative to asphalt mixture strength testing (Figure 1). This research, thus, may provide the asphalt industry with a simple test method to determine asphalt materials properties that are critical in material specification and selection processes. The reduced specimen thickness makes this method an ideal candidate for investigating aging effects in real pavements. The smaller size of test specimen also allows for investigating the properties of thin and ultra thin layers made with premium materials, a technology that has seen considerable growth in recent years. (NTIS Report # PB2013-108442)

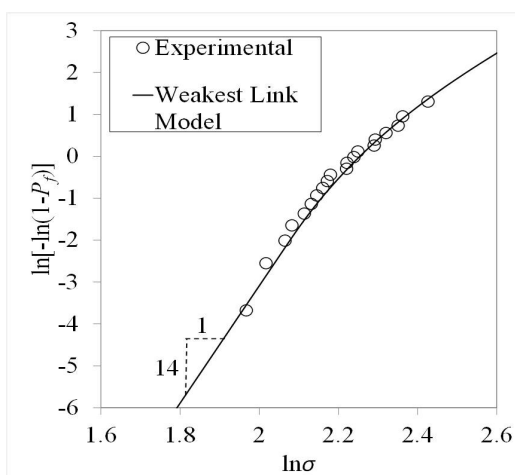


Figure 1

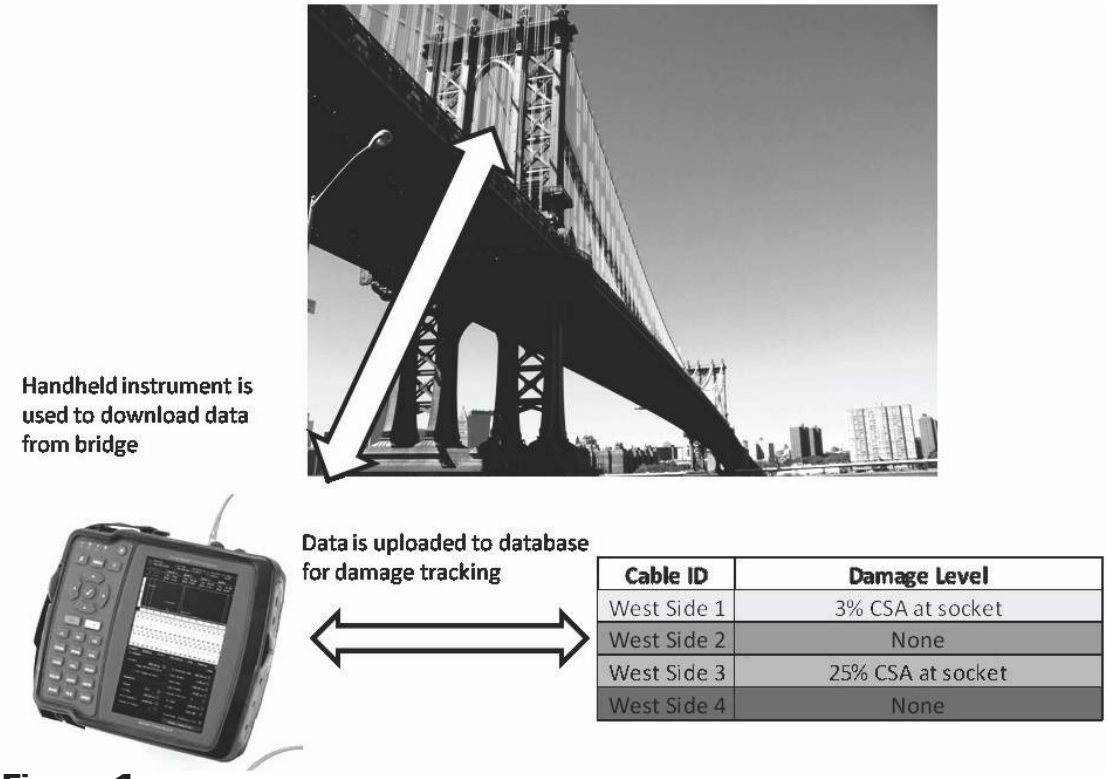
Bending beam rheometer (BBR) strength histograms and weakest link model prediction for asphalt mixture.

BRIDGE CABLE INSPECTION WITH LONG-RANGE ULTRASOUND

NCHRP-IDEA Project 152

Thomas R. Hay [Tel.: (814) 237-1031, Fax: (814) 237-1031,
Email: thomhay@wavesinsolids.com] WavesinSolids LLC, State College, Pennsylvania

This project developed and demonstrated the application of a rapid and reliable non-destructive method, based on long-range ultrasound, of inspecting bridge cables for corrosion, wire breaks, and other structural flaws (Figure 1). Cable inspection tests, performed in controlled laboratory environment by inserting artificial flaws at a suspender rope-cable socket interface showed the long-range ultrasound was sensitive to those small flaws and that the change in data relative to baseline data on a structurally sound cable could be used to track damage at this interface. Cable inspection was also performed in the field on the suspender ropes on the Manhattan Bridge. Changes in cross-sectional area (CSA) of all five ropes tested were identified using guided wave ultrasound. Visual inspection of these ropes confirmed these findings. The project also explored the feasibility of inspecting the main cable of a cable-stay bridge. From a single sensor position, the technology scanned approximately 120 feet of cable. The results showed, for the first time, that main cables could be inspected with the proposed technology and that the technology is sensitive enough find changes in CSA as small as 3%, as it showed a strong correlation between changes in select waveform features and increases in CSA loss. Based on an initial estimate, the cost for retrofitting a bridge and periodic inspection appear to be $34,000 and $8,000, respectively, for a 200 cable bridge. The final report is available from the National Technical Information Service (NTIS # PB2012-110783).



Cable ID	Damage Level
West Side 1	3% CSA at socket
West Side 2	None
West Side 3	25% CSA at socket
West Side 4	None

Figure 1

Suspender rope correlation coefficient with increasing percent cross-sectional area (CSA) loss.

BRIDGE RETROFIT LASER SYSTEM

NCHRP-IDEA Project 153

Paul Fuchs [Tel.: (703) 737-3871, Fax: (703) 737-6381,
Email: paul.fuchs@fuchsconsultinginc.com] Fuchs Consulting, Inc., Leesburg, Virginia

This project developed laser metrology instrumentation to aid in the bridge retrofit process. The complete system can make measurements that are difficult or impossible to make with manual string-line or tape measurements. It can measure with minimal impact at the bridge site, including measurements over water or other difficult access conditions, such as rail lines. A noncontact laser system measures the sections of a bridge structure that are involved in a retrofit process. These laser measurements produce CAD design drawings of retrofit parts. The laser system can measure the shape, position, and dimension of members on the bridge. The complete system is driven to a bridge site in a vehicle, quickly setup, and used to make measurements. No special targets are needed on the bridge, and the system can make highly accurate measurements over very large distances directly on the bridge members, including the exact dimensions and spatial location of bridge details. It has the potential to replace currently used manual measurements that use string lines and conventional survey equipment. Work was performed with retrofit fabricators and state departments of transportation to determine measurement requirements and application areas. A number of field measurements were made that included measurements on a bridge struck by an over-height load (Figure 1). Measurements were made quickly and efficiently on multiple lanes in traffic without lane closures. The system accurately measured localized damaged, and it can also measure global change in an entire girder. The system has been used to evaluate steel truss bridges to measure vertical and diagonal members, and localized damage in gusset plates. The researcher is working with several key partners in the bridge retrofit process with the intent of producing a system to immediately benefit the current retrofit process. (NTIS Report # PB2013-108642)

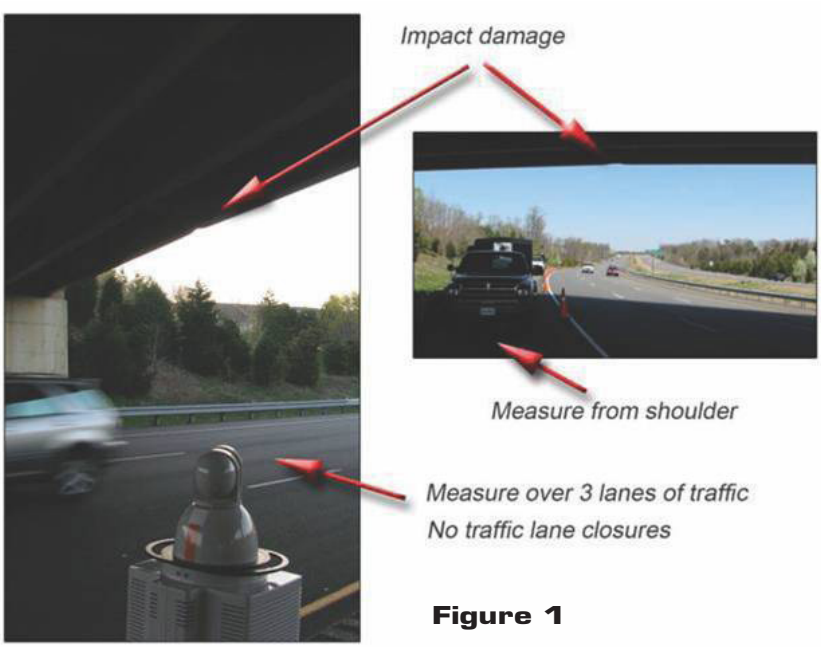


Figure 1

Measurement of impact damage on a steel girder bridge over a roadway without altering traffic.

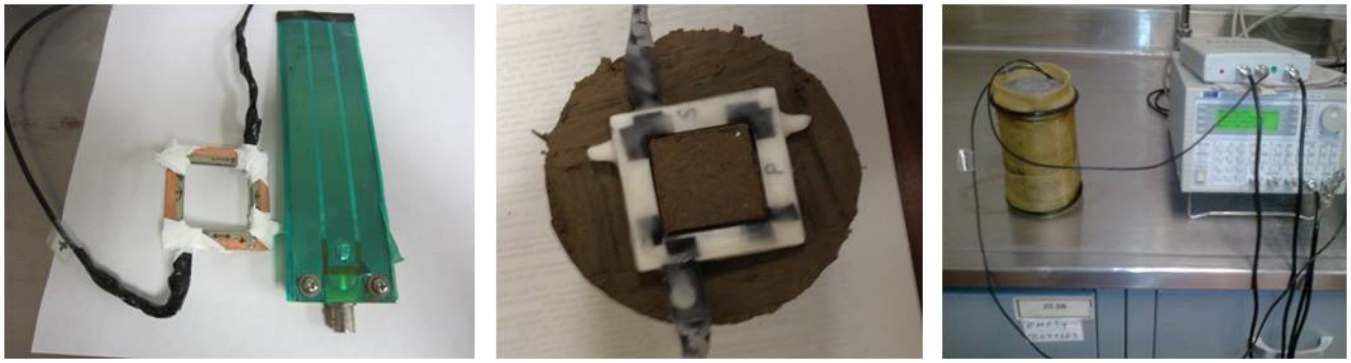
AN INNOVATIVE HYBRID SENSOR FOR RAPID ASSESSMENT OF SULFATE INDUCED HEAVING IN STABILIZED SOILS

NCHRP-IDEA Project 154

Anand J. Puppala [Tel.: (817) 272-5821, Fax: (817) 272-2630, Email: anand@uta.edu]
The University of Texas, Arlington, Texas

The concept of this project was to develop a sensor (Figure 1) that uses both time-domain reflectometry and bender element technologies to detect the stiffness and moisture contents of soils. This sensor could be used to conduct a quick assessment of sulfate heaving problems in chemically treated sulfate soils or it could be used to conduct continuous measurements of water content, shear wave velocities, and compression wave velocities in a soil sample.

The developed sensor was embedded in lime- and cement-treated soils to monitor changes in both moisture content and shear wave velocity at various time periods. Laboratory assessments indicated that cement-treated soils experienced higher stiffness losses as compared with lime-treated soils. For field implementation and validation, a test section was chosen in the median area between Highway 114 and International Parkway near the Dallas/Fort Worth airport. Sulfate tests conducted on the natural soils indicated that the sulfate content was in excess of 30,000 ppm. A 25-ft. x 60-ft. section was built in this area and the subgrade was treated with 6% lime. The developed hybrid sensor was embedded at a depth of 8 in. in the treated section. The treated section was watered three times a day to keep continuous supply moisture for un-inhibited sulfate reactions in the treated soil. Field test results indicated a reduction in shear modulus with time in the lime-treated test section. The results also reconfirm the laboratory findings that the shear modulus decreased in chemically treated sulfate rich soils owing to the deleterious reactions among soils and mineral and chemical stabilizers. Addition field testing and evaluation is needed before this technology can be implemented by highway agencies (NTIS Report # 2014-100624).



(a) *(b)* *(c)*

Figure 1

(a) Present bender element sensor with time-domain reflectometry strip; (b) embedment of sensor in a treated soil specimen; and (c) stiffness measurements.

CORROSION RESISTANT, STRUCTURALLY REINFORCED, THERMAL SPRAY COATINGS FOR IN-SITU REPAIR OF LOAD-BEARING STRUCTURES

NCHRP-IDEA Project 155

Sanjay Sampath [Tel.: (631) 632-9512, Fax: (631) 632-7878,
Email: Sanjay.Sampath@stonybrook.edu] Stony Brook University, Stony Brook, New York

This project was aimed at developing and demonstrating the feasibility of in-situ reclamation of corroded components in load-bearing infrastructures (such as bridges) to provide robust corrosion protection with high-velocity thermal spray coating (Figure 1). A high-velocity oxy-fuel (HVOF) thermal spray process was used to deposit iron (Fe) or nickel (Ni) as the reclaimed materials. Process optimization with in-situ monitoring of residual stresses demonstrated that compressive residual stresses could be achieved in HVOF reclamation material. Mechanical testing showed that the addition of the coating resulted in load recovery and enhancement in yield stress, suggesting good coupling between the reclaimed material and the parent metal, as well as demonstrating load-bearing capability of the HVOF coating. Thin Ni coatings presented a better performance compared to Fe coating since they were able to endure excessive loads and displacements without delamination. Still, both coatings presented an increased load-bearing capacity compared to virgins, uncoated tensile test specimens. At thick coatings, new spraying parameters were required in order to produce more compressive coatings as they were showing premature failure. The new compressive Ni coatings presented the highest load-bearing capacities, compared to all coatings and virgin tensile specimens. The composite repaired structure with Ni overlay also showed excellent corrosion resistance. These results represent a good transition opportunity to further and implement the technology on larger-scale structural components in collaboration with state departments of transportation. The final report is available from the National Technical Information Service (NTIS # PB2013-108643).

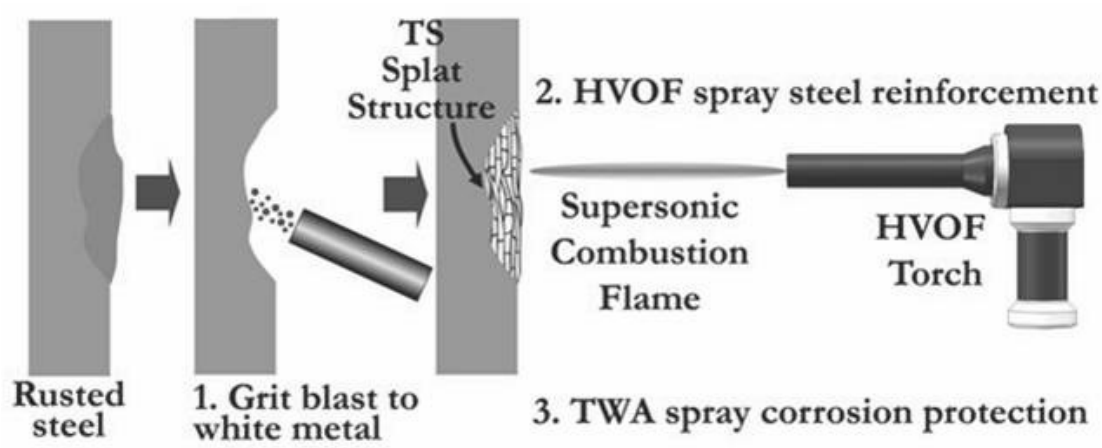


Figure 1

Schematic of the proposed thermal spray reclamation process (HVOF = high-velocity oxy-fuel; TWA = twin wire arc).

NOVEL COATING TECHNOLOGY FOR IMPROVING THE CORROSION RESISTANCE AND MECHANICAL PROPERTIES OF REINFORCING STEEL IN CONCRETE

NCHRP IDEA Project 156

Leonardo Caseres [Tel.: (210) 522-5538, Fax: (210) 522-5122,
Email: leonardo.caseres@swri.org] Southwest Research Institute, San Antonio, Texas

The goal of this project was to develop a new solution-based diamond-like carbon (s-DLC) coating with improved corrosion and mechanical performance as compared with commercially available coatings for concrete-reinforcing steel. The s-DLC synthesis process differs from traditional techniques in that it does not require high temperature or vacuum conditions. Work in the initial stage involved optimizing the coating performance prior to application to reinforcing steels. For coating optimization, scanning electron microscopy (SEM), Raman spectroscopy, and electrochemical techniques [such as electrochemical impedance spectroscopy (EIS), and linear polarization resistance] were used to characterize the coating applied to flat steel coupons. After coating optimization, several coated bars were embedded in mortar samples admixed with various amounts of chloride (from 0 to 5% wt. of mortar) and partially immersed in simulated seawater for up to 140 days. For comparison, additional reinforcing steel samples were vacuum deposited with DLC coatings such as standard DLC, multilayer Si DLC, Si-F-O DLC, and thick DLC coatings, and tested in mortar in a way similar to the s-DLC samples. SEM analysis revealed microcracks in the s-DLC films deposited on the rebar surface. To mitigate cracking, changes in pyrolysis process parameters such as the heating and cooling rates were investigated along with exploring alternative wet-coating techniques. Multiple layers of s-DLC films were also applied to the rebars in efforts to mitigate cracking. Both approaches appeared successful in mitigating cracks. The corrosion properties of the coated mortar samples were examined using the linear polarization technique.

The results showed that for 0% chloride corrosion rates were negligible/low (<0.1 mpy) for the s-DLC, Si-F-O DLC, and thick DLC coatings, but moderate (0.65–0.90 mpy) for standard DLC and multilayer Si DLC coatings. The corrosion rates increased with an increase in chloride content, which was more notable for the s-DLC coating. By the end of the 140-day exposure, the corrosion rate for 0.5% chloride was high (1.9 mpy) for the s-DLC coating, moderate (0.55 mpy) for the standard DLC and multilayer Si DLC coatings, and negligible (<0.07 mpy) for the Si-F-O DLC and thick DLC coatings, indicating that coating defects are likely to be present in the s-DLC, standard DLC, and multilayer Si DLC coatings. Similar trends were recorded for the 1% and 3% chloride contents. For the 5% chloride content, all of the DLC coatings showed high corrosion rates (>1.4 mpy) except for the thick DLC coating, which exhibited a moderate corrosion rate (0.75 mpy). The linear polarization results were in agreement with the EIS measurements. Further research is needed to improve the corrosion protection of s-DLC coating if it is to be viable for use on reinforcing steel. The Southwest Research Institute is working on this issue and, once this is resolved, will formalize teaming arrangements through negotiated business agreements to support technology integration and transition. The Institute intends to involve small businesses for scaling up synthesis from the pilot synthesis to larger production (500–2,000 gallons) of s-DLC coatings. Additional potential technical transfer teaming partners include large chemical and coatings companies.

USING NONLINEAR ACOUSTICS TO IDENTIFY THE STRESS STATE OF CRITICAL BRIDGE COMPONENTS

NCHRP-IDEA Project 158

Didem Ozevin [Tel.: (312) 413-3051, Fax: (312) 996-2426, Email: dozevin@uic.edu]
University of Illinois at Chicago, Chicago, Illinois

This project was aimed at developing and demonstrating the application of a nonlinear acoustics-based technique (Figure 1) for identifying the stress state of critical highway bridge components through laboratory-scale and field testing. Currently, there is no rapid, cost-effective method for measuring actual loading on structural elements as a result of the dead load of existing structures. Increasing transportation demand as well as fatigue and corrosion may lead to critical bridge components reaching an overstressed state. The proposed approach can serve as a rapid inspection method for bridge inspectors to obtain the stress level of critical bridge components. Theoretical and numerical models were developed to identify the most sensitive ultrasonic waves to the level of stress on structural steel. The selected ultrasonic waves were tested on an L profile loaded uniaxially and a gusset plate loaded uniaxially and bi-axially. The method was tested on two bridges located in Illinois (a fracture critical bridge spanning the Calumet River allowing access to Halsted Street) and Virginia (Norris Bridge). Work has continued with support from the National Science Foundation. Communications have been initiated with a manufacturer of hand-held ultrasonic testing devices. Once the algorithm is finalized, it can be easily embedded into the integrated circuit FPGA (field-programmable gate array) for automated stress measurement. The approach has been successfully demonstrated on two actual highways, which is a critical step in proving the readiness of this technology.

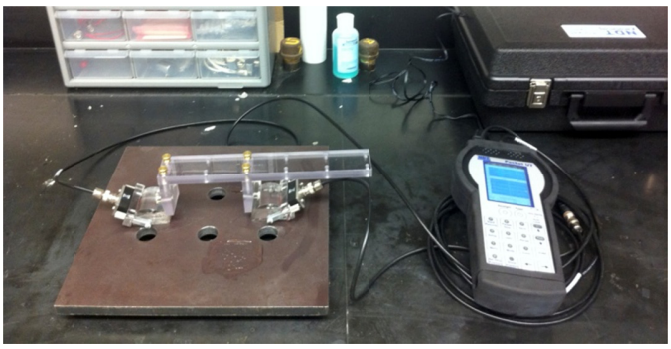
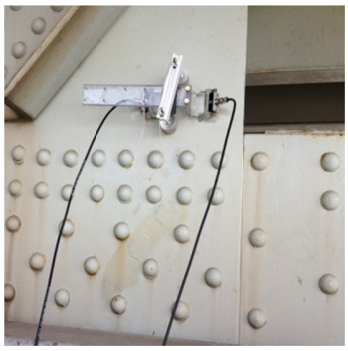
(a)  (b) 

Figure 1

Fixture designed for ultrasonic wave transmitter and receiver with variable angle and distance: (a) on a laboratory sample and (b) on a gusset plate at a fracture critical bridge in Illinois.

ADVANCED CLEANING DEVICE TO REMOVE DEBRIS AND CHEMICALS FOR CRACK/JOINT SEALING

NCHRP-IDEA Project 159

Yong Cho [Tel.: (402) 554-3277, Fax: (402) 554-3850, Email: yong.cho@ce.gatech.edu]
Georgia Institute of Technology, Atlanta, Georgia

The aims of this project were to improve and retrofit the design of a pavement crack cleaning device (CCD), developed in the previous IDEA project (NCHRP-148), to make it more practical and functional by adding functions such as routing, hot air blasting, and vacuuming (Figure 1). As an outcome of the previous research, a conceptual prototype of a CCD was designed, utilizing pneumatic power for air blasting and abrasive wire brushing to simultaneously remove debris or de-icing chemicals that were used in cold winter and remained in cracks. In the current project, a router, an electric heat lance, and a vacuum system have been incorporated as possible options for the CCD. An electrical heat lance was designed to properly warm the pavement and expel moisture to promote bond adhesion. In addition, a vacuum system was developed as a means of collecting debris and dust to remove road hazards and improve operator safety while conforming to OSHA and EPA guidelines. Routing and saw cutting functions were also added to the CCD. For field validation of the CCD and to gain industry acceptance of the technology, several industry demonstrations and field tests were conducted. CCD units were provided to the Nebraska Department of Roads (NDOR) for use during the full sealing season in 2012–2013. Also, demonstrations were conducted at the Crafco, Inc. manufacturing facility in Chandler, Arizona, and at the City of Omaha, Nebraska, road maintenance division. Productivity data along with the crews' feedback were collected during the field tests. The analyzed results showed the CCD design concepts to be well received by all participating industries for the CCD's positive impact highway on road maintenance and for improving productivity, safety, and maintenance cost. Crafco, Inc. has shown strong interest in the commercialization of the CCD. Successful commercialization and industry adoption of the CCD for crack and joint preparation would lead to an increase in overall quality of pavement maintenance, an increase in the useful life of pavements, and a reduction in the costs of rehabilitation or new construction of roadways (NTIS Report # PB2014-100625).

Figure 1

The latest versions of heat lance (left) and vacuum attachments (right).

SUPER-WEATHERING STEEL FOR INFRASTRUCTURE APPLICATIONS

NCHRP-IDEA Project 160

Semyon Vaynman [Tel.: (847) 491-4475, Fax: (847) 491-7820,
Email: saynman@northwestern.edu] Northwestern University, Evanston, Illinois

This project developed and tested the mechanical, fracture toughness, weathering, and welding properties of a new "super" weathering (SW), cost-competitive steel for transportation infrastructure applications. The new steel's compositions were modifications of the composition of an ASTM A710 Grade B 70-ksi-yield, copper-precipitation-strengthening, hot-rolled, and air-cooled steel, previously developed at Northwestern University, that showed excellent fracture properties at low temperatures and a corrosion loss about 40% less than that in A709 HPS70W steel (as measured in automotive accelerated SAE J2334 test at Bethlehem Steel/Arcelor Mittal). To increase the weatherability of steel phosphorus appears to be the most potent element to enhance the corrosion resistance of steel. However, phosphorus also increases the steel's brittleness. Consequently, addition of phosphorus to A710 Grade B steel (developed previously at Northwestern University) and mitigation of the steel embrittlement by addition of a specific amount of titanium to keep phosphorous from migration to the grain boundaries was the approach taken in this IDEA project. Other elements, such as chromium and molybdenum, which enhance steel weathering, were also added. Four SW steels were designed and tested. The steels were very ductile and fracture-tough to –100°F, thus significantly outperforming the requirements of ASTM A709 bridge steel standard (Figure 1). No brittle heat-affected zone was formed as a result of high-power laser welding simulation, thus indicating that the steels could be easily welded without pre- or post-welding heat treatment. Accelerated studies indicated that the developed steels have better weathering characteristics than A588 weathering steels that are currently used for bridge construction. The production of these new steels does not require special processing or thermal treatment; therefore, these steels can be produced by any steel manufacturer in any steel plate sizes.

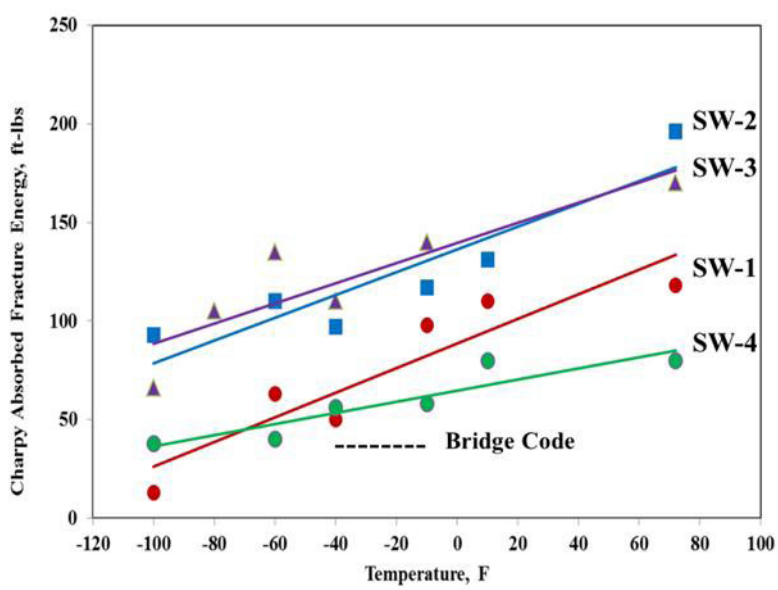


Figure 1

Charpy absorbed fracture energy of experimental super-weathering steels.

TOOLS FOR DETERMINING YIELD STRESS OF IN-SERVICE GUSSET PLATES

NCHRP-IDEA Project 161

Therese Pflaum and Christopher Higgins [Tel.: (541) 737-8869, Fax: (541) 737-3052, Email: chris.higgins@oregonstate.edu] Oregon State University, Corvallis, Oregon

The project developed and tested a prototype device to nondestructively assess the yield stress of steel gusset plates for use in bridge evaluation and rating. The prototype device is fabricated from titanium, which has very high strength and relatively low weight to facilitate field portability. The hand-held device uses a manually actuated hydraulic cylinder to apply an out-of-plane load to the free edge of a steel plate. The applied load, measured with a load cell, creates bending deflection of the plate that is measured with a displacement sensor. The applied load and plate displacement measurements are collected with a portable data acquisition system. Both the prototype device and data collection system are self-contained and require no external power source. This portability allows a bridge inspector to collect and analyze data in the field. The acquired load and deformation data are used to estimate the yield stress as the deflections become nonlinear at the onset of plate yielding. The load and deformation responses are calibrated to finite element (FE) analyses and empirical reference tests. Based on statistical analysis of results with the prototype device over a range of plate materials and thicknesses, a yield stress reduction factor of 0.85 was developed to ensure that the predicted yield stress would not exceed the actual yield stress with 1/10,000 probability when three (3) replicate tests are performed. The device is capable of testing mild steel plates up to 1 in. thick. After testing, there are imperceptible residual displacements on the plate at the defined yielding threshold. These characteristics provide a nondestructive method to estimate the yield stress of bridge steel plates in the field, which was previously not possible and as such may be a technological breakthrough.

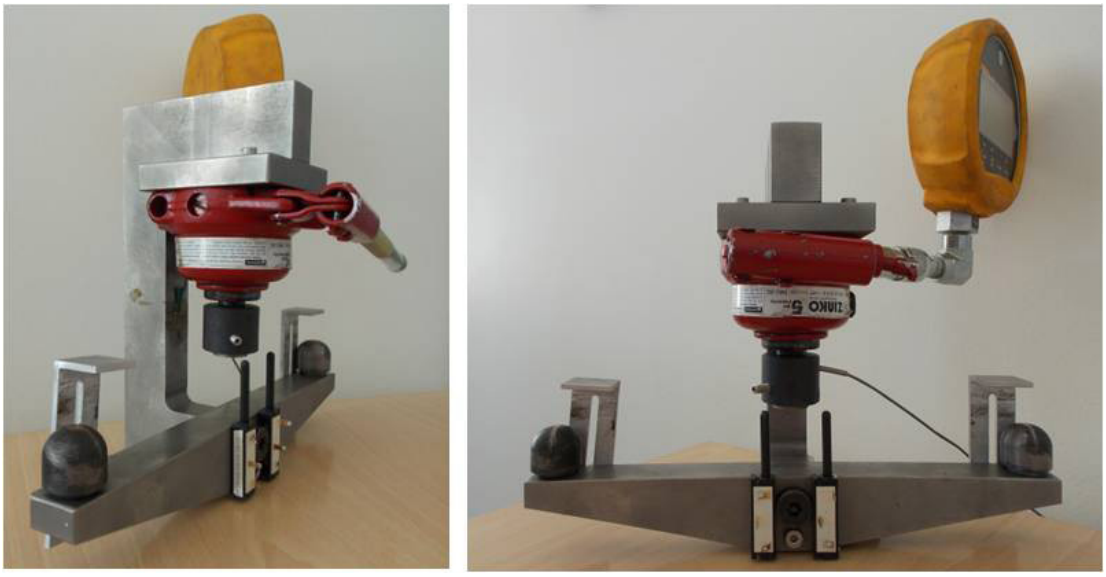


Figure 1

Prototype device used to bend plates at free edge.

FULL-SCALE PROTOTYPE TESTING AND MANUFACTURING AND INSTALLATION PLANS FOR NEW SCOUR-VORTEX-PREVENTION scAUR AND VorGAUR PRODUCTS FOR A REPRESENTATIVE SCOUR-CRITICAL BRIDGE

NCHRP-IDEA Project 162

Roger L. Simpson [Tel.: (540) 961-3005; Email: rogersimpson@aurinc.com]
Applied University Research (AUR), Inc., Blacksburg, Virginia

This project tested and developed manufacturing and installation plans for scAUR and VorGAUR products for scour-critical bridges to demonstrate their effectiveness in preventing scour-causing vortical flow characteristics at piers and abutments. Plans were developed and refined for the manufacture and installation of full-scale scAUR and VorGAUR products on a scour-critical bridge in Virginia, representative of scour-critical bridges across the United States. Reynolds number and bridge pier and abutment size effects were examined using computations that showed that scAUR with VorGAUR was effective in preventing scour-causing vortical flow at both model and full scale. Data on the performance of these products with several smaller size sediments at model scale were obtained in the AUR flume. No scour was observed around the scAUR with VorGAUR model for any gravel in this range. The performance of scAUR and VorGAUR concepts for a larger class of abutments was examined in model scale AUR flume tests. Wing-wall (Figure 1) and spill-through abutment flume models, with and without scAUR and VorGAUR features, were tested to show that the product features prevented scour for these abutments. A full-scale scAUR and VorGAUR pier model was constructed and tested under various conditions in the large flume at the Iowa Institute for Hydraulic Research (Figure 2) with results comparable to results for 1/7 size models in the AUR flume. Manufacturing methods and installation processes for scAUR and VorGAUR products were refined and plans and cost estimates for manufacturing full-scale products were developed. A cost-effective manufacturing alternative for a scAUR retrofit bridge pier or abutment fairing is to use stainless steel (SS) or weathering steel rather than shotcrete or precast concrete. Its corrosion resistance gives it a lifetime of 100 years even in seawater environments. The present value cost of these products over the life of a bridge is an order of magnitude cheaper than current scour countermeasures (NTIS Report # PB2014-104002).

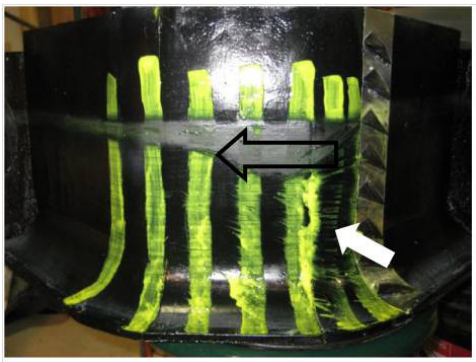


Figure 1

Wing-wall abutment with a scAUR *fairing with* VorGAUR™ *vortex generators that move lower speed flow up the abutment.*

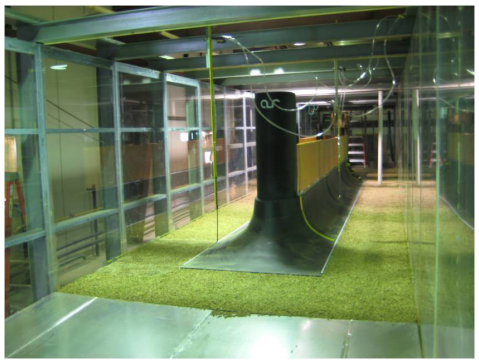


Figure 2

Full-scale scAUR with VorGAUR vortex generators model in the Iowa Institute for Hydraulic Research Flume facility.

DEVELOPMENT OF AN ASPHALT PAVEMENT RAVELING DETECTION ALGORITHM USING EMERGING 3-D LASER TECHNOLOGY AND MACROTEXTURE ANALYSIS

NCHRP-IDEA Project 163

Yichang (James) Tsai [Tel.: (404) 894-6950, Email: james.tsai@ce.gatech.edu]
Georgia Institute of Technology, Atlanta, Georgia

Raveling is one of the pavement distresses that deteriorates in an exponential manner and requires identification at its earliest stage so that pavement preservation can be programmed in a timely manner. This project developed algorithms to automatically detect raveling using emerging 3-D line laser imaging technology (Figure 1). The algorithm was tested and validated using Georgia DOT pavement condition survey protocol on Interstates I-85 and I-285 near Atlanta, Georgia. The 3-D pavement data were collected on four test sections on I-85 (each 1 mile long) and on the entire outer lane of asphalt pavement (61 miles) on I-285. Tests on I-285 also showed promising results for automatic raveling detection, classification, and measurement. All pavements (with or without raveling) were 100% correctly detected and classified at the segment level (each segment 1 mile long). However, due to the difficulty of correctly labeling all the raveling areas using videolog images and 3-D pavement data and due to the impact of cracking and flat-tire scratches, the raveling extent showed some variation in comparison with the manually labeled ground truth. However, the differences between the surveyed results and the automatically detected and measured results were less than 15%. While the developed algorithms show much promise, further field evaluation is needed for implementation of the method by the departments of transportation.

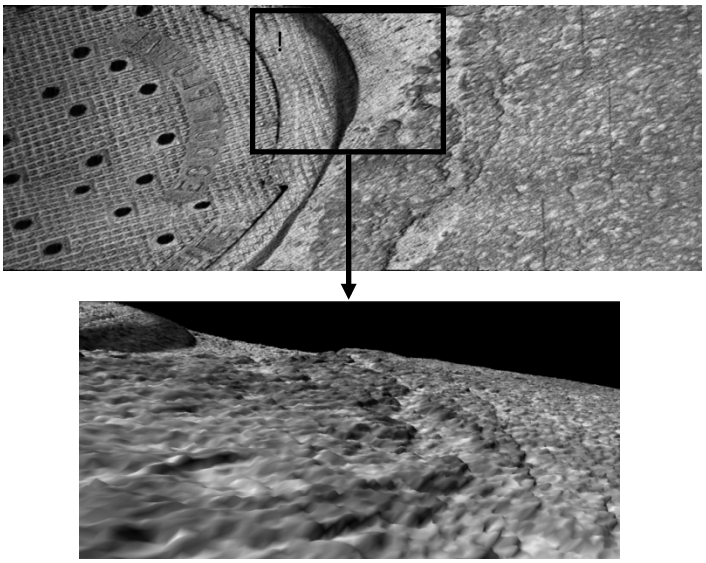


Figure 1

Visualization of 3-D pavement surface data for analyzing loss of stones.

LASER SPECTROSCOPY FOR RAPID PROFILING OF STEEL BRIDGE COATING, CORROSION, AND HEAVY METALS

NCHRP-IDEA Project 164

Warren Chesner [Tel.: (516) 431-4031, Fax: (516) 717-2621, Email: wchesner@chesnerengineering.com] Chesner Engineering, P.C., Long Beach, New York

The project was designed to develop and demonstrate the application of a laser scanning technology to rapidly identify and profile the presence of heavy metals (Pb, Cd, and Cr) and titanium (Ti) in paint coatings. In addition, the potential for using laser scanning to identify the type of coating used and the presence and the severity of corrosion under layers of coatings on steel structures was investigated. Finally, special testing was undertaken to evaluate the use of laser equipment to drill through and depth-profile coating layers. Findings have shown that laser spectroscopy readily distinguishes coatings with high levels of Pb, Cd, and Cr from coatings with minimal levels. The presence and concentration of titanium present in coatings is readily identifiable. Zinc-rich coatings are easily distinguishable from other coatings and epoxies. Study findings also showed that it is possible to distinguish between degrees of corrosion. The research team developed and successfully tested a combined drilling and laser ablation tool to achieve a high-resolution depth profile of coating layers (Figure 1). Such a tool has applicability as a research tool as well as a field inspection tool to assess the presence of coatings containing high levels of heavy metals, the thickness of the coatings, the type of coating, and level of corrosion at the surface and under the coating layers, The depth profiling technology featured in this research has the potential for use as a diagnostic tool in a variety of structures including concrete, asphalt, and steel surfaces.

Future activities will require further development of the design basis for the fabrication and deployment of a commercial prototype, and testing the depth profiling capacity of the system using other materials.

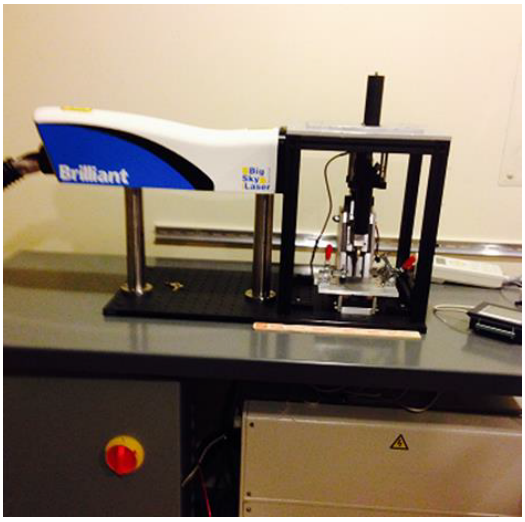


Figure 1

Micro-drill depth profiling laser system.

BATTERY-LESS WIRELESS WEIGH-IN-MOTION SENSOR

NCHRP-IDEA Project 165

Rajesh Rajamani [Tel.: (612) 626-7961, Fax: (612) 625-4344, Email: rajamani@me.umn.edu]
University of Minnesota at Twin Cities, Minneapolis, Minnesota

The goal of this project was to develop a battery-less wireless weigh-in-motion (WIM) sensor and a smart phone app that wirelessly received information from the sensor to display the weight of each passing vehicle. The WIM sensor utilized a previously developed vibration energy harvesting system that obtained all energy required for its operation from the vibrations of each passing vehicle. Building on previous work, this project developed two new rigid WIM sensor designs, an all-metal casing for sensor operation, and a smart phone app for wireless access to the sensor signals. Figure 1a shows the open sensor enclosure box and Figure 1b shows the sensor inside the box grouted to the asphalt pavement.

The sensor was evaluated at the Minnesota Road Research Facility (MnRoad) in an asphalt pavement using a number of different types of vehicles. The WIM system provided weight measurements that increased monotonically with increasing axle weights, but showed significant variability from one test to another for the same vehicles and the same axle loads. Vibrations measured on the truck axles showed low vibrations at 10 mph and high vibration levels reaching up to 500 mg rms at 50 mph. Since significant variability in measured axle weights was seen even at 10 mph, it was concluded that the measurement variability was not purely the result of truck suspension vibrations. The variability was diagnosed to be due to the sensor enclosure box, which provided variability in load depending on the lateral position of the vehicle in the lane. The variability issue made the sensor unreliable for field testing and therefore further work on the project was discontinued.

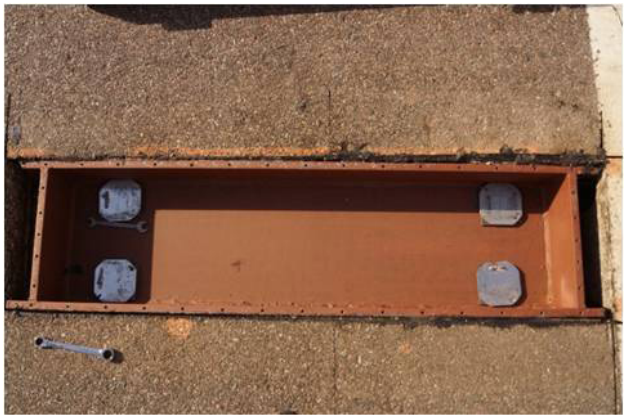


Figure 1a

A box enclosure for installation of sensor inside pavement.

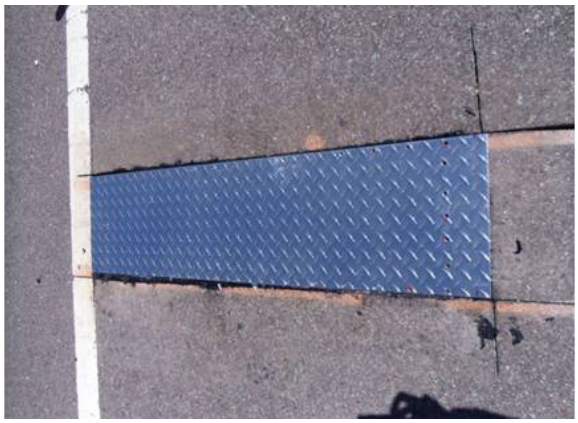


Figure 1b

Photograph of sensor in external box that has been grouted in asphalt pavement.

GUIDELINES FOR THE USE OF WASTE CONCRETE FINES

NCHRP-IDEA Project 166

Julie Vandenbossche [Tel.: (412) 624-9879, Fax: (412) 624-0135, Email: jmv7@pitt.edu]
University of Pittsburgh, Pittsburgh, Pennsylvania

Donald Janssen [Tel.: (206) 543-9655, Fax: (206) 543-1543, Email: dnjan@msn.com]
University of Washington, Seattle, Washington

This project developed guidelines for using waste concrete fines (and the associated wastewater) in concrete by developing methods to rapidly characterize fines samples and evaluating the performance of concrete using these recycled materials. Unfortunately, a considerable amount of wastewater with high pH, as well as dissolved and suspended solids, is associated with concrete production (clean-up), the rehabilitation of concrete structures, and the recycling of concrete at the end of the structure's life (Figure 1). Sources of recycled fines were identified and the fines were characterized after mixing them with water to create solutions and suspensions and their indices of refraction, pH, and conductivity determined. Mortar samples were prepared and their setting times and strengths measured for a range of fines particle sizes and contents. Correlations were established from the collected data to help develop a performance-prediction model for different recycled fines materials. This model was used to develop guidelines for using recycled concrete fines in new concrete mixtures. In the next step, a water recirculation system was constructed, which incorporated in-line (continuous reading) sensors for measuring the index of refraction, conductivity, and pH. Waste materials were added to the recirculation system and evaluated using the in-line sensors to validate the implementation plan and the model. The implementation plan for ready-mix concrete producers when upgrading plants with in-line sensors was finalized along with instructions on applying the guidelines for using recycled fines. Work has continued beyond the IDEA project with support from Northwest Regional Transportation Center. Sensors were installed in the recycled water recirculation system at the Stoneway Concrete plant in Seattle, Washington. Mixtures with recycled and "city water" were tested and strength test results compared with predictions from the IDEA developed models. Results were presented to the Seattle Department of Transportation (DOT), City of Seattle Department of Planning and Development, and Washington State DOT as part of the implementation effort

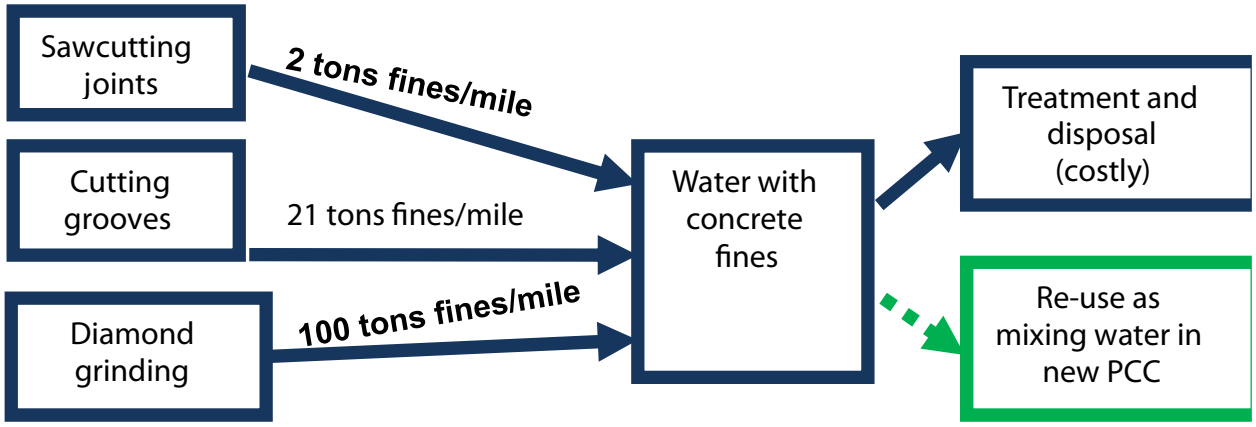


Figure 1

Sources of recycled concrete fines and the rate at which they are generated.

AUTOMATED AND CONTINUOUS AGGREGATE SAMPLING AND LASER TARGETING SYSTEM: PROTOTYPE DEVELOPMENT

NCHRP-IDEA Project 168

Warren Chesner [Tel.: (516) 431-4031, Fax: (516) 717-2621, Email: wchesner@chesnerengineering.com] Chesner Engineering, P.C., Long Beach, New York

This project was aimed at developing and demonstrating the field application of an automated real-time, quality control, aggregate laser scanning monitoring system developed in an earlier project (NCHRP-150). Figure 1 illustrates the concept. The system, referred to as the sampling and laser targeting system (SLT), consists of a laser, a spectrometer, a fiber optic cable, mirrors and lenses, a housing with a ventilation system, and a laptop computer to monitor aggregate materials introduced into the system. The SLT system works by focusing a high-powered laser at flowing aggregate materials and recovering and analyzing the light generated in this process. The recovered light provides a unique fingerprint of the target material. Aggregate materials received from several state departments of transportation, including Kansas, Oklahoma, Pennsylvania, Ohio, and New York, were scanned. A special software was developed to analyze spectral data generated during laser scans. The results suggest that laser scanning and multivariate analysis of spectra generated using the SLT could predict values of acid insoluble residue, specific gravity, micro-Deval, D-cracking, and percent chert in the aggregates tested. A key conclusion of this research is that laser scanning of aggregate is a technology capable of altering the manner in which aggregate quality control procedures are employed by the industry in the future. The system, which has been granted a U.S. patent, is being demonstrated at a quarry near Albany, New York, and is further evaluated in a pooled fund study sponsored by several states (Ohio, New York, Kansas, Oklahoma, and Pennsylvania). A draft Standard of Practice or a Test Method on the laser scanning technology has been prepared for consideration by AASHTO.

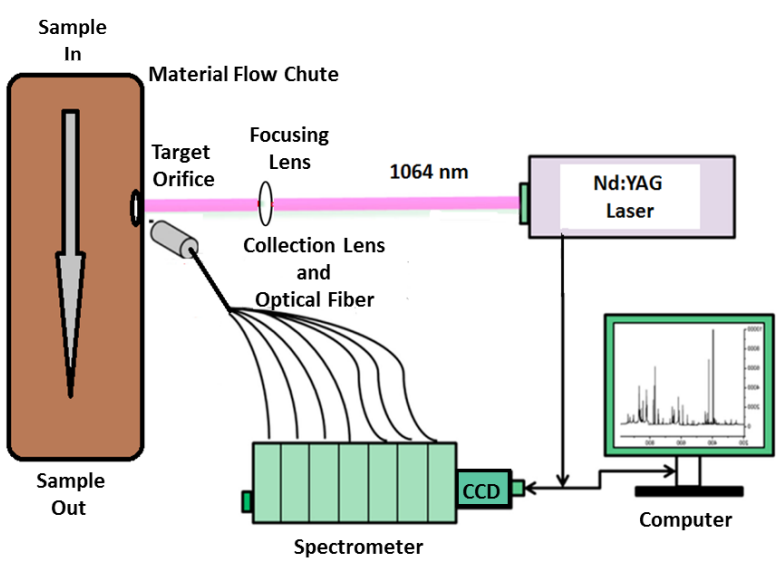


Figure 1

Sampling and laser targeting system concept.

AN INEXPENSIVE VISION-BASED APPROACH FOR THE AUTONOMOUS DETECTION, LOCALIZATION, AND QUANTIFICATION OF PAVEMENT DEFECTS

NCHRP-IDEA Project 169

Burcin Becerik-Gerber [Tel.: (213) 740-4383, Fax: (213) 744-1426, Email: becerik@usc.edu]

Sami F. Masri [Tel.: (213) 740-0602, Fax: (213) 744-1426, Email: masri@usc.edu]
University of Southern California, Los Angeles, California

Mohammad R. Jahanshahi [Tel: (765) 494-2217; Fax: (765) 494-0395;
Email: jahansha@purdue.edu] Purdue University, West Lafayette, Indiana

The goal of this project was to develop and demonstrate the application of an imaging system based on inexpensive sensors for an automated detection and quantification of pavement defects, including cracks and potholes. Figure 1 provides an overview of the imaging/inspection system. The approach used off-the-shelf Microsoft Kinect, costing under $200, to collect color images and 3D point clouds of roadway surfaces. A compact-size pavement data collection system was built that could be easily installed on a car and collect data at highway speeds. The system used multiple Microsoft Kinect sensors to cover a lane width and was designed to reach scanning speed. It also included 3-axis accelerometers to record orientations of the system and Global Positioning System to obtain location and velocity. Several road tests were performed on local streets and freeways. The tests presented a few challenges. The main challenges were sunlight interference, motion blur, and rolling shutter distortion. A top cover was designed to reduce the sunlight interference. A stroboscopic technique was used to solve the motion blur problem for Kinect's color image acquisition and capture slow motion pictures. A rectification algorithm was developed to correct distorted images These improvements enabled the pavement data collection system to obtain good imaging results when moving at less than 30 mph (residential speed limit in most states). Furthermore, pavement crack detection using a hybrid algorithm based on anisotropic diffusion filtering and eigenanalysis of Hessian matrix showed a promising outcome in segmenting the cracks as compared with a modified bottom-hat morphological method. Further improvement and evaluation are needed before the system would be implementable by the state departments of transportation.

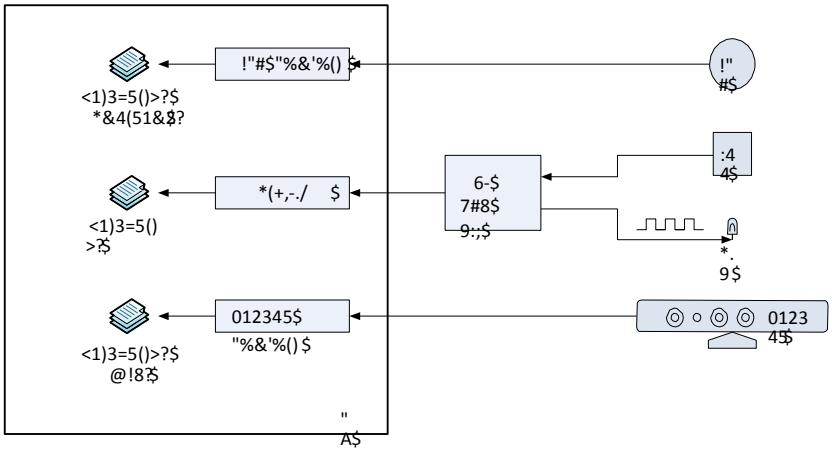


Figure 1

Overview of the 3D scanning system for pavement inspection.

DEVELOPMENT AND IMPLEMENTATION OF THE ASPHALT EMBRITTLEMENT ANALYZER

NCHRP-IDEA Project 170

William G. Buttlar [Tel.: (217) 333-5966, Fax: (217) 333-1924, Email: buttlar@illinois.edu]
University of Illinois, Urbana-Champaign, Illinois
Henrique M. Reis [Tel.: (217) 333-1228, Fax: (217) 244-5705, Email: h-reis@illinois.edu]
University of Illinois, Urbana-Champaign, Illinois
Behzad Behnia [Tel.: (217) 7214842, Fax: (413) 782-1576, Email: behzad.behnia@wne.edu]
Western New England University, Massachusetts

This project developed an asphalt embrittlement temperature detection system, referred to as the asphalt embrittlement analyzer (AEA), to rapidly and reliably characterize the asphalt material embrittlement threshold at various pavement depths using small-diameter field cores (Figure 1). Working with collaborating industrial partners (Troxler, Inc., Road Science, and Asphalt Institute), a temperature-controlled device coupled with multi-channel AEA and software was completed to calculate T_{EMB} vs. depth and a prototype AEA system for commercialization was designed. A series of maintenance strategies and an expert system to guide designers toward an optimally designed rehabilitation strategy were also developed.

The prototype AEA device, now capable of measuring graded in situ embrittlement characteristics, is ready for final commercialization. This will likely involve field validation across a broad range of materials and climates across the United States, vetting through the FHWA mixtures expert task group, development of an AASHTO test standard, round robin testing, and finalization of commercial equipment based data and experience from these subsequent efforts.

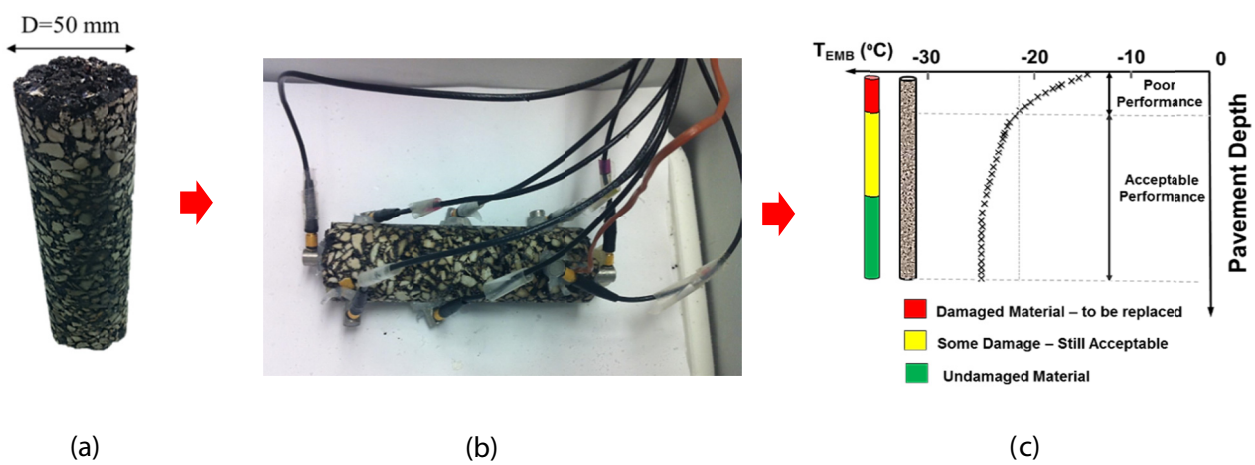


Figure 1

Continuous embrittlement temperature property characterization of age-graded field core materials: (a) 50-mm diameter field core sample, (b) AEA sensing system mounted on mixture sample, and (c) real-time graphical display of embrittlement temperature profile throughout the pavement thickness.

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all NCHRP-IDEA projects that were completed or active during the 2016 program year.

DEVELOPMENT OF AN INTRINSICALLY CONDUCTING POLYMER-BASED LOW-COST, HEAVY-DUTY, AND ENVIRONMENTALLY FRIENDLY COATING SYSTEM FOR CORROSION PROTECTION OF STRUCTURAL STEELS

NCHRP-IDEA Project 157

Tongyan Pan [Tel.: (312) 567-5860, Fax: (312) 567-3519, Email: tpan@iit.edu]
Illinois Institute of Technology, Chicago, Illinois

IDEA Concept and Product

The concept of this study is to use the intrinsic electroconductivity of a pi-conjugated polymer for the purpose of developing a cost-effective, heavy-duty, and environmentally friendly two-layer coating system for corrosion protection of structural steels. The project has two stages. In Stage 1, a properly doped pi-conjugated polymer was synthesized and used to make the primer layer of the proposed two-layer coating system. The primer was covered with a top-coat to ensure durability, aesthetics, and compliance with air-quality regulations. Table 1 lists the laboratory evaluation scheme of eight two-layer coating systems including Systems 3, 4, 7, and 8 that each have a primer made of the developed pi-conjugated polymer. Surface analysis tools including scanning kelvin probe force microscopy and electrochemical impedance spectroscopy, along with three ASTM standard tests ASTM B117, ASTM D5894, and ASTM D4541, were used to evaluate the long-term anti-corrosion capacity of the pi-conjugated polymer-based coating system. Figure 1 shows the cyclic-weathering test and adhesion test of the coated samples. It is expected that this novel and durable coating system will enhance the service life of steel structures such as highway bridges.

Table 1

Two-Layer Coating Systems Evaluated in Stage 1 (P: Primer, T: Topcoat)

System Number	Coating Description (primer/topcoat)	Nominal Dry-Film Thickness (μm)	Max VOC Content (g/L)
1	Zinc-rich Epoxy (P1)/Polyurethane (T1)	100/125	340/300
2	Zinc-rich Epoxy (P1)/Epoxy (T2)	100/125	340/250
3	PANi Epoxy (P2)/Polyurethane (T1)	100/125	340/300
4	PANi Epoxy (P2)/Epoxy (T2)	100/125	340/250
5	Epoxy (P3)/Polyurethane (T1)	100/125	250/300
6	Epoxy (P3)/Epoxy (T2)	100/125	250/250
7	PANi Water-based Epoxy (P4)/Polyurethane (T1)	100/125	340/300
8	PANi Water-based Epoxy (P4)/Epoxy (T2)	100/125	340/250

Figure 1

Cyclic-weathering test (left) and adhesion test (right) of coated steel panels.

Project Results

In Stage 2, the two-layer system based on the pi-conjugated polymer developed in Stage 1 was subjected to field testing to evaluate the durability of the system under field service conditions. Figure 2 shows the field testing stacks and the SEM images of the substrate-primer-topcoat interfaces for two of the systems after 1 year of field exposure; that is, System 3: PANi-Epoxy primer with a Polyurethane topcoat and System 5: Epoxy-only primer with a Polyurethane topcoat (refer to Table 1). Apparent corrosion products of substrate steel can be found under the epoxy-only primer (System 5) as opposite to the scenario under the PANi-Epoxy primer (System 3). The levels of blistering, rusting, undercutting, and pull-off strength of the coated steel panels were evaluated for the 1-year field-tested samples. It was found that System 3, which includes a PANi-Epoxy primer and a polyurethane topcoat, had comparable performance to System 1 that includes a zinc-rich epoxy primer and a polyurethane topcoat, both showing performance superior to the other systems.

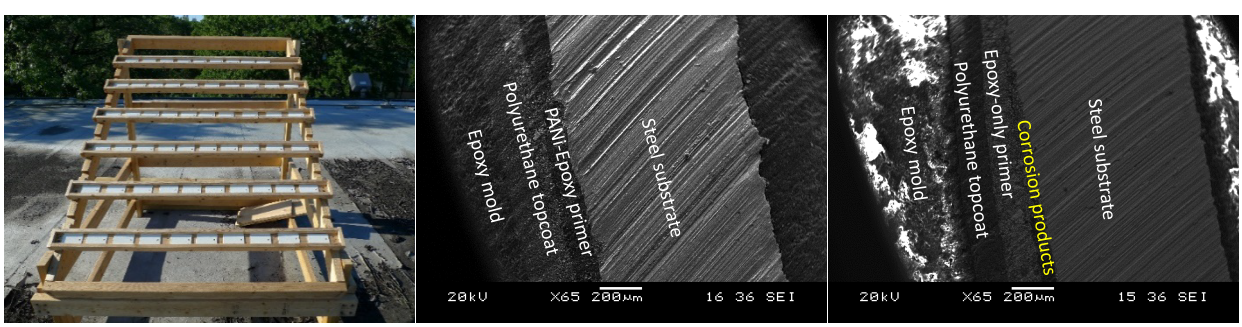


Figure 2

Field testing scheme (left) and SEM images of substrate-primer-topcoat interfaces of System 3 (middle): PANi Epoxy primer with a polyurethane topcoat, and System 5 (right): epoxy-only primer with a polyurethane topcoat.

Product Pay-Off Potential

Aiming to enhance the service lives of highway steel structures, this project will offer three extra potential benefits. First, the targeted two-coat system avoids the expensive removal of mill scale steel, which is required when applying the conventional zinc-rich system, leading to significant cost reduction for the end product. Second, the conductive polymer-based primer can be quickly applied and cured in open-air conditions, which can facilitate field coating repairs and replacements when needed. The coating system also has low material and production costs and negligible environmental impacts during service and after removal.

Product Transfer

At the end of Stage 2 the developed product was reported to TRB, which will be made available to interested highway agencies. Highway agency personnel will evaluate the product and provide feedback from the owner/designer/inspector perspective. Given satisfactory performance, the developed coating system will be further evaluated in the NEPCOAT states and eventually in the nationwide scope.

EXPLORATORY ANALYSIS OF AUGMENTED REALITY VISUALIZATION FOR RIGHT-OF-WAY EXCAVATION SAFETY

NCHRP-IDEA Project 167

Vineet R. Kamat [Tel.: (734) 764-4325, Fax: (734) 764-4292, Email: vkamat@umich.edu]
University of Michigan, Ann Arbor, Michigan

IDEA Concept and Product

An excavator unintentionally hits a buried utility every 60 seconds in the United States, causing billions of dollars in damage each year. Most of these accidents occur along public rights-of-way (ROWs). Typically, these accidents occur either because excavator operators do not know where utilities are buried (inaccurate or missing utility location data) or because they cannot perceive where the utilities are relative to the digging excavator (inaccurate spatial perception). This IDEA project attempted to address these problems by exploring new methods to communicate "quality-aware" utility location data to equipment operators during excavation (Figure 1). The research plan focused on creating and evaluating two key capabilities: (1) persistent visualization of assets buried in an excavator's vicinity using a georeferenced augmented reality (AR) approach, and (2) real-time monitoring of an excavator's proximity to underground utilities using a graphical emulation approach. These unique capabilities can allow an excavator operator to be visually aware of buried assets in a machine's vicinity and provide a real-time quantitative measure of a machine's distance to nearby obstructions, significantly reducing the potential of buried utility strikes in ROW excavation.

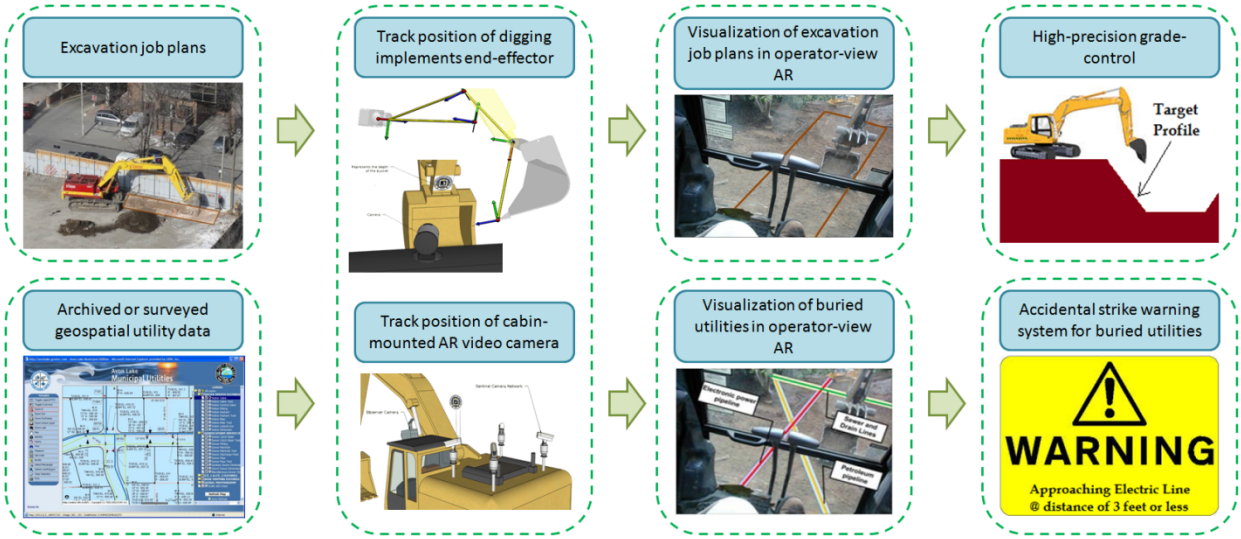


Figure 1

Augmented reality visualization of geospatial utility data: precise grade-control (above) and utility avoidance (below).

Project Results

Phase II of the project concluded this year and focused on practical implementation of the designed algorithms on excavators in the field. Prior technologies in place to determine the pose of an articulated excavator were investigated and the limitations in current methods were analyzed. The pose of an articulated machine includes the position and orientation of not only the machine base (e.g., tracks or wheels), but also each of its major articulated components (e.g., stick and bucket). A computer vision-based solution using a network of cameras and markers was designed to enable such a capability for articulated machines. A planar marker is magnetically mounted on the stick (dipper) of an excavator. Another marker is fixed on the job site, whose 3D pose is pre-surveyed in a project coordinate frame. Then a cluster of at least two cameras respectively observing and tracking the two markers simultaneously forms a camera-marker network and transfers the excavator's pose into the desired project frame, based on a pre-calibration of the relative poses between each pair of cameras. Through extensive sets of uncertainty analyses and field experiments, this approach was shown to be able to achieve centimeter level tracking accuracy within 10 meters with only two ordinary cameras and a few markers. A working prototype was tested on several active construction sites with positive feedback from excavator operators confirming the solution's effectiveness (Figure 2).

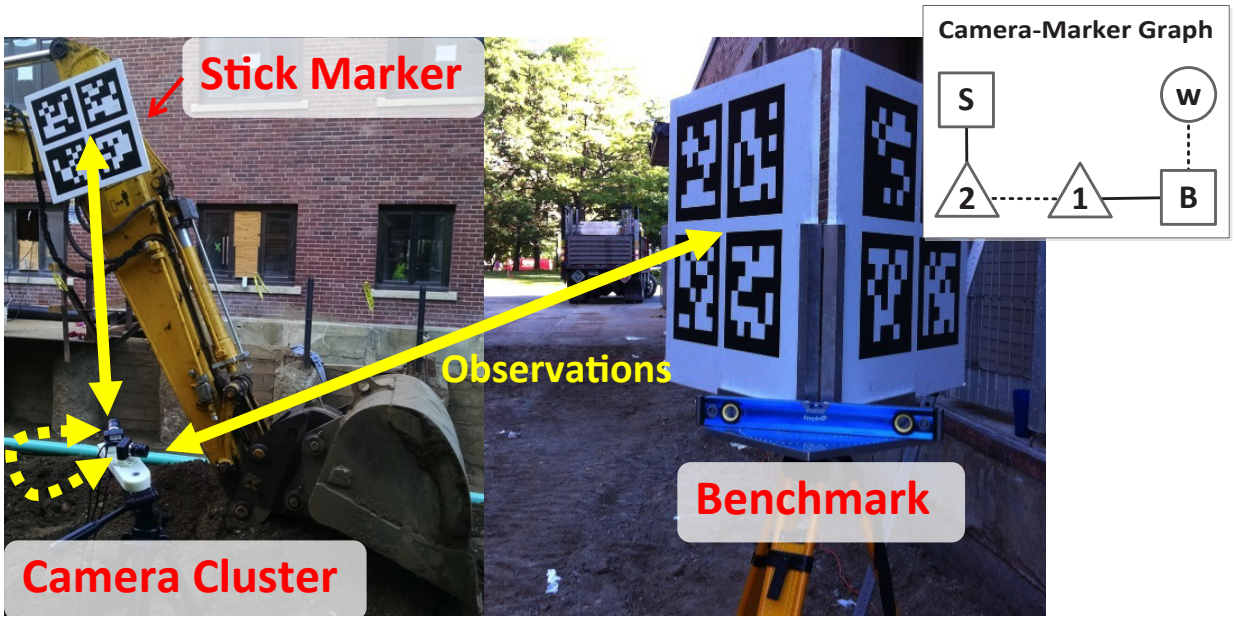


Figure 2

Overview of computer vision-based pose estimation system.

Product Pay-Off Potential

Accidents involving excavator hits to utilities have been a long-standing and significant societal problem that leads to unacceptable fatalities, injuries, property damage, and other costs each year. Inadvertent utility strikes disrupt life and commerce and pose physical danger to workers, bystanders, and the general public. The explored innovations from this IDEA project can potentially transform excavator operation from a skill-based to a knowledge-based process so that future accidents are prevented.

Product Transfer

This IDEA project was conducted in collaboration with multiple industry stakeholders that included the DTE Energy Company (Michigan's largest electricity and gas provider), Miss Dig System (MDS) (Michigan's one-call excavation safety company), Eagle Excavation (specialty excavation contractor), and Walbridge (large general contractor). Many of these collaborators are also associated with the Michigan Infrastructure & Transportation Association (MITA), which is a statewide construction trade association that consists of nearly 600 Michigan companies representing construction disciplines such as road and bridge, sewer and water, utility, railroad, excavation, and specialty construction throughout the state of Michigan. The industry collaborators have provided the research team with expert guidance on how the developed technology would impact their established member markets and access to their excavators on construction sites for experimentation. The participation of the industry stakeholders has been guiding the knowledge transfer and commercialization process for the IDEA products explored in this project.

PRODUCING A SUSTAINABLE AND BIO-BASED ALTERNATIVE FOR PETROLEUM-BASED ASPHALT

NCHRP-IDEA Project 171

Elham Fini [Tel.: (336) 285-3676, Fax: (336) 334-7126, Email: efini@ncat.edu]

Mahour Mellat-Parast [Tel.: (336) 285-3111, Email: mahour@ncat.edu]

Daniel Oldham [Tel.: (336) 334-7737, Email: djoldham@aggies.ncat.edu]

Zachery Mclaughlin [Tel.: (336) 334-7737, Email: zrmclaughlin@gmail.com]

Shahrzad Hossein Nezhad [Tel.: (336) 809-2121, Email: sh.hosseinnezhad@yahoo.com]

North Carolina A&T State University, Greensboro, North Carolina

IDEA Concept and Product

This project is investigating production of asphalt binder from animal waste to address the issue of diminishing petroleum resources and the need for reproducible alternatives to petroleum asphalt binders. In addition, the approach could provide a solution for animal waste management by synthesizing a new bio-binder from pig waste. The project will use the thermochemical liquefaction processing of swine manure to produce bio-oil, which will be further polymerized and fractionated using vacuum distillation to produce a bio-binder.

Project Results

The project has proceeded in two stages of research. In the first stage, a vacuum distillation unit was developed and experimentally customized for distilling bio-oil. Specific attention was given to removing odor and certain functional groups from the bio-oil to not only enhance its quality but also the ease of application. After removing specific compounds from bio-oil, physiochemical characterization of the residue so-called bio-binder was conducted. Gas chromatography–mass spectrometry (GC-MS) and Fourier transform infrared (FT-IR) analysis showed that bio-binder mainly consists of aromatic and naphthalene compounds. Comparing chemical structure of asphalt binder and bio-binder by FT-IR analysis showed very similar functional groups. Bio-oil fractionation under vacuum distillation has been done to separate certain desirable components and further study their chemical structures and formation process. Chemical characterization was conducted utilizing several analytical tools (CHN, GC-MS, GPC, H-NMR, C-NMR, TLC-FID, SimDist, and FT-IR) to evaluate chemical structure of bio-binder and further correlate that with bio-binder mechanical properties. The rheological characterization is under way using a Brookfield viscometer and a dynamic shear rheometer (DSR) to study the viscoelastic properties of bio-binder in comparison with petroleum-based asphalt binder. Study results so far have shown better performance in both lower temperature and higher frequency for bio-binder compared with petroleum-based binder.

Furthermore, the effect of introducing ground tire rubber to bio-binder is being investigated. According to chemical analysis, the rubber polymer gradually penetrates into the resin part of bio-binder while alkanes and aromatics are absorbed into the rubber particles. The initial experimentation was conducted by blending 10% rubbers into bio-binder at shearing rate of 1,000 rpm. Viscosity and DSR data were analyzed to evaluate the effect of the introduction of rubber into bio-binder as measured by the change in its physical and chemical properties.

Bio-modified rubber (BMR) has been produced by introducing bio-binder (ranging from 5% to 50%) into two asphalt rubbers (with 15% and 20% rubber content). Rheological investigation showed that BMR with enhanced elastic properties, rutting resistance, and temperature susceptibility could be obtained through this process. Figure 1 shows phase angle parameter (δ) for blends made with 15% rubber and modified with at various percentages of bio-binder.

Rheological studies showed that the addition of bio-binder to rubberized asphalt could be divided into three phases: lubrication, surface treatment, and dilution. Viscosity measurements showed significant reduction by introducing 5% bio-adhesive to a blend with 20% rubber concentration, which appears to be the lubrication effect. When bio-binder content increased beyond this point, viscosity value remained almost constant up to 20% bio-binder content; the latter can be attributed to the dissolution of rubber due to interaction between amine compound and disulfide bonds between styrene butadiene polymers. Further increase of bio-binder beyond 20% led to continuous reduction in viscosity indicating saturating of the rubber surface with bio-adhesive working as diluent. It was concluded that to optimize the use of bio-binder, its content should be designed to maximize rubber surface treatment while avoiding dilution.

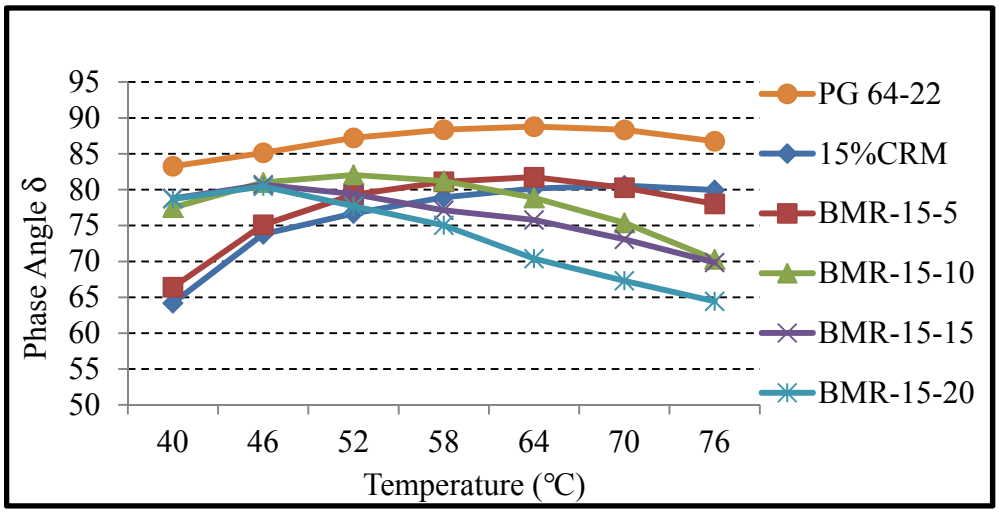


Figure 1

Effect of temperature on bio-modified rubber phase angle (δ).

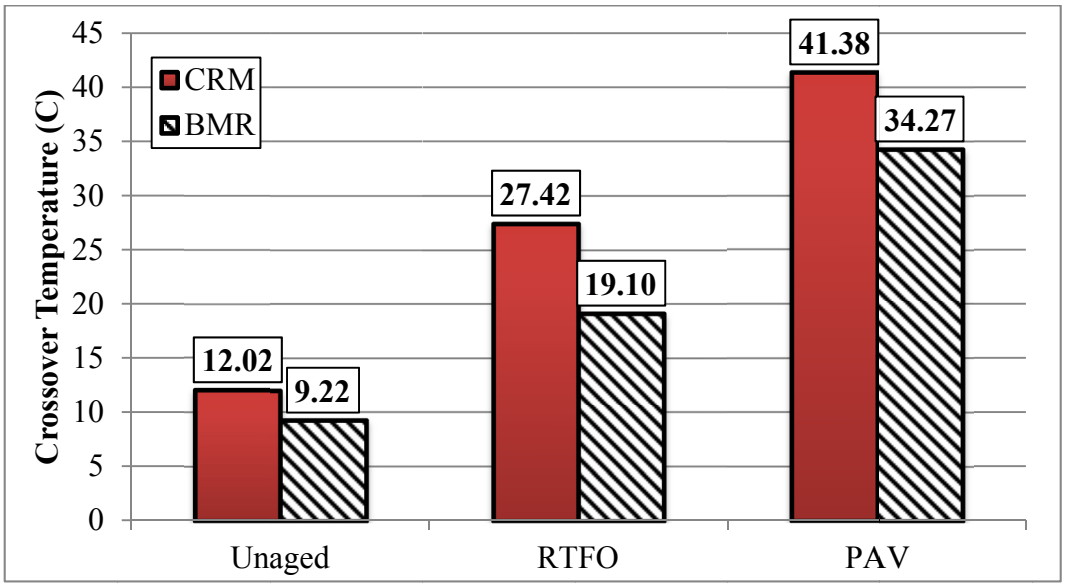


Figure 2

Crossover temperatures from BMR and CRM crossover frequencies for unaged, RTFO, and PAV specimens.

As it can be seen in Figure 2, the crossover temperatures are given for the unaged, RTFO, and PAV CRM and BMR modified binders. The crossover temperatures of the BMR are shown to be consistently lower compared with the CRM specimens, even after short- and long-term aging. This may be attributed to enhanced aging resistance of bio-modified rubber, which is achieved not only because of partial surface devulcanization of the rubber, but also because of lower affinity of BMR component to oxidation. The latter stems from a dual-protection mechanism of bio-binder components that defers asphalt aging: the less reactive molecular species found in bio-binder that show little propensity toward oxidation and consequently are less affected by the new polar functionalities and the highly reactive components (such as α-tocopherol) that are the primary targets for oxidative attacks, acting as sacrificing elements to save key components of asphalt materials (such as asphaltenes) from oxidative agents. Our polarizability calculations further showed that bio-binder constituents are considerably less polarizable than asphalt molecules. Lower polarizability of BMR component is indicative of the lower propensity of these chemical species toward new polar functionalities arising from the presence of oxidative agents.

To study further the effects of conditioning time, the stiffness of both CRM and BMR after 0 and 12 hours of isothermal conditioning at –18°C were compared. It can be seen in Figures 3 and 4 that both the CRM and BMR had stiffness values 34% and 40% lower than that of the neat binder. BMR was shown to have a 15% lower stiffness value compared with the CRM at 0 hour conditioning. However, after isothermal low temperature conditioning, the CRM stiffness was shown to increase 20%, while the BMR increased only 10%. Therefore, the inclusion of bio-binder showed improved results compared with the CRM even after 12 hours at cold temperature (six degrees below binder low temperature grade, which in this case is PG 64-22). The study of fracture energy values measured using the direct tension test method also showed that after PAV aging the BMR had significantly higher fracture energy at both 0- and 12-hour conditioning (Figure 4).

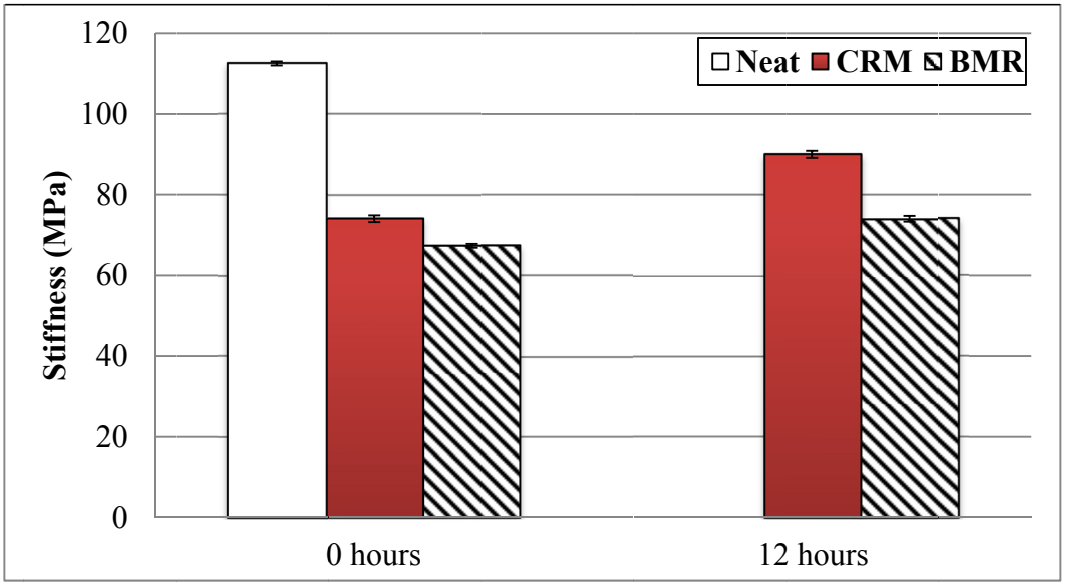


Figure 3

BBR stiffness results for unaged neat, CRM, and BMR at 0 and 12 hours conditioning.

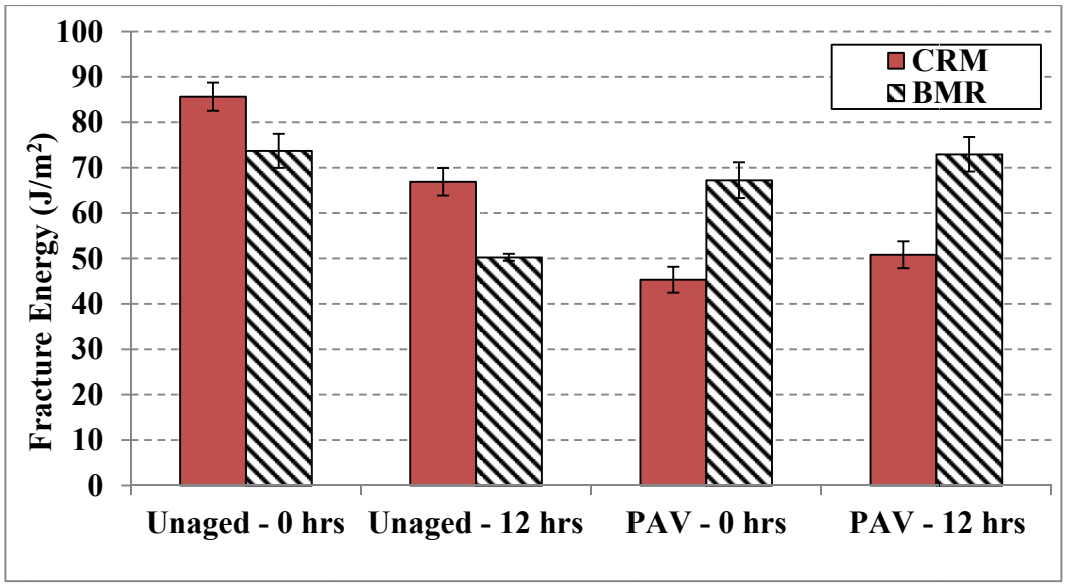


Figure 4

Fracture energy for unaged and PAV aged CRM and BMR at 0 and 12 h conditioning at –18ºC.

Furthermore, analysis of the FT-IR spectra confirmed that surface devulcanization of scrap tire takes place during the process of bio-modification releasing some of the polymer chains. The rubber polymer release was most evident when 20% rubber was treated by 20% bio-binder (by the weight of asphalt binder). Therefore, this combination was selected as the most suitable BMR asphalt among the scenarios studied in this IDEA project and was used in mixture evaluation.

At the mixture level a comparison among BMR, neat asphalt and crumb rubber modified asphalt without bio-binder (CRM) was performed. Initial study showed that the level of compaction energy required for BMR specimens was relatively lower than those of CRM specimens indicating a better workability in BMR specimens. In addition, it was found that both BMR and CRM samples have better rutting resistance in the Hamburg wheel track test compared with neat asphalt. Overall, BMR mixtures found to be softer than CRM, with this being even more evident at low temperatures. During the creep test performed at low temperatures (0, –12ºC, and –24ºC), BMR samples were shown to have higher creep compliance than both neat and CRM. Accordingly, it was shown that BMR samples took more energy to fracture during DC (T) fracture tests (following ASTM D7313) compared with both CRM and neat samples (Figure 5).

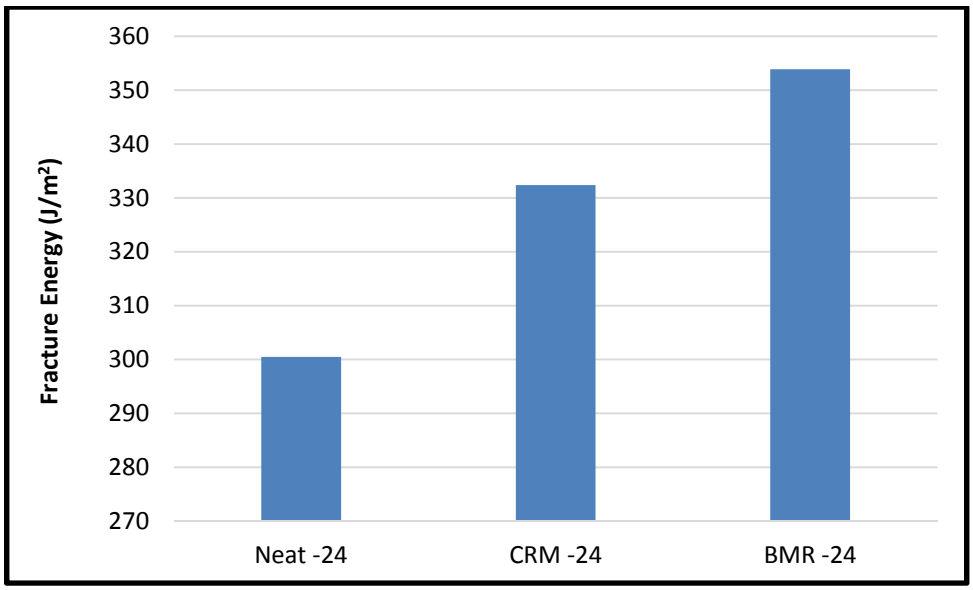


Figure 5

Comparison on DC (T) fracture energy results among Neat, CRM, and BMR Mixtures at –24ºC.

Product Pay-Off Potential

BMR asphalt is a novel adhesive with specific rheological properties that can be engineered to behave similar to petroleum asphalt. BMR can provide significant positive environmental impact, including reduction of greenhouse gas emissions, water pollution from swine manure stored in lagoons, and pavement construction and maintenance cost while providing alternatives to petroleum-based asphalt. When manure is transformed to bio-binder, the majority of carbon and nutrient content are left in the by-product of the process, the so called bio-char. This is when the bio-binder produced in this process is composed mostly of carbon (about 72%); therefore, it sequesters a large proportion of the carbon from manure. Overall, the outcome of this project can allow 40.2 million tons of swine manure produced annually in the United States to be used to supply about 28 million tons of bio-binder for use as a complimentary supply for petroleum-based asphalt binder used in pavement construction In addition, BMR can promote application of rubber modified asphalt by facilitating application and re-use of recycled rubber while enhancing mixture workability, reducing extent of rubber-asphalt segregation during mixing and compaction and enhancing its low temperature performance.

Product Transfer

This project produced BMR asphalt for use in pavement construction. Other application of BMR could be in roofing, sealing, and flooring. However, this NCHRP-Phase I IDEA project focused on producing BMR solely for application in pavement. To facilitate and accelerate technology transfer, the team is planning to design and build a prototype to be scalable and produce enough BMR for placing a trial road section. Upon validation, the commercial units will be developed via strategic alliance with rubber recyclers and asphalt blending terminals. BMR production facilities will be built close to hog farms at centralized locations.

We talked to several asphalt blending terminals and asphalt plants and contractors who showed interest in including BMR in their product portfolio. Accordingly, the research team is closely working with industry partners to ensure successful technology transfer and implementation of the scale-up process. Building on our experience from phase I project testing several combinations of bio-modified rubber, we have determined suitable processing parameters to produce effective BMR. Such processing parameters will be further built into the prototype to produce BMR for trial field sections. The technology has received good market traction so far, while being featured by the following multiple media outlets:

http://www.cnbc.com/2016/06/29/paving-roads-with-pig-manure.html

https://news.science360.gov/archives/20160628
https://www.nsf.gov/news/special_reports/science_nation/swinebioadhesives.jsp

http://www.gizmag.com/pig-manure-asphalt/44110/?utm_source=Gizmag+Subscribers&utm_campaign=e3e07d832e-UA-2235360-4&utm_medium=email&utm_term=0_65b67362bd-e3e07d832e-91093113

http://www.elmundo.es/motor/2016/07/05/577b8ed422601d56758b4657.html

http://www.popsci.com/roads-paved-with-pig-manure-could-mean-cleaner-future

http://www.equipmentworld.com/future-roads-may-contain-100-more-pig-poop/?utm_source=daily&utm_medium=email&utm_content=07-09-2016&utm_campaign=Equipment%20World&ust_id=9c0b99f1b25445f1fdfed89b088a31b7#

BIDIRECTIONAL-DUCTILE END DIAPHRAGMS FOR SEISMIC PERFORMANCE AND SUBSTRUCTURE PROTECTION

NCHRP-IDEA Project 172

Michel Bruneau [Tel.: (716) 645-3398, Fax.: (716) 645-3733, Email: bruneau@buffalo.edu]

Xiaone Wei [Email: xiaonewe@buffalo.edu]

Luna Ngeljaratan [Email: lunangel@buffalo.edu] University at Buffalo, Buffalo, New York

IDEA Concept and Product

This project seeks to develop a bidirectional ductile diaphragm concept to implement ductile end diaphragms in skewed bridge superstructures in order to simultaneously resist bidirectional earthquake excitations. Like the limited existing ductile diaphragm addressed by the AASHTO *Guide Specifications for Load and Resistance Factor Design* (*LRFD*) *Seismic Design* (Section 2.1.1), it would also limit demands in substructure elements. The concept relies on hysteretic energy dissipation devices (also referred to as structural fuses because they are intended to be easily replaceable devices) arrayed to provide ductile response to horizontal earthquake excitations acting from any direction. Two proposed end diaphragm systems (EDSs) (i.e., geometrical layouts) are proposed for this purpose, namely EDS-1 and EDS-2, which are described as follows:

- End Diaphragm System-1 (EDS-1): Two pairs of structural fuses are installed at each end of a span, in a configuration that coincides with the skew and longitudinal directions (Figure 1a).
- End Diaphragm System-2 (EDS-2): A single pair of structural fuses is installed at each end of a span at an angle that does not coincide with the bridge longitudinal and skew directions (Figure 1b).

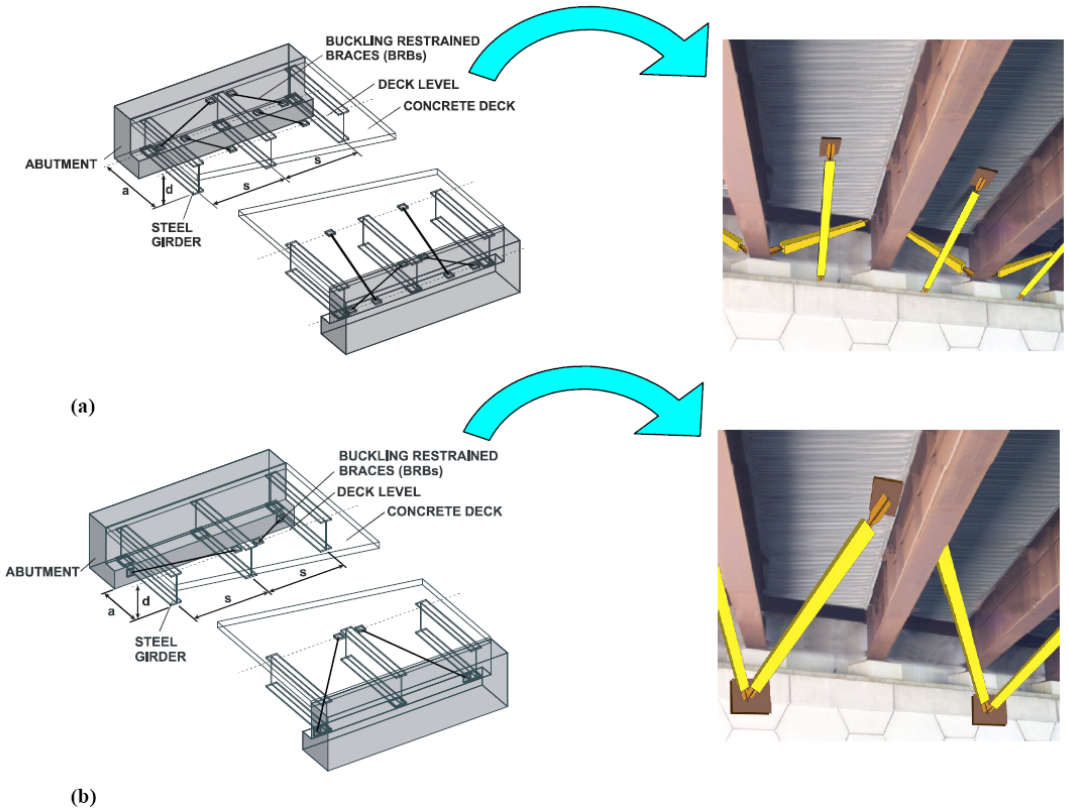


Figure 1

Proposed schemes for bridge ductile end diaphragms: (a) end diaphragm system-1 (EDS-1); (b) end diaphragm system-2 (EDS-2).

Project Results

In Stage 1, the two proposed ductile EDSs were designed for benchmark skew and nonskew bridges and analyzed using nonlinear time history analysis to examine their seismic performance. Buckling Restrained Braces (BRBs) were used to serve as the diaphragm ductile seismic fuses (other hysteretic energy dissipation devices could equally work for this purpose). Variations in skew, fundamental period of vibration, and earthquake excitation characteristics were also considered. These dynamic analyses allowed investigating the impact of these parameters on global behavior, as well as understanding the magnitude of local demands and the extent of bidirectional displacements that the BRBs must be able to accommodate while delivering their ductile response. A design procedure for the EDSs in skew bridges with BRBs was developed based on the analysis results. The long-term service life of EDSs installed across expansion joints and subjected to bridge thermal expansion histories was also investigated and a minimum ratio of the BRB length over the whole bridge length was recommended. Work was also conducted to identify preliminary effective and practical details for BRBs. The outcome of Stage 1 is an understanding of expected dynamic seismic performance as a function of key design parameters, and details for the proposed energy dissipated elements to be investigated in Stage 2. Work in Stage 2 involving quasi-static experiments were conducted to subject BRB to a regime of relative end displacements representative of the results predicted from

parametric analytical studies in stage 1. A test set-up was developed consisting of connecting the BRB from the strong floor to a shake table in the SEESL. One end of the BRB was connected to a reaction block tied down to holes in the strong floor, while the other end was connected to the shake table. The table was then used to apply horizontal bidirectional end displacement demands to the BRB. The loading protocols included the bidirectional displacement histories to be applied to the specimens for the cyclic inelastic test and the uniaxial displacement histories for the low cycle fatigue test due to temperature changes. Two types of BRBs with flat end plates and unidirectional pinholes, BRB-1 and BRB-2, were designed. The end plates of BRB-1 were designed to bend laterally to accommodate the required lateral displacement. The end plates of BRB-2 were connected to a spherical bearing, itself kept in place in a pre-drilled hole in the gusset plate in the reaction block. The spherical bearing works as bidirectional hinge (similar to those used by some dampers manufacturers). Four specimens of each type of BRB were tested and different combinations of displacement protocols were applied to them. BRB's hysteretic behaviors under different displacement protocols were studied and compared. The ultimate behavior of a BRB was typically quantified in terms of the cumulative inelastic displacements that the BRB's core plate experiences during the tests. All the BRB specimens tested developed cumulative inelastic deformations of more than 200 times the BRB's axial yield displacement, which is the threshold of inelastic performance specified by the AISC Prequalification and Cyclic Qualification Testing Provisions as part of its acceptance criteria for BRBs. More significantly, the specimens were able to sustain multiple years of severe temperature cycles in addition to meeting the prequalification criterion. Ultimately, as expected, all the BRBs failed in tension after extensive cycles of inelastic deformations. No end-plate failure or instability was observed (which would have been undesirable failure modes). Following the tests, some BRBs were opened. It was found that fracture typically occurred where the BRB's core plate locally buckled the most. Detailed analyses of cumulative inelastic deformations and low-cycle fatigue life of all BRBs using data from the experiments were performed. A recommended design procedure for the EDSs in both nonskew and skew bridges was developed based on the paramedic analysis and experimental results. The analytical and experimental work in Stages 1 and 2 in this project have demonstrated the feasibility of implementing the bidirectional ductile diaphragm in both skew and nonskew bridges. The BRB specifically designed end connection details (either by having a long end plate or have the

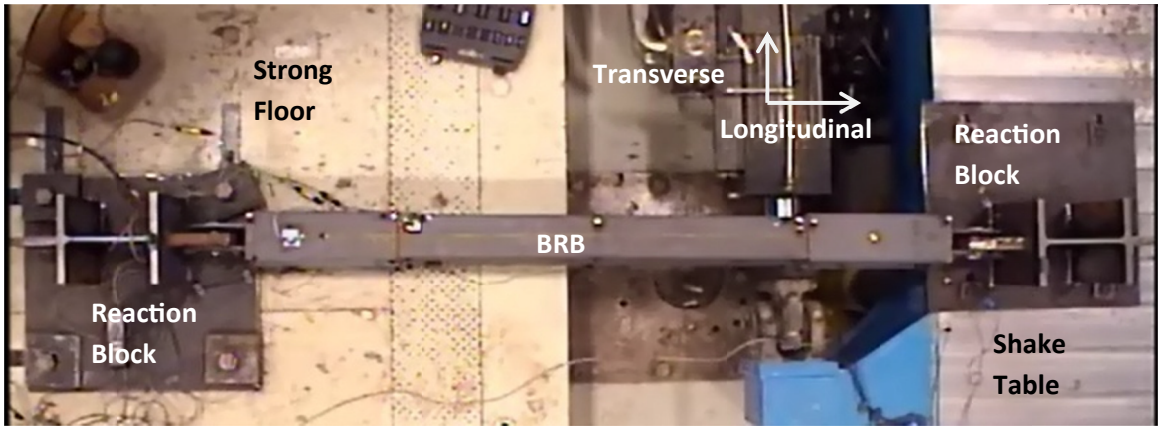


Figure 2

BRB test setup with BRB type 2.

spherical bearing configuration) performed adequately and succeeded after extensive cycles of inelastic deformations without end-plate failure or instability, under both bidirectional and temperature-induced axial displacement test protocols representative of expected demands in bidirectional ductile diaphragm applications.

Product Pay-Off Potential

Without addressing the issues of skew and bidirectionality, implementations of the ductile diaphragm concept will remain limited (or rare) because the ductile diaphragms covered by the AASHTO *Guide Specifications for LRFD Seismic Bridge Design* only work for bridges without skew and only provide resistance to earthquake excitations acting in the direction transverse to the bridge axis. This is a serious limitation and a real impediment to the implementation of ductile diaphragms, which is unfortunate because ductile diaphragms are a low-cost seismic solution compared with other alternatives. By providing an analytically and experimentally proven solution for ductile diaphragms able to explicitly address the fact that earthquakes simultaneously shake a bridge in all horizontal directions (not just transversely to the bridge axis), and by making this solution also applicable to skew bridges (a large percentage of all bridges), this research is therefore poised to make ductile diaphragms a commonly used seismic-resistance solution for most short and medium span steel bridges in all seismic regions (i.e., in regions exposed to low levels of seismicity, ranging up to those exposed to more severe earthquakes). Although the proposed research conducted in the perspective of new bridge design, the information generated by this project will be equally applicable to existing bridges for seismic retrofit purposes.

Product Transfer

Transitioning of this technology to field application will require (through NCHRP IDEA Type 2 research) shake table tests of a full bridge having bidirectional diaphragms to demonstrate the expected seismic performance, combined with analytical work to investigate how this technology can be implemented in multi-span bridges. Then, together with results from this project, the work will be used to formulate design guidelines and examples of bidirectional ductile diaphragms to resist earthquakes from any directions regardless of skewness, provided for implementation by AASHTO (via T3 Seismic and T14 Steel Design) and departments of transportation. Design engineers and consultants are the primary audience. If the product were adopted as a design document, it would significantly overcome potential impediments to deployment.

GRAPHENE NANO-PLATELET (GNP) REINFORCED ASPHALT MIXTURES: A NOVEL MULTI-FUNCTIONAL PAVEMENT MATERIAL

NCHRP-IDEA Project 173

Jialiang Le [Tel.: (612) 625-0752, Fax: (612) 626-7750, Email: jle@umn.edu]
University of Minnesota, Minneapolis, Minnesota

IDEA Concept and Product

Since the discovery of exfoliated graphene, graphene-based materials have found many engineering applications such as electronics, bio-devices, optical devices, etc., owing to its superior mechanical, thermal, and electronic properties. The objective of this research is to explore a new cost-effective multi-functional pavement material that is made from a combination of graphene nano-platelets (GNPs) and conventional asphalt mixtures. This research consists of two parts: (1) experimental investigation of various mechanical properties of GNP-reinforced asphalt binders and mixtures including creep stiffness, strength, and fracture energy; and (2) investigation of the compaction and rutting performance of GNP-reinforced asphalt mixtures. The results of these investigations will enable us understand the various aspects of the performance of this new class of asphalt materials, which may open many opportunities for various applications in asphalt industry.

Project Results

In this research, we investigated two types of properties of the GNP-reinforced asphalt binders and mixtures, which are highly relevant to the construction and performance of asphalt pavements. One is the mechanical properties of the asphalt binders and mixtures, and the other is the compaction performance of the asphalt mixtures. These two aspects represent the two phases of this research.

In the first phase of the research, we prepared the asphalt binder and mixture specimens with two types of binders (unmodified binder and polymer-modified binder) and three types of GNP additions, which included M750 (a graphene nano-flake powder with minimum 97% carbon), M850 (a graphene nano-flake powder with minimum 98.5% carbon), and 4827 (a surface-enhanced synthetic graphite material with 99% carbon). For each type of GNP addition, three different amounts of GNP (0%, 3%, and 6% by weight of the binder) were used in the experiments. For each mix design, we performed four types of mechanical tests: (1) a resilient modulus test at room temperature, (2) indirect tension creep test measuring the relaxation properties, (3) strength tests including the bending beam rheometer test and the indirect tension test, and (4) fracture test at low temperature measuring the fracture energy.

During the specimen preparation, it was found that the GNP can be mixed with asphalt binders without major dispersion issues. Mechanical tests showed that the addition of GNP can greatly enhance the strength of asphalt binders at low temperatures, moderately improve the creep stiffness, and have no adverse effects on the relaxation properties. Meanwhile, it has been shown that the GNP can also enhance the strength and fracture energy of asphalt mixtures at low temperatures. Figure 1 presents the comparison of the measured flexural strengths of asphalt binders reinforced by different amounts of GNPs and Figure 2 presents the measured indirect tensile strengths of various GNP-reinforced asphalt mixtures.

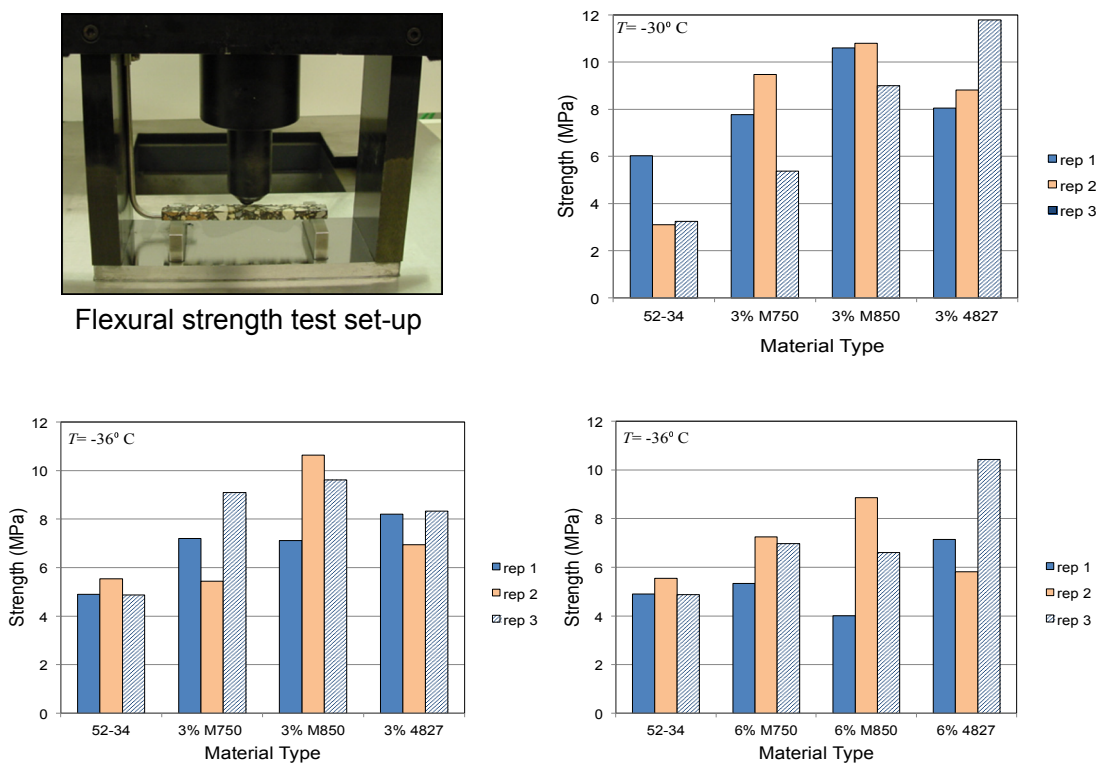
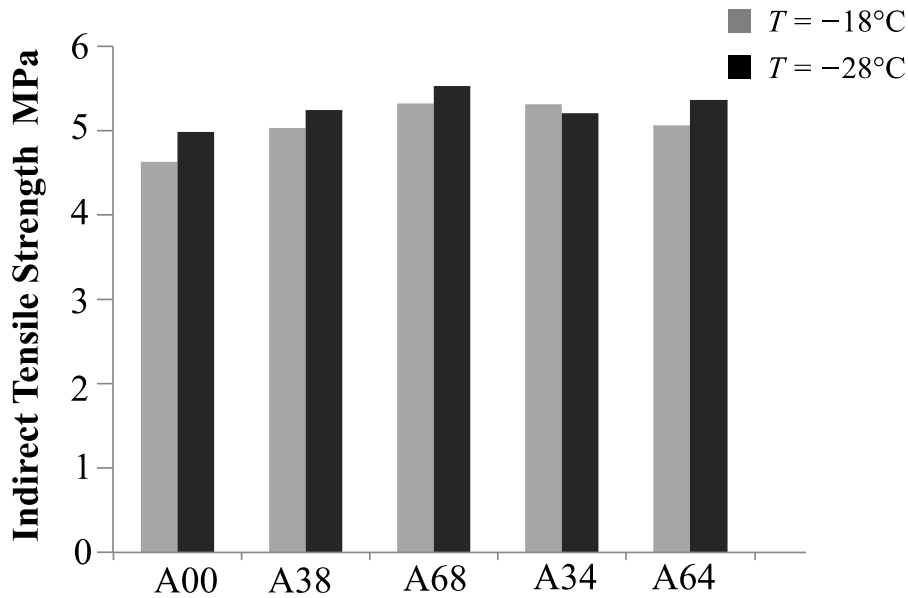


Figure 1

Comparison of flexural strengths of asphalt binders modified by different amounts of GNPs.



A00: Asphalt mixture with polymer-modified binder only
A38: Asphalt mixture with polymer-modified binder and 3% M850 GNP
A68: Asphalt mixture with polymer-modified binder and 6% M850 GNP
A34: Asphalt mixture with polymer-modified binder and 3% 4827 GNP
A64: Asphalt mixture with polymer-modified binder and 6% 4827 GNP

Figure 2

Indirect tensile strength of GNP-reinforced asphalt mixtures.

The second phase of the research focused on the compaction performance of GNP-reinforced asphalt mixtures. Based on the results of the first phase, we considered two types of GNP-reinforced asphalt mixtures for the compaction tests, which included the unmodified binder with 3% 4827 GNP and polymer-modified binder with 6% M850 GNP. The tests were performed by using a gyrator compactor, and the number of gyrations to reach a target air void ratio was recorded. It was observed that, for a given target air void ratio, the addition of GNP can reduce the number of gyrations by 20%–40% (Figure 3). Meanwhile, it was found that for some mix designs the GNP can also reduce the temperature dependence of the compaction process, which would allow engineers to produce warm asphalt mixtures. These results indicated that the GNP can effectively lead to a faster construction process for a given targeted air void ratio implying a reduction in construction costs. On the other hand, for a given number of gyrations, the GNP can reduce the air void ratio of the mixtures, which would improve the durability of the road.

In parallel with the compaction tests, we also performed the rutting test on the GNP-reinforced asphalt mixtures (polymer-modified binder with 6% M850 GNP). It was observed that the addition of GNP can improve the rutting performance of the asphalt mixtures, where the maximum rutting depth is reduced and at the same time the number of cycles to the maximum rutting depth is significantly increased (Figure 4).

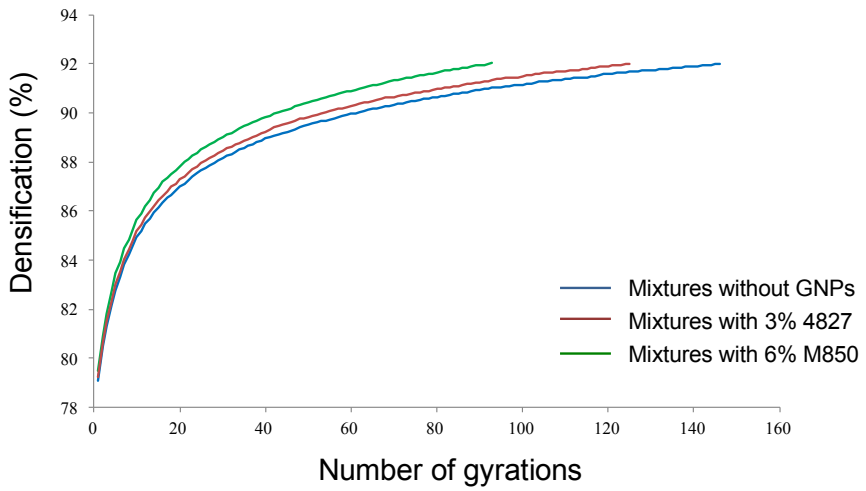


Figure 3

Measured compaction curves of GNP-reinforced asphalt mixtures.

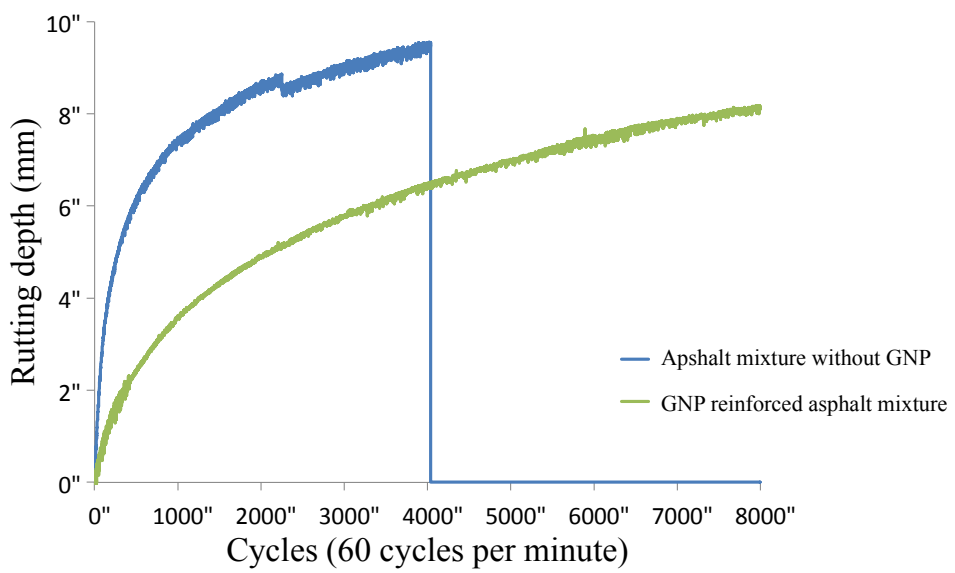


Figure 4

Rutting performance of GNP-reinforced asphalt mixtures.

Product Pay-Off Potential

This research effort provides the asphalt pavement community with a new multi-functional asphalt pavement material that has a number of attractive features including: 1) improved material properties in terms of stiffness, strength, and fracture energy, which could help us mitigate the mechanical damage especially in the cold environment; and 2) significant reduction of compaction energy and improved rutting performance. These features will enable us to build more durable and crack-resistant pavements, and at the same time to effectively reduce the construction time and cost.

Product Transfer

For this research, we have been in close collaboration with Minnesota Department of Transportation (MnDOT). MnDOT has kindly assisted us with the mix designs and the rutting experiments. Through MnDOT, the findings of this research have been effectively disseminated to county engineers and contractors, which has inspired some new applications of this material for pavement rehabilitation. With the support from MnDOT, we are currently exploring different applications of GNP-reinforced asphalt materials, such as pothole repairs and full-depth reclamation. Through the University of Minnesota, a U.S. patent application has been filed for potential industrial commercialization of this new asphalt pavement material.

ENHANCED PERFORMANCE ZINC COATING FOR STEEL IN CONCRETE

NCHRP-IDEA Project 174

Neal Berke [Tel.: (269) 384-9980, Fax: (269) 384-9981, Email: nberke@tourneyconsulting.com]
Tourney Consulting Group, LLC, Kalamazoo, Michigan

IDEA Concept and Product

The objective of this study is to evaluate thermal zinc diffusion (TZD) coatings on reinforcing bars that provide the alloy bond found in hot-dipped galvanized (HDG) coatings with several advantages: (1) tighter thickness tolerances, (2) better ductility, (3) applicability to high tensile strength steels, and (4) less likely to embrittle. These coatings (ASTM A1059) have corrosion performance, surpassing (5–10X) that of HDG, but the use of these coatings in the past has been limited to fasteners and other hardware in atmospheric and marine exposures. This study will determine if TZD coated bars can provide cost-effective corrosion performance in concrete, with higher rebar cover depths, subject to cracking similar to that in field exposures, and when subjected to bending. Performance is being compared with black steel, epoxy-coated steel, HDG steel, low-chrome steel, and stainless steel. Another benefit of the program is the development of an accelerated test method to evaluate corrosion performance that is applicable to high-quality concrete.

Project Results

Results since the last report are discussed. However, the microstructure of the TZD bar versus a normal HDG bar is shown in Figure 1.

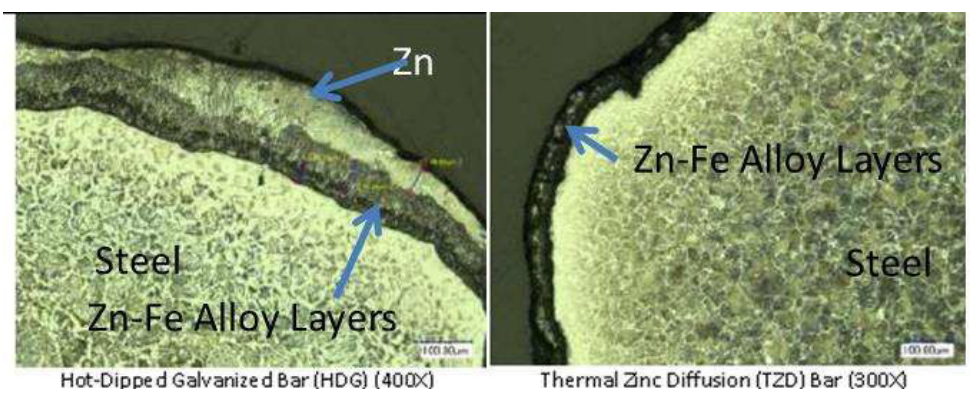


Figure 1

Comparison of HDG-coated rebar to TZD-coated rebar.

Corrosion testing in large beams with flexural cracks that are wedged open to approximately 0.01 in. was completed after 2 years of testing, under an extension of the original program. The beams were flexed to 75% of their 28-day flexural strength at multiples of 6 cycles (1 week chloride ponding, 1 week dry). The corrosion data continue to show that all of the alloy and coated reinforcing bars are outperforming the black bars. Both zinc-coated bars have shown a significant decrease in corrosion from the first ponding cycle, significantly less corrosion activity than the black bar controls. Beams were removed from testing after 34 cycles for chloride analyses and visual autopsy of the reinforcing bars. The remaining beams were autopsied at the end 52 cycles of corrosion testing. Figure 2 shows several cracked beams in corrosion testing. Although the coating was thinner on the TZD bars versus the HDG bars, performance was equivalent to better. The TZD bars were found to reduce chloride ingress below the crack, and analysis of the data shows that corrosion potentials follow a similar trend to black bar when corrosion initiates. This could facilitate monitoring of the field performance versus HDG bars.

Figure 2

Large cracked beam corrosion specimens. Specimens are 6 x 6 x 20-in.

Bent bars (U-bends) in concrete were evaluated in partial ponding in sodium chloride solution. At the end of testing at 2 years, black bar specimens had high measured corrosion rates and substantial rust staining on the surface that was not present in the other specimens. Chloride analyses were performed and show equivalent chloride contents in all the specimens. The TZD specimens are showing a high corrosion rate, but no damage. This is presumed to be due to the high surface area and electrochemical impedance spectroscopy supports that conclusion. Specimens were removed at the end of July 2015 for autopsies. The remaining specimens were autopsied in a similar procedure as used for the beams, and results are being analyzed for the final report. The first draft of the report will go out in the first week of August 2016.

Product Pay-Off Potential

If the TZD-coated bars perform well, they will provide a cost-effective alternative to epoxy-coated and HDG bars, and an enhanced service life cost advantage compared with stainless steel. Since the cracking and concrete cover is similar to the worst field cases, there should be a good correlation to expected field performance. In addition, a new test method will be available that can be used to determine how future products will perform. The U-bend specimens will provide data as to how the bars will perform when severely bent. The extended testing was strongly endorsed by the Review Committee, as the data will be useful to their departments of transportation and other agencies in determining which reinforcing bars to use.

Product Transfer

Several DOTs have expressed interest in the technology. TCG will work with the DOTs to evaluate the bars in a field application, and in larger specimens. A service life analysis using advanced modeling tools will be employed to determine life-cycle costs.

RAPID DETECTION OF FATIGUE CRACKING IN STEEL ANCHOR RODS USING THE IMPULSE RESPONSE METHOD

NCHRP-IDEA Project 175

Stephen Pessiki [Tel.: (610) 758-3494, Fax: (610) 758-5902, Email: pessiki@lehigh.edu]
Lehigh University, Bethlehem, Pennsylvania

Wesley Keller [Tel.: (610) 758-3525, Fax: (610) 758-5902, Email: wjk207@lehigh.edu]
Lehigh University, Bethlehem, Pennsylvania

Shamim Pakzad [Tel.: (610) 758-6978, Fax: (610) 758-5902, Email: pakzad@lehigh.edu]
Lehigh University, Bethlehem, Pennsylvania

IDEA Concept and Product

This project seeks to develop a nondestructive test procedure utilizing stress wave interrogation for fatigue crack detection in steel anchor rods for auxiliary highway structures; for example, sign, signal, and luminaire structures. A primary focus of the study is the development of a damage detection algorithm that will provide a relatively high level of sensitivity for crack detection (considering that fatigue cracks spend long periods of time as a small fraction of the anchor rod diameter), and that will be readily adaptable to a wide range of anchorage construction and in situ conditions. The technologies developed by the study will aid in the design of a prototype device for rapid inspection of steel anchor rods that will improve crack detection capabilities and inspection efficiency.

Project Results

Work to date has focused largely on a laboratory experimental program to detect the presence of known artificial cracks (saw cuts) in full-scale anchor rod assemblies. Variables treated in the tests include crack size and test configuration, including impact (source of stress waves) and receiving transducer positions on the anchor rod assembly. The experimental data from these laboratory tests, which also included tests of isolated rods with and without anchorage hardware, was used to evaluate potential damage features (i.e., characteristics of the instrument measurements) for crack identification, and to develop a reliable and repeatable test procedure. By establishing a baseline measurement for an uncracked rod, and evaluating the change in Mahalanobis distance between the alpha coefficients of regression models fitting the test data, the test method was able to identify saw cut cracks at the base of the leveling nut (a region known to be susceptible to fatigue cracking). Work is ongoing to improve the repeatability and sensitivity of the test method.

Experimental Program

Figure 1 shows the large-scale, structure-foundation anchorage assembly constructed for the experiments. The assembly is composed of a 30 in. diameter × 36 in. concrete foundation with eight 2 in. diameter × 3 ft-9 in. F1554 Gr36 steel anchor rods, and can be configured to study both single locking nut and double locking nut construction, as shown in Figure 2(a). The base plate for the assembly is a 27 in. diameter × 2 in. A709 steel section with a 22 in. bolt circle and 2-5/16 in. diameter holes. The offset dimension between the bottom of the base plate and

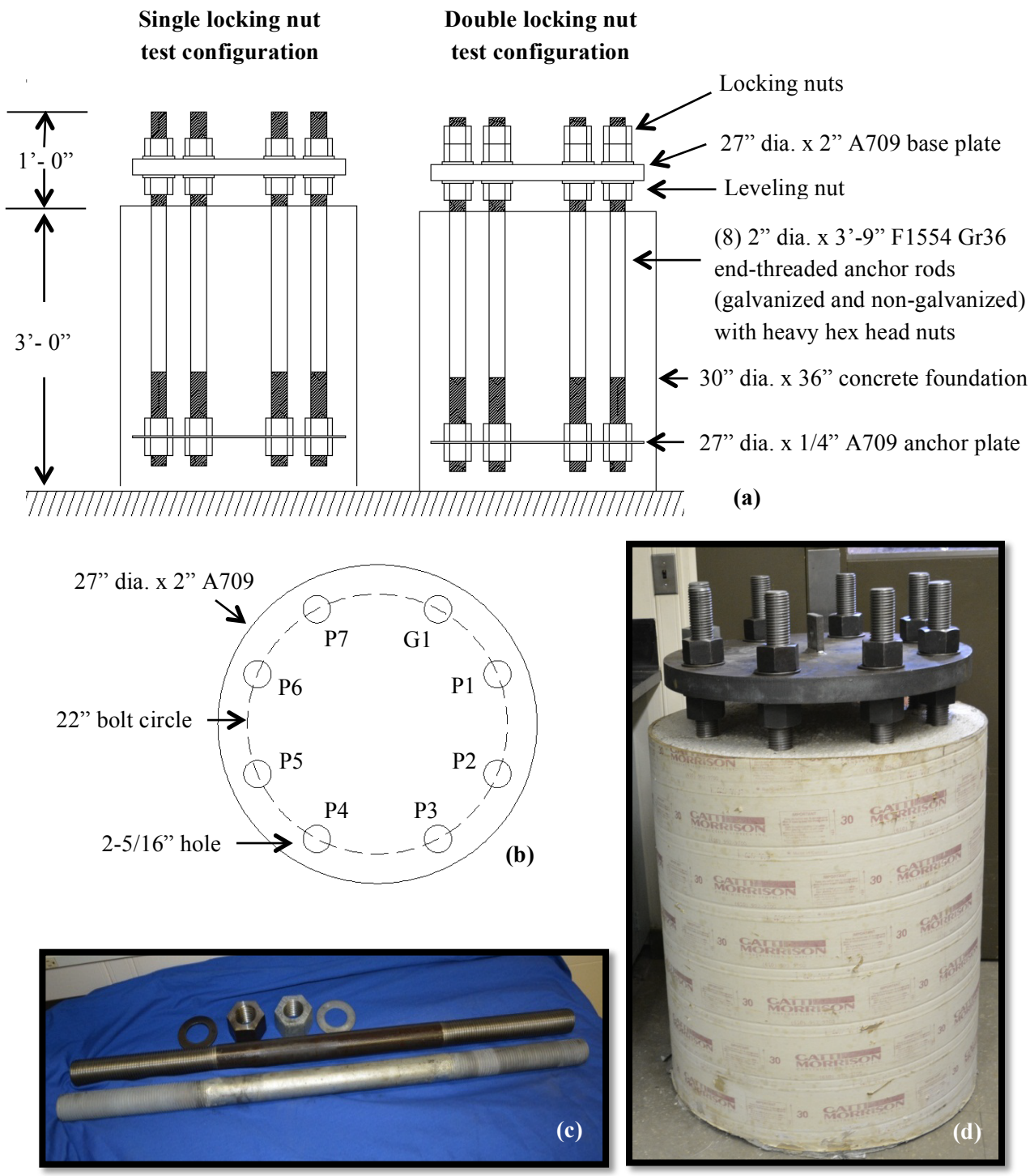


Figure 1

Structure-foundation anchorage assembly: (a) single locking nut and double locking nut test configurations, (b) base plate geometry and anchor rod designations, (c) galvanized and non-galvanized end-threaded F1554 Gr36 anchor rods with heavy hex head nuts and washers, and (d) completed assembly (single locking nut configuration shown).

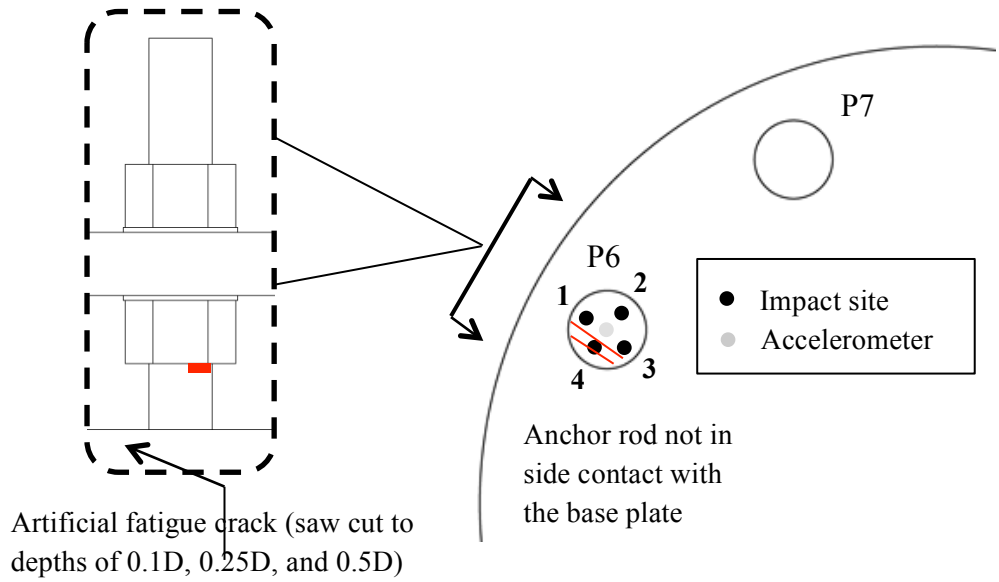


Figure 2

Test configuration for the crack detection study.

the top of the concrete foundation is 4.25 in. The assembly also includes an embedded 27 in. diameter × 1/4 in. A709 steel anchor plate that is located 7 in. from the base of the foundation. The heavy hex nuts used in the assembly are 3.5 in. (width across flats) × 2-13/64 in. thick. The anchor rod-to-base plate connection uses 4 in. diameter × 1/4 in. washers, while the anchor rod-to-anchor plate connection excludes washers. The anchor rod nuts located below the base plate are designated as the "leveling nuts," whereas the nuts located above the base plate are designated as "locking nuts." Designations for the plain (non-galvanized) and galvanized anchor rods are shown in Figure 1(b), noting that the 'P' designation denotes a non-galvanized rod and the 'G' designation denotes a galvanized rod. All of the anchor rods investigated in the study were partially threaded at both ends [Figure 1(c)], with a 12 in. threaded length and a thread pitch conforming to the ANSI/ASME B1.1 Unified Coarse Thread Series (4.5 threads/in.).

Baseline Testing of Isolated and Embedded Anchor Rods without Anchorage Hardware

Baseline tests of isolated and embedded anchor rods without anchorage hardware were conducted in order to identify geometric features and material interfaces attributed with stress wave reflections, to evaluate frequency content for stress wave interrogation, and to characterize signals for uncracked rods without anchorage hardware. The tests were conducted using a specially designed instrumented hammer and a piezoelectric accelerometer. The accelerometer has a flat response range (±5%) out to 10 kHz and a resonant frequency of 70 kHz. In both the isolated and embedded rod tests, the accelerometer was mounted to the top surface of the rod (near the center) using a high vacuum grease coupling agent. The instrumented hammer was used to impart a stress pulse in the rod by impacting the top surface near the quarter points in the four cardinal directions.

Baseline Testing of the Completed Structure-Foundation Anchorage Assembly

In order to characterize impulse response measurements for uncracked anchor rods and to evaluate the effect of anchorage construction (specifically, side contact between the anchor rods and base plate) on crack detection, testing was conducted on the completed structure-foundation anchorage assembly [(Figure 1(d)]. Similar to the isolated and embedded rod tests without anchorage hardware, the accelerometer was mounted on the top surface of the rod (near the center) using a high vacuum grease coupling agent, and the instrumented hammer was used to impart an impulse at four designated impact sites. To explore the role of transducer coupling, additional tests were performed with the transducer threaded in to a drilled and tapped hole in the top of the anchor rod.

Example Result—Crack Detection Study

As an example of a result, rod P6 was tested with a saw cut crack at the base of the leveling nut over a range of crack depths (Figure 2). This crack location was selected based on experimental tests of the fatigue performance of double nut anchorage connections under cyclic loading. Crack depths of 10%, 25%, and 50% of the rod diameter (D) were investigated. The crack was introduced at the location that allowed for the closest placement of the crack to the base of the leveling nut. Field experience and testing has shown that cracking generally initiates in a groove near the first thread engagement due to non-uniform stress distribution in the threaded connection. This places the crack near an abrupt geometric transition in the assembly (i.e. the base of the leveling nut).

Regression Models and Damage-Sensitive Features

In order to identify indicators of fatigue cracking in impulse response data, several damage-sensitive features extracted from univariate and multivariate regression models were considered, including alpha-based regression coefficients, angle coefficients, cosh spectral distances, and regression residuals. Of the investigated features, alpha-based regression coefficients show promise as a reliable indicator of anchor rod cracking.

Evaluation of impulse response data for the purpose of damage identification involves measuring the variation in the response signal from a known baseline (healthy or uncracked condition). Since the recorded data is a collection of discrete points, regression models are employed to develop best-fit functions for statistical comparison. Autoregressive models (AR) are a particular classification of regression model that relate the current value of a time series to past values of the same series. In the present application, the AR models are used to fit accelerometer recordings, which are normalized by the maximum peak. The AR model (Eqn 1) can be expanded to include information about the system from past and present time points:

$$y_j(n) = \sum_{p=1}^{P} \alpha_p y_j(n-p) + \varepsilon(n) \tag{1}$$

where y_j is the output at location j, α_p's are AR coefficients, $\varepsilon(n)$ represents the residuals, n is the time index, and P is the order of the AR model.

When the driving (or exogenous) input is considered, the modeling approach is referred to as autoregressive with exogenous input (ARX), where the time series is not only a function of its own history, but also the present and past values of the exogenous series (Eqn 2).

$$y_j(n)+\sum_{p=1}^{P}\alpha_{jp}y_j(n-p)=\sum_{q=0}^{Q}\beta_{iq}y_i(n-q)+\varepsilon(n) \tag{2}$$

where the subscripts i and j designate unique locations, β_{iq}'s are exogenous coefficients, and P and Q are the order of the AR and exogenous parts, respectively.

For regression coefficients, Mahalanobis distance (Eqn 3) can be used to form a scalar representation of the regression coefficients for direct comparison.

$$D_m(x)=\sqrt{(x-\mu)^T S^{-1}(x-\mu)} \tag{3}$$

where μ is the mean of the baseline regression coefficient matrix and S is its covariance matrix.

Damage Feature Extraction and Crack Detection

Damage feature calculations from the test measurements were performed using the DIT (Damage Identification Toolsuite) software (Pakzad, S., Shahidi, G., Yao, R., and Chamberlain, M. (2014) Damage Identification Toolsuite (DIT), Center for Advanced Technology for Large Structural Systems, Lehigh University). Normalized accelerometer records were used as input in a univariate regression model analysis. In order to remove the influence of the initial R-wave (surface wave), which is more sensitive to variation in impact location, the first 80 μs was removed from the records. The accelerometer records were then down-sampled from 500 kHz to 50 kHz in order to constrain the regression model to the frequency range of interest. Finally, the records were normalized by the first positive peak in order to account for variability in impulse magnitude, as well as coupling strength and instrument sensitivity.

The initial study considered 50 baseline measurements and 20 measurements for each crack depth with impact over the cracked section. Thirty of the baseline measurements were used to establish the regression model (model order of 30), while the remaining twenty served as the control data for establishing a baseline Mahalanobis distance between alpha coefficients ($D_m\alpha$). Figure 3 presents the mean Mahalanobis distance for each crack condition. Tests of the 0.25D and 0.5D cracked rod produced mean distances of 7.9E15 and 8.2E15, respectively, while tests of the uncracked rod (control data) and the 0.1D cracked rod produced mean distances of 2.3E15 and 2.9E15, respectively. As a result, tests of the 0.25D and 0.5D cracked rod could be distinguished from the uncracked baseline with at least 95% confidence.

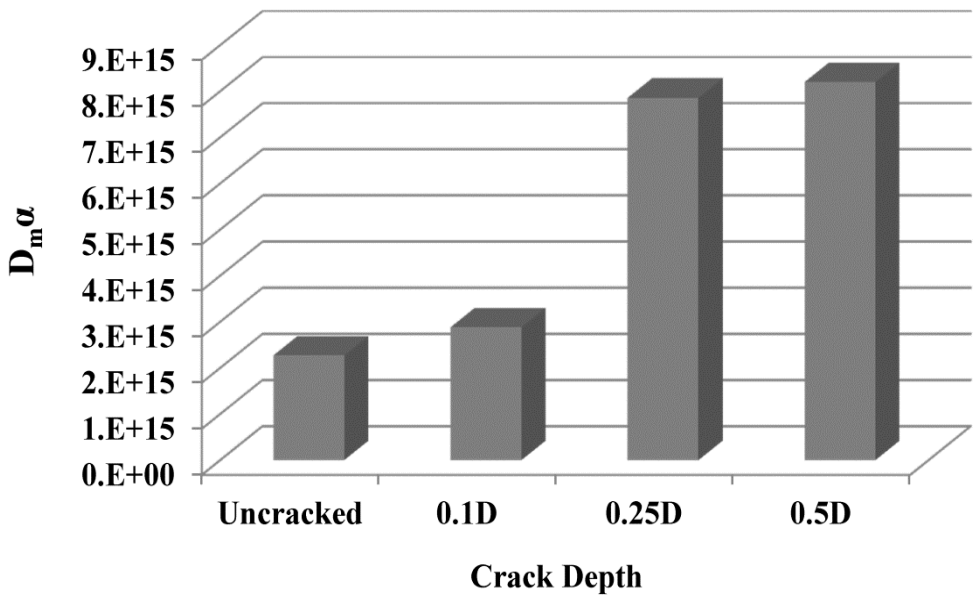


Figure 3

Mean Mahalanobis distance between the alpha coefficients of regression models fitting the P6 test data for various crack depths.

Product Pay-Off Potential

This project seeks to develop a nondestructive stress wave, interrogation-based test procedure for identifying fatigue cracks in steel anchor rods. The objective is to develop a robust and reliable test approach and damage detection algorithm that can be implemented in a portable, easy to use device for rapid inspection of steel anchor rods, thereby improving crack detection capabilities and inspection efficiency.

Product Transfer

During the final phase of the project, field trials will be conducted to evaluate practical implementation of the test procedure and to identify essential design features for the prototype testing device. Feedback from state DOT agencies and equipment manufacturers during the study will ensure that the end product can be readily integrated into existing or planned inspection programs.

CONTACTLESS ELECTRODE FOR FAST SURVEY OF CONCRETE REINFORCEMENT CORROSION

NCHRP-IDEA Project 176

Alberto A. Sagüés [Tel.: (813) 974 5819, E-mail: sagues@usf.edu]
University of South Florida, Tampa, Florida

IDEA Concept and Product

The project develops a device for a means to sample the surface of reinforced concrete with a novel contactless electrode, providing rapid and stable electrode potential mapping for early corrosion detection. Unlike present technology, the electrode response is nearly instantaneous and without need for surface preconditioning or contact with the concrete surface. The outcome could thus allow low-cost corrosion surveys, from moving vehicles, of bridge decks in deicing salt service regimes, as well as rapid evaluation of other structure elements by means of traveling sensors. The electrode is based on the Kelvin Probe (KP) principle, where surface potential is measured by means of a vibrating disk placed near to but not touching the concrete surface, then zeroing the resulting alternating capacitive current. Its novel use on concrete in basic laboratory conditions has been recently demonstrated in early trials with promising results. In this project, the probe will be adapted for practical potential profiling on field concrete surfaces and from a wheeled platform. If successful, the technology can become a powerful additional tool for rapid assessment of the corrosion condition of bridges at low cost, permitting much wider deployment than present methods and improving the ability of transportation agencies to implement timely corrosion control measures.

Investigation in Progress

Project Stage 1 took a miniature proof-of-concept KP electrode device and scaled it up to dimensions suitable for realistic field conditions. In the resulting prototype, the rugged vibrating wire mesh disk is 10 cm in diameter and hovers at up to 2 cm above the concrete surface on a wheeled platform. The device operation was demonstrated on an outdoor reinforced concrete test slab, where part of the rebar assembly can be made at will to be anodic to the rest, replicating local corrosion conditions. Results were highly encouraging. The sequential nearly instantaneous KP contactless measurements from the mobile platform, without disturbing the concrete surface, successfully identified the anodic location in the resulting potential map. Subsequent validation tests with a slower conventional surface contacting copper/copper sulfate electrode confirmed the potential pattern.

Stage 2, which is in progress, has demonstrated coordinated operation of probes for effective potential mapping and field operation. An array of two independent probes was constructed and made to operate jointly in a wheeled platform. The probe array has been successfully operated on a bridge deck in cooperation with the Florida Department of Transportation, providing results consistent with those obtained by slower traditional methods (Figure 1). Additional cooperative tests are sought with agencies working on the FHWA Long Term Bridge Performance Program with instrumentation that includes a robotic assisted bridge inspection tool.

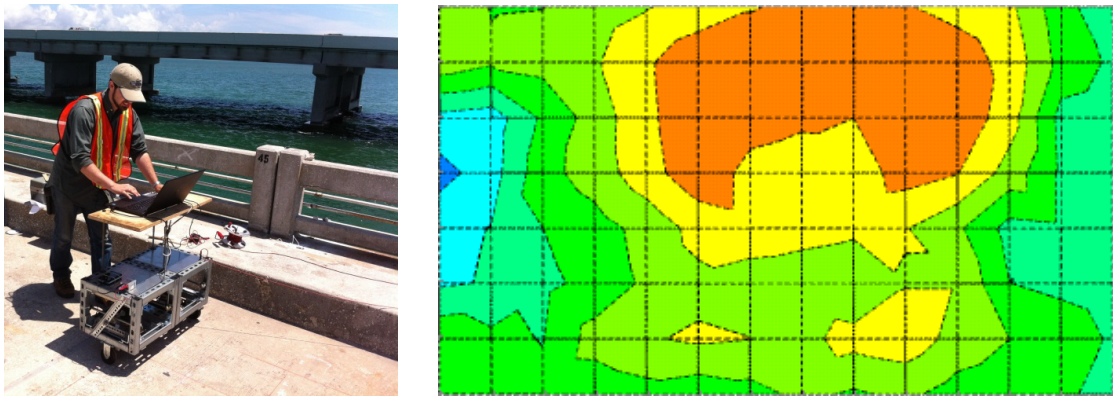


Figure 1

Left: Dual probe prototype (Patent Pending) in field tests on an aged Florida reinforced concrete bridge deck. Right: Potential map obtained by the contactless probe successfully spots rebar corroding region (roughly the orange area, with steel potential hundreds of mV more negative than places further away) on an ~3 x 5 m deck portion. Results are consistent with traditional contact electrode measurements on the same portion.

Project Pay-Off Potential

The availability of contactless probe systems could dramatically expand the availability and updating of corrosion condition information on much of the national bridge deck inventory in deicing salt and marine regimes. Operations that in the past required extended lane closings and costly labor contracts could now be conducted with minimal traffic disruption and at a fraction of the cost. Hence, corrosion diagnostics could be conducted routinely and frequently; for example, concurrent with regularly scheduled periodic bridge inspections. Frequent evaluations have the added benefit of aiding to reveal evolving features that would be missed in a single time snapshot survey. The resulting aggregate data could then be an integral feature of the bridge maintenance record, providing transportation agencies with an important added tool in assessing the need for remedial action and for forecasting future resource demands.

Importantly, the contactless probe systems would also enhance the collective safety of a state transportation system by providing early warning of corrosion damage. That damage would otherwise have remained undetected if evaluation had to wait until resources became available for a conventional potential survey.

Product Transfer

This project resolves scale-up technical issues necessary to establish functionality in a working prototype. During completion of the project the PI will contact candidate companies for development and construction of commercial units; U.S. patent applications are already in place from the preliminary experimental work conducted by the PI. The materials, circuitry components, and mechanical parts needed to construct this type of equipment in future commercial units are commonly available and readily adaptable from present day technology; therefore, potential for rapid implementation is high. Interactions with state and nationwide agencies are being sought during the project to establish a contact base for optimal transfer of the product of the investigation to practical application.

AUTOMATED TURNING MOVEMENT COUNTS FOR SHARED LANES USING EXISTING VEHICLE DETECTION INFRASTRUCTURE

NCHRP-IDEA Project 177

David A. Noyce [Tel.: (608) 265-1882; Fax: (608) 262-5199; Email: noyce@engr.wisc.edu]

Madhav Chitturi [E-Mail: mchitturi@wisc.edu]

Kelvin R. Santiago [Email: ksantiago@wisc.edu] University of Wisconsin, Madison, Wisconsin

IDEA Concept and Product

Existing vehicle detection systems can provide vehicular volume on a per-lane basis. However, breaking down the volume by movement type for shared lanes is not possible with commercially available systems without additional detection zones. Additional detection zones (virtual or real) on exit lanes could be used to estimate the turning movement counts. However, existing approaches are fraught with errors and cannot be accurately applied at all locations such as where right turn on red is permitted. No commercially available detection systems (including radar-based detection) can output turning movement counts at shared lanes without the use of supplemental detection zones. The proposed software-based system harnesses the potential of existing radar-based vehicle detection systems to automatically obtain turning movement counts for shared and non-shared lanes in a format useful for end users. The underlying analyses are possible by continuously monitoring the coordinates (x, y) of vehicles approaching the intersection in the underlying data stream of the vehicle detection system; something not possible with existing systems in the market today. Based on feedback from potential end users and members of the advisory panel, the project involved the creation of an algorithm capable of processing logged trajectory data and generating turning movement count reports. The approach used is a post-processing one; however, if closer to real-time computations are desired the frequency at which the reporting process runs can be increased to more than once a day. For example, it can be configured to produce reports every 15 minutes. The algorithm was implemented as a script in the R programming language.

Project Results

As of July 2016 the project was complete. An existing software tool was adapted to log trajectory data from a radar-based vehicle detection system in a format useful for the trajectory classification algorithm created as part of the project. Trajectory data were collected in Appleton and Madison, Wisconsin. The algorithm produces turning movement count reports using 15-minute intervals. An evaluation of the algorithm performance suggests that the average absolute error of the algorithm every 15 minutes is 2.3 vehicles. Figure 1 shows a sample visualization of the algorithm results. A final report documenting the details of the algorithm performance has been submitted to the NCHRP IDEA program.

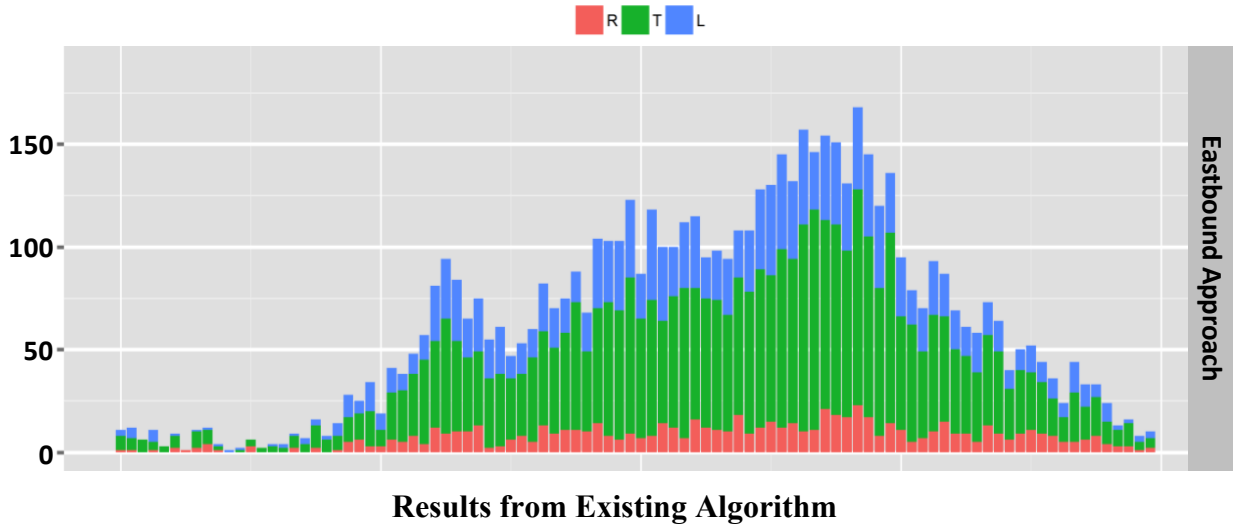


Figure 1

Sample visualization of algorithm results.

Product Pay-Off Potential

The most noteworthy impact of this innovation is the possibility of transforming every intersection equipped with radar-based detection (or any other system capable of monitoring vehicle trajectories) into an automatic traffic recorder that can log vehicle movements regardless of lane configuration. The transfer to practice can be achieved through improvements to the algorithm and by creating a market-ready solution. Turning movement data will have the most direct effect on signal retiming while enabling diverse applications in transportation operations, planning, and safety domains. According to the *Signal Timing Manual* (STM), outdated or poor traffic signal timing accounts for a significant portion of traffic delay on urban arterials. Traffic signal retiming is one of the most cost-effective ways to improve traffic flow and mitigate congestion.

Despite several studies demonstrating the enormous benefits of signal retiming, many agencies are delaying or unable to perform the work due to diminishing budgets and staff. The STM states that "Turning movement counts are typically one of the more costly items in the scope of a traffic signal retiming study." Hence, the proposed system can provide agencies with readily available turning movement count reports throughout the year without the need for additional capital investment (given that the algorithm developed can be implemented as a software solution) and significant staff time.

Product Transfer

Several thousand radar-based detection systems are currently in use at signalized intersections. Many more are expected because research has shown that they have superior performance among non-intrusive detection systems. Providing the additional capability of generating turning movement count reports (regardless of lanes configuration) could make radar-based detection systems more appealing to transportation agencies. Once the algorithm is implemented as a software tool the system could be licensed by manufacturers of radar devices. Therefore, new detection units could ship with the system pre-installed and existing units could be updated through a firmware upgrade or through a dedicated data collection unit placed inside the signal cabinet.

Furthermore, although the research is focused on trajectory data obtained from radar-based vehicle detection systems, the concepts developed are universal. As a result, the technology developed as part of this research could be used by vehicle detection systems that rely on technologies other than radar, but are capable of producing vehicle trajectory data. Consequently, the market for the proposed system is large and expected to increase with time.

DEVELOPMENT OF RENEWABLE POLYMERS FOR USE IN ASPHALT PAVEMENTS

NCHRP-IDEA Project 178

R. Christopher Williams [Tel.: (515) 294-4419, Fax: (515) 294-8216, Email: rwilliam@iastate.edu] Iowa State University, Ames, Iowa

IDEA Concept and Product

The continued high pricing of crude petroleum-derived products is creating opportunities for non-crude petroleum materials to be used as economic alternatives. In the asphalt materials industry these alternatives include the development of alternative binders from cellulosic-based materials through fast pyrolysis and the use of vegetable-derived products. Additional bioderived alternatives exist in the asphalt industry in the areas of anti-stripping agents, fluxes, and polymers. It is imperative that the bioderived products be cost advantaged, performance advantaged, or possibly both cost and performance advantaged. This NCHRP IDEA funded project is supporting further tuning of the developed biopolymers and supporting laboratory testing and analyses, production of biopolymers through a commercial scale pilot plant for subsequent use in demonstration paving projects including a test section on the National Center for Asphalt Technology Test Track.

Project Results

The project results for this year built on the finding from the previous year and focused on achieving improved asphalt-polymer blends and the development of mix designs. To achieve uniform dispersity of the polymers in asphalt binder, all modified blends were prepared by conducting the high temperature shear blending at 190°C temperature and 3,000 rpm shear rate for 3 hours at a polymer dosing of 3% by the total modified blends weight. The following summarizes the outcome of this work for this project.

- The varying functionality PS-PAESO polymers were blended with a neat asphalt binder (PG 52-34). The critical high temperatures obtained from a DSR (dynamic shear rheometer) were compared with the critical high temperatures of neat asphalt binder and Kraton® D1118 SB modified asphalt binder. The results are shown in Figure 1.
- Considering the possibility of physically synthesizing the predicted formulated PS-PAESO, several different formulations were suggested to produce. One of the predicted PS-PAESO with 35 kDa of polystyrene molecular weight and 5% of polystyrene content was produced for verification. The predicted critical high temperature was 66.7°C and the actually produced PS-PAESO was tested in DSR and the obtained critical high temperature was 65.0°C, which is only 1.7°C removed from what the formulation models estimated.
- The PS-PAESO with 10 kDa of polystyrene and 20% of polystyrene-modified asphalt binder was retested in the same TA DSR for high temperature performance grade after one-year storage in an alumina can. The critical high temperature was exactly the same as one year ago, implying that the polymer was well dispersed and swelled in the asphalt after blending with good storage ability.

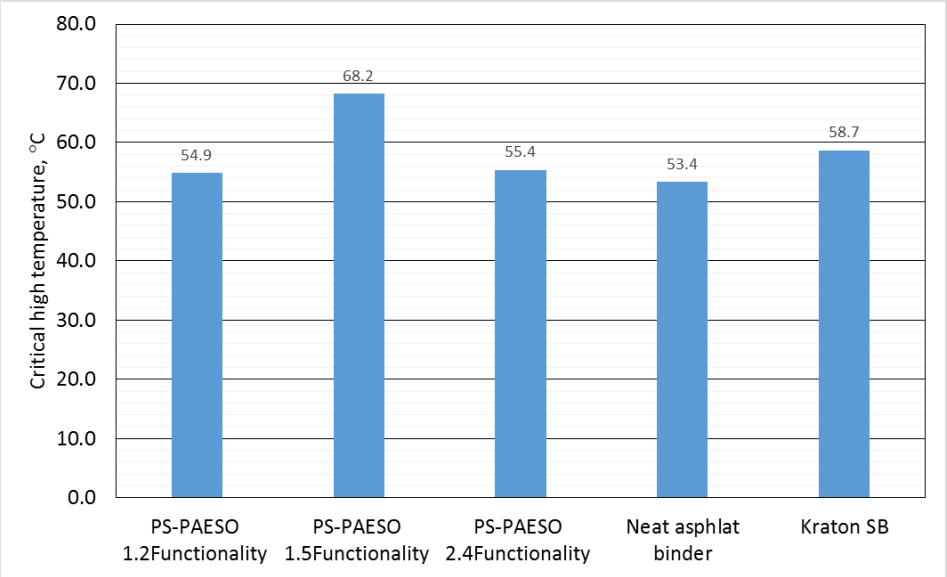


Figure 1

Critical high temperature results.

- The linear viscoelastic (LVE) regions of the materials at different test temperatures were quantified by performing strain sweep tests on the neat asphalt binder, Kraton® SB modified asphalt binder, and PS-PAESO modified binder. The strain sweep tests were performed on 8 mm and 25 mm plates in a DSR. The most appropriate strain for 8 mm and 25 mm size materials should be set up at 5% (at 20°C and 30°C) and 10% (at 40°C, 46°C, 52°C, 58°C, and 64°C), respectively. Therefore, smoother master curves and black diagrams can be obtained for comparing the stiffness and elasticity of the materials.
- A mix design was developed following the Iowa Department of Transportation (DOT) hot mix asphalt (HMA) design criteria. The HMA was designed for 30 million design equivalent single axle loads, a high trafficking level typical of interstate highways. Three trial gradations (Figure 2) were developed by using ½ in. limestone, 3/8 in. limestone, quartzite, manufactured sand, natural sand, and agg lime.

The mixtures were prepared according to AASHTO specifications using a Superpave gyratory compactor to produce specimens for volumetric analysis. However, the estimated volumetric and mixture compaction properties for the first two trial blends at 4.0% air voids @ Ndes failed to meet all of the volumetric mix design criteria, whereas the third mix design did meet the criteria.

Product Payoff Potential

The initial polymers produced by a demonstration scale facility will only serve a small fraction of the total markets reachable by thermoplastic elastomers at a price point below that of butadiene with equal or better performance. To realize the full potential of this emerging family of environmentally benign polymers, ongoing research is being done both at the benchtop and on the process floor with the NCHRP IDEA program.

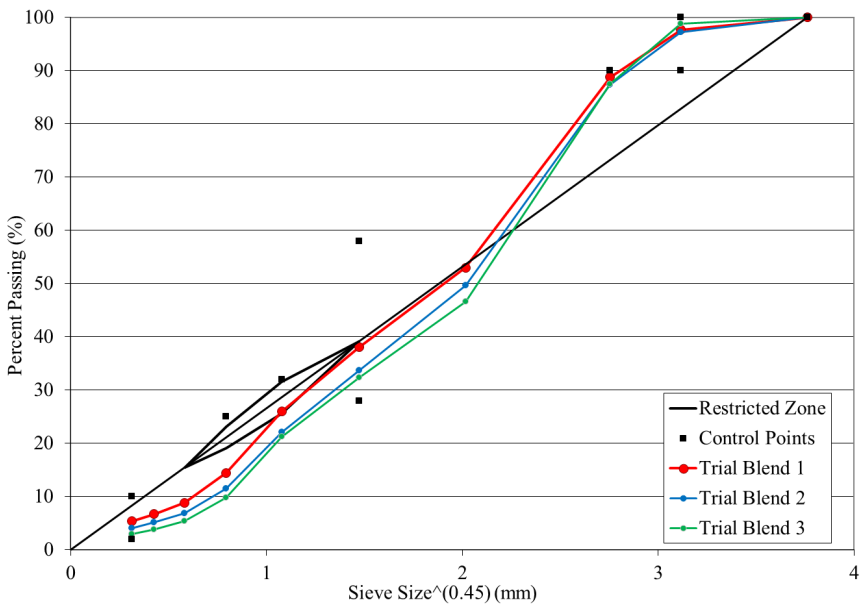


Figure 2

Trial gradations.

Product Transfer

Argo Genesis Chemical, a partner company of Seneca Petroleum, has spent and allocated more than $12 million toward bringing the technology to a demonstration scale level with a 1 ton per day facility that was donated to Iowa State University in August 2015 and is shown in Figure 3. The commissioning of the pilot plant is nearing completion with an anticipated production timeframe of Fall 2016.

Figure 3

Commercial scale pilot plant in Boone, Iowa.

DEVELOPMENT OF A PORTABLE TOTAL-STRESS MEASUREMENT INSTRUMENT

NCHRP-IDEA Project 179

Glenn A. Washer [Tel.: (573) 884-0320, Fax: (573) 882-1365,
Email: washerg@missouri.edu] University of Missouri, Columbia, Missouri

IDEA Concept and Product

The concept is a portable instrument that provides bridge engineers with quantitative, easy-to-interpret measurements of the in situ forces carried in steel bridge members. This tool will assist in the condition assessment of bridges by identifying critically stressed members to improve analysis, identify repair or replacement needs, and ensure bridge safety. The proposed technology is a nondestructive measurement tool based on ultrasonic birefringence measurement technologies previously developed and tested by the research team. The key innovations in this research include the ability to measure in situ stresses in bridge members for both dead and live loads, the development of a unique approach for testing the proposed method in the field, the development of a practical field-portable instrument, and the development of new methods to identify critically stressed structural members. The product of the research is the development of a portable, battery-operated instrument that can be applied for practical field measurements.

Project Results

The project is nearing completion. A prototype instrument has been developed that is battery-operated and suitable for field application (see Figure 1). The technology consists of a custom designed transducer that enables the unique Ultrasonic Stress Measurement (USM) to be completed in a matter of seconds. A custom enclosure suitable for field implementation contains data acquisition, battery, signal processing, and a wireless communication link. Newly developed software operates on a separate laptop computer to analyze data transferred wirelessly from the instrument. Data are processed to provide the magnitude of stress at the position of the transducer.

The project included a number of laboratory tests that were used to develop the USM technology, characterize key properties of typical bridge steels, and develop procedures for implementation. Figure 1B shows results from laboratory testing of the USM technology for measuring shear stresses, comparing the USM results (using birefringence) with conventional strain gage measurements. The ability of the technology to operate under field conditions was demonstrated with a field test during which the technology was implemented on a highway bridge in Missouri. During the field test, shear stresses in the gusset plate of a truss bridge were determined under different loading scenarios. Because the technology measures total stress, including dead load, live load, and residual stresses, verifying this technology presented a unique challenge. The USM technology was verified using strain gage measurements; this required a special procedure for the strain gages, which normally are unable to measure total stress (including dead load) for an in-service highway bridge. Results of the field test demonstrated that the USM technology could be practically implemented under field conditions for the measurement of total stress.

Product Pay-Off Potential

The research in this project will help to meet the need for innovative methods to evaluate bridge structures by providing a tool for evaluating the level of total stresses in gusset plates and other steel structural members, such that the in situ stresses can be compared with the calculated capacity of the members to ensure the safety of the bridge. There is currently no other tool that can perform a total stress measurement on a highway bridge. The new technology could be very significant in terms of providing information currently unavailable to bridge engineers. The developed tool could have a significant impact on the current state of the art for evaluating bridge capacities and enable more reliable assessments that ensure bridge safety nationwide. The instrument could be used in a variety of applications for highway bridges, including the assessment of gusset plates, primary load bearing members, jointless bridges, pin-and-hanger connections, and force distribution in trusses.

Product Transfer

The research team is uniquely positioned to transfer this instrument to practice in the highway bridge community. We maintain a close working relationship with state departments of transportation (DOTs) across the United States and come from a background of working with the FHWA, providing a larger picture of needs for the bridge community. The research team has the ability to test and implement this instrument with a wide range of DOT customers in order to better assess the needs of the end-user. In addition, the research team consists of both academic researchers and a for-profit instrumentation company. We are in collaboration with other instrumentation manufacturers to commercialize the instrument developed under this project. Publication of research results is also underway to transfer these data to the broader community.

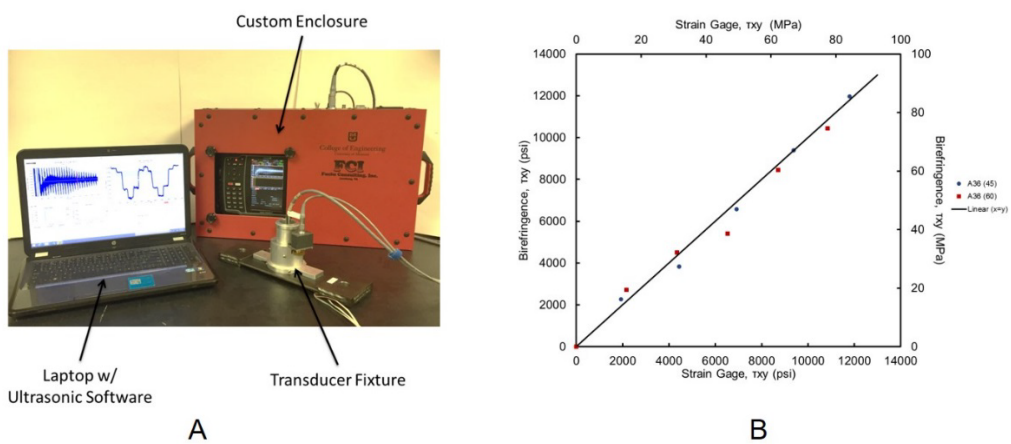


Figure 1

Photograph of the USM technology developed through the research (A) and results showing the correlation between stresses measured by USM and actual stresses (B).

DRAINED TIMBER PILE GROUND IMPROVEMENT FOR LIQUEFACTION MITIGATION

NCHRP-IDEA Project 180

Armin Stuedlein [Tel.: (541) 224-2242, Fax: (541) 737-311,
Email: armin.stuedlein@oregonstate.edu] Oregon State University, Corvallis, Oregon

IDEA Concept and Product

Practitioners and researchers have developed and evaluated numerous approaches for the mitigation of liquefaction and its deleterious effect on civil infrastructure. Although some ground improvement methods may contribute multiple mechanisms for mitigating liquefaction, these existing technologies are either unreliable (e.g., produce the mixing of open pore networks with silty fines) or require two separate pieces of equipment for installation, which raises installations costs. The concept explored with this research focuses on the effectiveness of piles constructed with drainage elements to promote densification during pile driving and potentially reduce pore pressures during earthquake shaking. The primary objectives of this research, focused on conventional and drained timber piles, are (1) to investigate the effect of timber pile spacing on the amount of soil densification (Figure 1), (2) to determine the effect drainage at the soil–pile interface on the dissipation of driving-induced excess pore pressures and densification, and (3) to investigate the effectiveness of providing drainage on the limitation and dissipation of seismically induced excess pore pressures in potentially liquefiable silty sand soils. This research centers on a field experiment conducted at a test site characterized with a thick, potentially liquefiable silty sand layer.

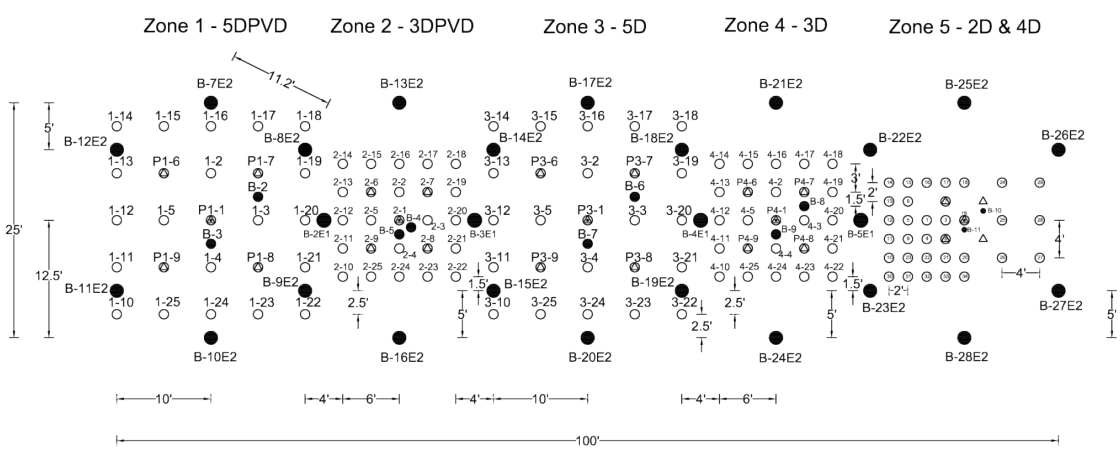


Figure 1

Site and exploration plan indicating the location of the timber pile test area and the control zone. Timber piles are indicated by the open circles, whereas closed circles indicate boring locations.

Project Results

To accomplish the project objectives, the subsurface of the test site was characterized to establish the pre-installation in situ conditions. An example of the pre-installation relative density of the soil correlated from cone penetration tests (CPTs) is shown in Figure 2 (red line). Following installation, subsequent CPTs were conducted and illustrated the increase in relative density associated with different pile spacings and with prefabricated vertical drainage elements (PVDs). Other in situ tests, including standard penetration and shear wave velocity tests, indicate that the ground has been densified, with magnitudes of densification increasing with decreases in pile spacing. The drained piles were shown to produce better densification than the conventional piles when spaced at three pile diameters, but did not appear to produce an advantage at less dense spacings.

Controlled blasting was conducted in an unimproved portion of the test site to make one-to-one comparisons of pore pressure response to the treated portion. Following complete dissipation of the blast-induced excess pore pressure, a maximum ground surface settlement of 200 mm was measured and indicated the severity of liquefaction potential prior to improvement with the piling. Application of the same blast pattern to the treated zone indicated the treated areas produced pore pressures less than those associated with full liquefaction. Additionally, the excess pore pressure response at later blasts demonstrated a dilative response, and indicated that the pore pressure reduced during each loading cycle (i.e., blast). Measurements of the ground surface following blasting indicated that the general range in post-blasting

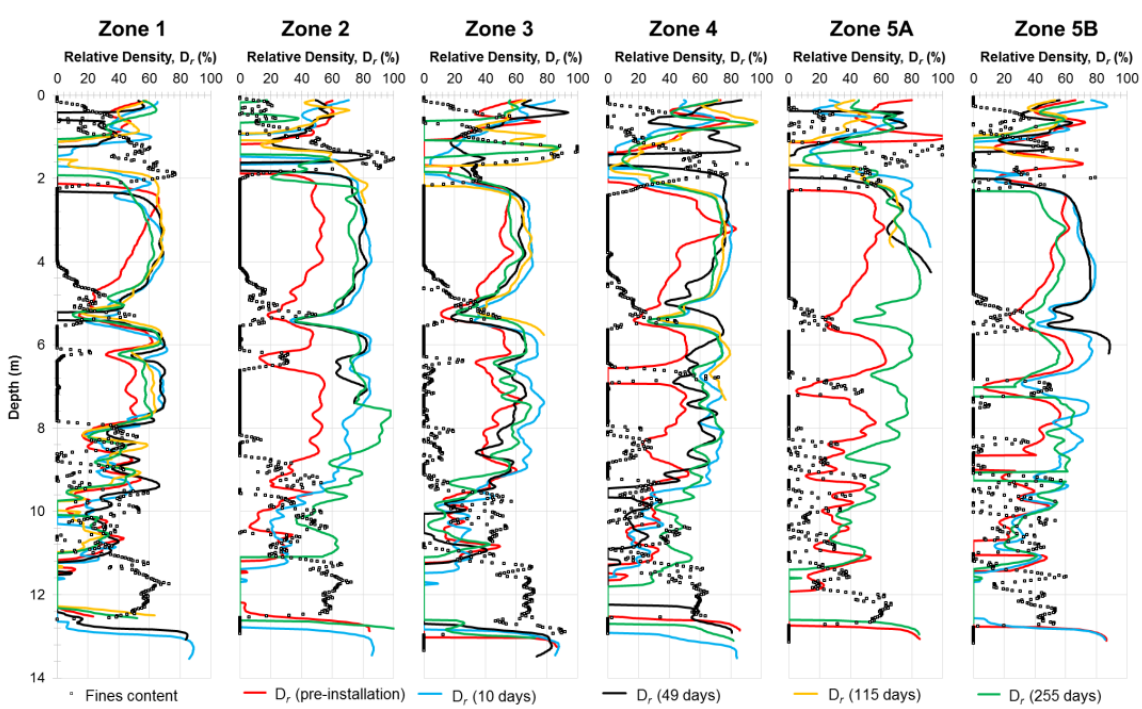


Figure 2

Increases in relative density (i.e., densification) based on a CPT-based cone tip resistance correlation.

settlements ranged from 25 to 80 mm (one-third to one-eighth that of the unimproved ground) and that the piles that were embedded within the underlying bearing layer settled approximately 20 mm on average.

Product Pay-Off Potential

The United States is home to several regions that are characterized with high seismic activity. Because ground improvement methods applied to potentially liquefiable foundations soils are relatively common, the potential for cost savings with a relatively cheap alternative that may provide multiple mechanisms of improvement is very high. In addition, use of timber piles, with or without drainage elements, allows owner agencies to implement sustainable, renewable materials and reduce their carbon footprint.

Product Transfer

In addition to the usual reports required by the IDEA program, this work will be communicated to the profession through conference and journal papers, and conference presentations at departments of transportation and other professional workshops and seminars. By cooperating with the Pile Driving Contractor's Association, this technology will find ready implementation in actual projects across the nation.

DEVELOPMENT OF SMALL SPECIMEN GEOMETRY FOR ASPHALT MIXTURE PERFORMANCE TESTING

NCHRP-IDEA Project 181

Cassie Castorena [Tel.: (919) 515-6411, Email: cahintz@ncsu.edu]
North Carolina State University, Raleigh, North Carolina

IDEA Concept and Product

The project is developing a small specimen geometry for uniaxial dynamic modulus and fatigue testing of asphalt mixtures in the Asphalt Mixture Performance Tester (AMPT). Dynamic modulus is a key input to the mechanistic–empirical pavement design framework and fatigue characterization of asphalt concrete mixtures is critical to prevent fatigue cracking, one of the leading causes of distress to asphalt pavements. AASHTO standards for both dynamic modulus testing and fatigue testing require 100-mm-diameter cylindrical specimens. Pavement layers are generally thinner than 100 mm, which does not allow for testing field cores from as-built pavement layers. Testing of thin pavement layers is possible using smaller cylindrical specimens with 38-mm diameter or with prisms with a cross section 25 mm by 50 mm. Field core testing in the AMPT could enable performance-based construction quality acceptance and allow for forensic field investigations of individual pavement layers over the course of a pavement's life. Testing laboratory-fabricated mixtures can also be greatly aided by the small specimen geometry as multiple small geometry test specimens can be extracted from a single gyratory compacted specimen. Monotonic direct tension testing is advantageous over cyclic fatigue testing because tests only take several minutes following the onset of loading. However, current load cell capacities of the AMPT prohibit the use of monotonic testing of full-size specimens. With small specimens, loading requirements are reduced allowing for monotonic testing in the AMPT.

Project Results

Dynamic modulus testing was performed on five different asphalt mixtures with varying nominal maximum aggregate sizes (NMAS) and binder grades. The master curves for the mixture with 9.5 mm NMAS, PG 64-22 binder are shown in Figure 1, which are generally representative of the results of all mixtures. The small specimens show increased dynamic modulus at low reduced frequency (high temperature or low frequency), which may be caused by a drift in mean strain throughout the test.

Cyclic direct tension tests (AASHTO TP 107) were conducted using three different mixtures with varying NMAS: 9.5 mm, 19.0 mm, and 25.0 mm. To analyze the results, the Simplified Viscoelastic Continuum Damage (S-VECD) model was used to develop damage characteristic curves (i.e., C vs. S curves) and the pseudostrain energy based G^R failure criterion. Damage characteristic curves represent the relationship between material integrity (C) and damage (S). The damage characteristic curve, according to continuum theory, should be independent of loading and temperature history, allowing for deriving a model to predict fatigue damage evolution under any loading and temperature history of interest using limited test results. The damage characteristic curves for the 9.5 mm NMAS mixture are shown in Figure 2(a). Results demonstrate good agreement between large, small, and prism specimen cyclic test results. The failure criteria consist of the relationship between the average rate

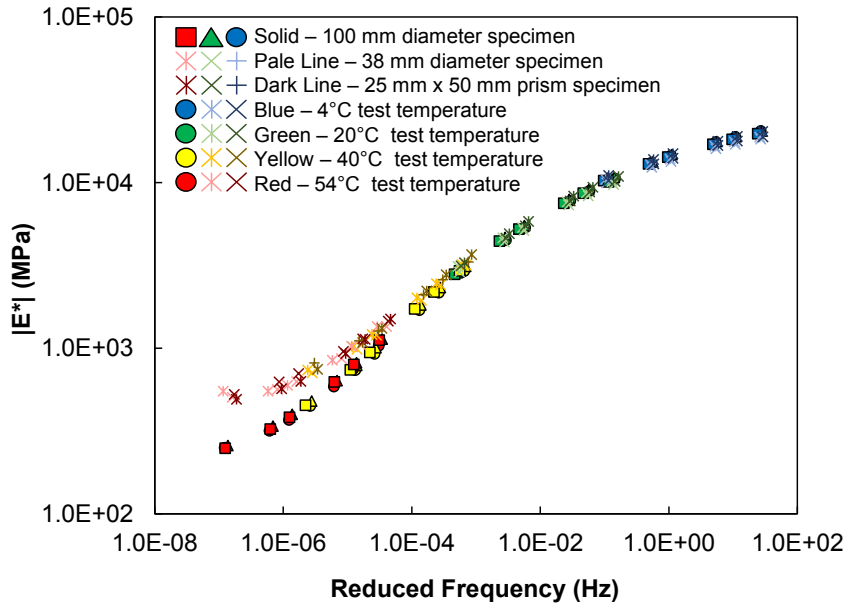


Figure 1

Comparison of dynamic modulus master curves of small and full size specimens.

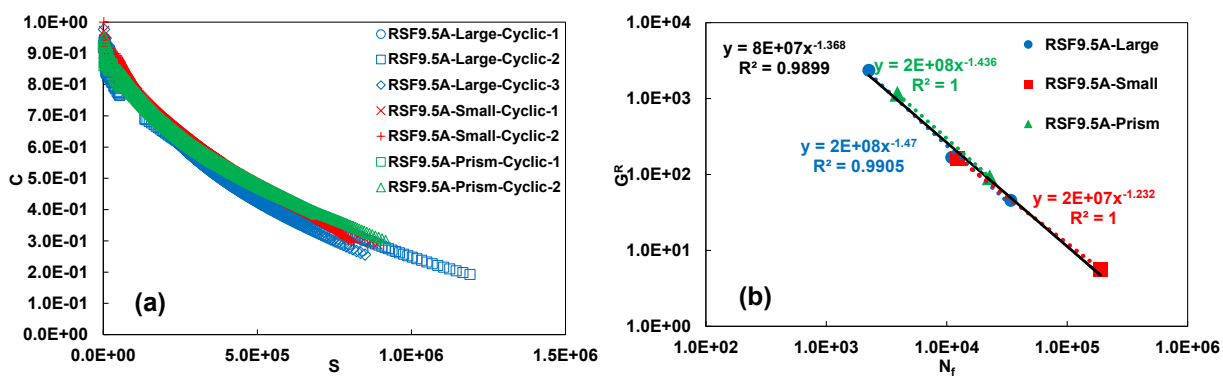


Figure 2

Comparison of S-VECD damage characteristic curves and failure criteria of small and full size specimens.

of pseudostrain energy release up to failure (G^R) and fatigue life (N_f). The failure criteria are unique to loading and temperature history and allow for predicting when failure will occur in damage evolution predictions. The failure criteria for the 9.5 mm NMAS mixture is shown in Figure 2(b). Results indicate that large, small, and prism specimen results all fall on a single curve, indicating good agreement between large, small, and prism specimen results. However, in some instances, small specimens exhibited a higher tendency of aggregate breakage and end failure than large specimens. The 25 mm NMAS mixture proved problematic both in large and small specimen fatigue testing, which is speculated to be related to high variability in the air void distribution within specimens and potential over compaction.

Product Pay-Off Potential

The primary benefits of the small specimen geometry to field core testing include enabling performance-based quality acceptance and forensic investigations of asphalt mixture properties of individual pavement layers throughout a pavement's service life. Laboratory-prepared specimen testing will be aided by improved efficiency in specimen preparation. Both laboratory and field core testing will be enhanced through the ability to perform monotonic direct tension tests that, when coupled with Viscoelastic Continuum Damage (VECD) analysis, allow for comprehensive fatigue characterization without the need for prolonged repeated loading tests under a wide range of loading conditions and temperatures.

Product Transfer

The research team has partnered with Instrotek Inc. to allow for development of all necessary tools for implementing small specimen testing in the AMPT, which will allow the necessary tools to be commercially available upon completion of the project. In addition, a project task is to develop draft AASHTO standards for small specimen testing; thus, detailed procedures will be available for use upon completion of the project.

REDUCING STORMWATER RUNOFF AND POLLUTANT LOADING WITH BIOCHAR ADDITION TO HIGHWAY GREENWAYS

NCHRP-IDEA Project 182

Paul T. Imhoff [Tel.: (302) 831-0541, Fax: (302) 831-3640, Email: imhoff@udel.edu]
University of Delaware, Newark, Delaware

IDEA Concept and Product

The purpose of this study is the reduction of nutrient loading and stormwater runoff volume by adding biochar to the soils of highway greenways. Biochar is a charcoal-like material formed by combusting waste organic matter in an oxygen-free environment and has high internal porosity and surface area, significant cation exchange capacity and adsorption capacity, and a stable carbon structure consisting of electroactive quinoid functional groups that serve as an efficient medium for electron transfer; properties we believe important for increasing nutrient sorption, denitrification, water retention, and infiltration rate. These properties may prove a critical benefit for highway greenways, since holding nutrient-laden water in the soil zone provides time for evapotranspiration, plant uptake, and microbial degradation of nutrients, while simultaneously reducing stormwater runoff volume. Although the focus in this work is the reduction of nutrient loading and stormwater runoff volume, there is also significant potential for other benefits, including reduction of metals and organics that biochar is known to remove in other contexts. Application of biochar as a soil amendment to highway greenways creates "green" infrastructure that simulates or imitates natural systems.

Project Results

The research is divided into two tasks. In Task 1, three typical soils found in highway greenways (loamy sand, sandy loam, and silt loam) are collected and amended with 2% and 6% of the commercially available Soil Reef biochar. This biochar is recognized as having high internal porosity and surface area, properties that can improve water and nutrient retention significantly. These soil/biochar mixtures were packed in laboratory columns to measure the complete water retention curve and unsaturated hydraulic conductivity. Initially, we planned to conduct these measurements using a tension table, pressure plate extractor, and saturated water column setup. However, in the fall of 2015, using another source of funding, we purchased a HYPROP instrument from Decagon, Inc., which is a new, fast, and accurate laboratory instrument for measuring soil hydraulic properties. This instrument enabled us to complete Task 1 more quickly and with greater precision. Incorporation of biochar decreased the soil bulk density up to 19% and increased the total porosity up to 19%, which is attributed to the high internal porosity and low particle density of biochar, as well as biochar's effect in modifying the particle size distribution. Biochar amendments enhanced water retention in both saturated and capillary regions of the water characteristic curve, and example data are shown for loamy sand in Figure 1. Biochar increased loamy sand's water holding capacity by 308% and hydraulic conductivity by up to 320%. These effects should result in significantly less stormwater runoff from roadway soils amended with biochar. In addition, we expect biochar amendment to reduce nutrient concentrations in stormwater runoff. Both effects will be evaluated in Task 2.

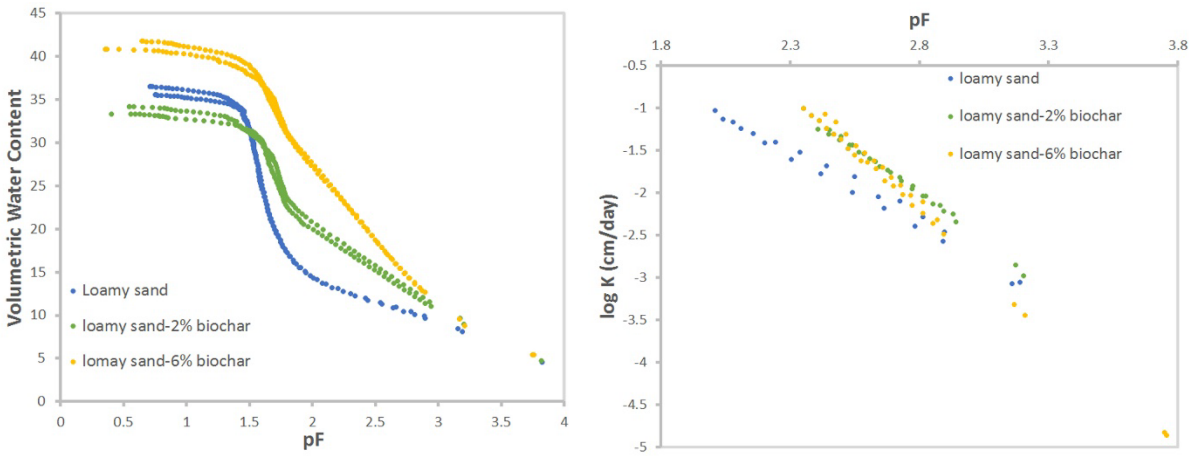


Figure 1

Soil water retention and unsaturated hydraulic conductivity data for loamy sand (pF = log (-h [cm H_2O])).

In Task 2, the impact of biochar-amended greenways on nutrient removal and stormwater runoff reduction is evaluated using 60 × 30 × 30 (length × width × depth) cm plot-sized highway greenways. These experimental systems were designed in early 2016 and construction will be completed by September 2016. Two of the four experimental cells will be filled with one of the three soil types and the other two filled with the soil and 6% Soil Reef biochar mixture. In order to have a complete mass balance of nitrogen, in addition to measuring the volume and nitrogenous compound concentrations in runoff and infiltration water, nitrogen and nitrogen oxide gas emissions from microbial activity will be periodically measured. Furthermore, changes in microbial population and species as an indicator of biological activity in the system will be monitored.

Finally, during the first year this project's advisory panel requested that we conduct preliminary experiments to assess the ability of biochar to reduce concentrations of polycyclic aromatic hydrocarbons (PAHs) in stormwater. To address this request, we selected naphthalene as a model PAH compound and are measuring biochar's ability to sorb this PAH from stormwater. These experiments have been designed and data are expected in fall 2016.

Product Pay-Off Potential

Use of biochar-amended soils is a broad-scale soil restoration best management practice (BMP) method that improves infiltration, water retention, and nutrient removal. In addition, biochar-amended soils will likely aid in the removal of metals and PAHs. The redevelopment of a healthy functioning soil (physical, chemical, and biological) goes beyond creating "green" infrastructure that simulates or imitates natural systems. It actually reestablishes the natural hydrologic function of soils. By restoring highway greenways, departments of transportation reduce the need to purchase additional rights-of-way to achieve nutrient removal goals, reduce the number and complexity of BMPs required, receive protection against inflationary operation and maintenance costs, and receive greater "return of investment" for assets already owned. It is possible that augmentation of this existing real estate with biochar could meet most of the total maximum daily load requirements for nutrient removal while reducing the National Pollution Discharge Elimination Standard (NPDES) stormwater footprint needs.

Product Transfer

The experimental information generated from this project will be used to scale up to a field site provided by either Delaware Department of Transportation (DelDOT) or Maryland Transit Authority (MDTA). Here we will develop a preliminary design for typical highway cross sections and slope configurations, an exercise that will help us identify the constraints, benefits, and preliminary costs of soil restoration using the new biochar amendment approach, and where possible determine where subsoiling techniques might also be considered to increase infiltration without jeopardizing highway safety. In addition, conceptual drawings and details will be created and a cost comparison conducted to assess how this practice compares with a bioswale (linear bioretention facility), the benchmark BMP often used along roadways in the state of Maryland, as well as other states in the Mid-Atlantic region. Preliminary results from this TRB project were presented to U.S. EPA Region 3 in Philadelphia (July 2016) and DelDOT (July 2016).

A RADIO FREQUENCY IDENTIFICATION (RFID) DETECTION SYSTEM FOR ASSESSING SCOUR COUNTERMEASURES AND THE STABILITY OF HYDRAULIC STRUCTURES

NCHRP-IDEA Project 183

Thanos Papanicolaou [Tel.: (865) 974-7836, Fax: (865) 974-2699, Email: tpapanic@utk.edu]
University of Tennessee, Knoxville, Tennessee.

IDEA Concept and Product

The concept of this IDEA research project is to apply the Radio Frequency IDentification (RFID) technology for reliable, remote monitoring and inspection of bed scour around hydraulic structures. The backbone of this project relies on the remote tracking of RFID sensor (transponder) movements that result from the scour action in nearly real time. To this end, our RFID system is capable of making automatic measurements of the transponder Return Signal Strength Indication (RSSI), which is a measure of the magnetic energy emitted by the transponder, as well as of the transponder orientation relative to the RFID base station antenna. By combining these automated measurements with relationships developed in-house, the RFID system determines in nearly real time the location of transponders relative to the base-station, while also accounting for the medium (e.g., water, sand, gravel, or clay) surrounding the transponder. The transponder tracking is performed in an automated fashion with a custom developed, user-friendly software package, PAPTSAK. It is expected that this project will, for the first time, offer hydraulic structure managers a simple, yet robust, tool for monitoring scour around hydraulic structures and allow them to perform meticulous inspection of scour around hydraulic structures in an automated fashion.

Project Results

For the purposes of this IDEA project, powerful RFID sensors (transponders), which had been previously developed by our group, were further enhanced by incorporating four additional functionalities (Figure 1A). These functionalities included: (1) a "wake-up" function for selectively activating and detecting a sensor, while also preserving the battery of the transponders, by retaining transponders that are not in use in sleep mode; (2) an inclinometer for automatically measuring the inclination of a sensor relative to the base-station antenna; (3) an automated function for RSSI measurement; and (4) waterproof encapsulation for protecting the transponder electronic circuits against moisture buildup, temperature gradients, and impacts. The PAPTSAK software, which is an in-house software package for operating the RFID system in a user-friendly graphical interface, was improved for accommodating the additional information resulting from the transponder enhancements (Figure 1B).

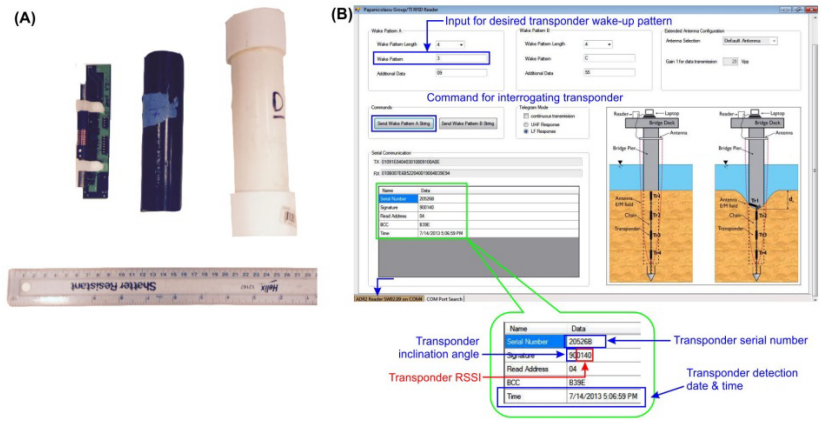


Figure 1

(A) Bare, encapsulated and PVC encased enhanced transponders; (B) Main view of the PAPTSAK software for operating the system.

Following their enhancement, the transponders were tested in the laboratory for determining the relationship between the transponder RSSI with its distance, d, from the base station antenna for a range of transponder inclination angles, θ, relative to the base station antenna. The relationship of RSSI with d and θ was determined with the transponder placed in air and water and is under development for various types of sediment media including sand, gravel, and clay. These relationships provide the basis for scour monitoring with the RFID system, as they allow estimation of the distance of the transponder from the base station antenna using the measurements of the transponder RSSI and inclination angle, which are automatically performed by the enhanced transponders.

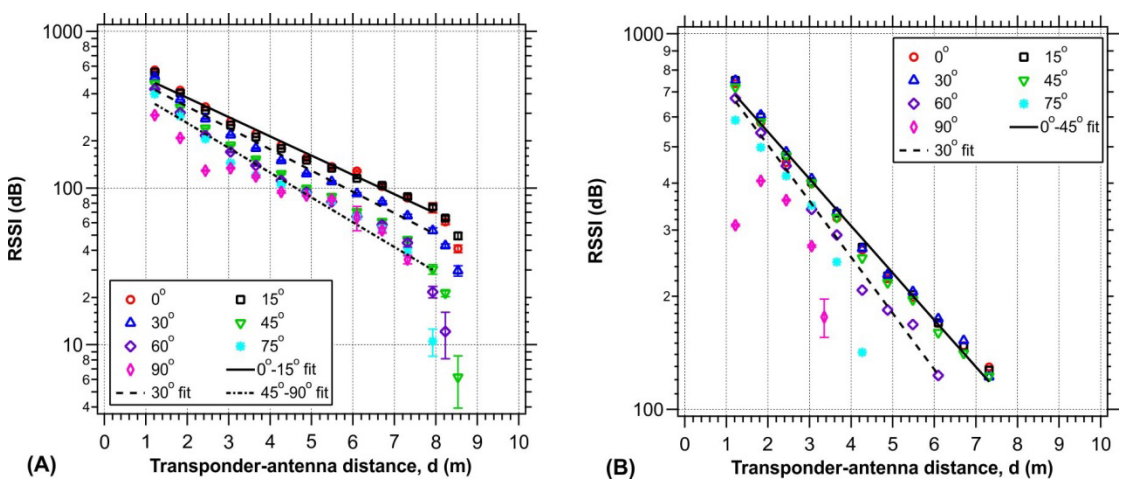


Figure 2

Relationship between the transponder RSSI and its distance from the base station antenna for a range of transponder inclination angles with the transponder placed in (A) air and (B) water.

Product Pay-Off Potential

The adoption of the RFID system is expected to yield direct savings over conventional scour data collection approaches and indirect savings through the adoption of an adaptive infrastructure management approach. Direct savings include the cost reduction in bridge scour monitoring by reducing the required man-hours for monitoring scour-critical hydraulic structures. Indirect benefits include potential savings brought by preventive maintenance in cases where the proposed system helps in the timely recognition avoiding accidents and potential repairs or replacement of damaged hydraulic structures. An additional indirect benefit is the improved safety of the DOT maintenance and monitoring crews, who can collect repeatable and reliable scour data remotely. In summary, the proposed RFID-based scour monitoring system could save lives and minimize economic impacts.

Product Transfer

The presentation and live demonstration of the RFID system for scour monitoring under development at the latest TRB Annual Meeting sparked the interest of stakeholders from the DOTs at multiple states, as well as from the private sector and other agencies. For the next phase of this IDEA project we are seeking "product/project champions," such as the Tennessee DOT, that will recommend an existing bridge site for installing the proposed system and monitoring scour. During this next phase, staff of the product/project champions will be trained in using the system for performing remote scour measurements. This training will also be extended to staff at the Turner–Fairbank Highway Research Center laboratory, where the system will be tested in the large environmental flume.

SYNTHETIC HOUSEHOLD TRAVEL DATA USING CONSUMER AND MOBILE PHONE DATA

NCHRP-IDEA Project 184

Josephine Kressner [Tel.: (630) 426-9076, Email: josie@transportfoundry.com]
Transport Foundry, Atlanta, Georgia

IDEA Concept and Product

Mobility is critical to the economic vitality and growth of any region. To decide where roads, buildings, transit, sidewalks, and other infrastructure should be built or improved in the future, one must know about the population and its movements. Traditionally, governments and the private sector have conducted surveys in order to understand the relationship between demographics and travel behavior; however, surveys are increasingly biased, expensive, infrequent, and onerous. This IDEA project will employ a data synthesis process that fuses data from different types of passive sources, including consumer (i.e., targeted marketing), Global Positioning System, triangulated wireless signal, and Wi-Fi positioning system data, to produce person-level, synthetic travel data. Synthetic data are representative of the real environment, but they do not contain any one person's exhibited travel to protect individual privacy. This means that collectively the data maintain the statistical relationships that are most important to planners, engineers, and researchers, but individually the synthetic travel data are generated using statistical techniques and data fusion. This type of data will allow transportation engineers and planners to investigate travel behavior in a way that is not feasible today, including improvements to travel demand modeling, tolling studies, before-and-after studies, and congestion mitigation studies.

Project Results

The aim of this project is to produce a person-level dataset from passive, big data for a representative full-sized population with individual information such as gender, age, household income, and number of vehicles. Appended to each person's demographic data are travel diaries that reveal where, when, why, and how each person travels. This project implemented a prototype of the data synthesis process—which was built for a small study area in the Atlanta metropolitan region—in a larger Seattle study area. Specifically, the focus was on evaluating the transferability of the prototype across different regions to develop a process that is consistent and systematic in producing locally sensitive and representative data.

Stage 1 work has been completed. A study area was defined in the Seattle metropolitan region that covers the entire four-county Puget Sound region, as defined by the Puget Sound Regional Council (PSRC). All input data for the synthesizing process was prepared and presented to the expert panel interactively online. During Stage 2, the data synthesis was implemented in the Seattle study area. The remaining work is aimed at validating the results.

In a separate application, the same synthesis process used in Atlanta and Seattle was implemented in the less complex region of Asheville, North Carolina. This allowed the team to swiftly implement a quantitative external validation by treating the synthesizing process as a demand model that feeds into the region's existing static assignment model, where the demand trips are assigned onto the transportation network. The modeled volumes were compared against traffic counts for both the existing regional trip-based (four-step) model and this passive data demand model. The passive data model produced effectively equivalent levels of accuracy when compared with the aggregate trip-based model using standard validation measures of the assignment results (see Table 1 and Figure 1). With these promising quantitative results in Asheville, the team is exploring a similar external validation in Seattle.

Additionally, other validations are being carried out to compare the synthetic travel diaries with the most recent local household travel survey, Census Transportation Planning Package Worker Flows, and Longitudinal Employer-Household Dynamics Longitudinal Origin-Destination Employment Statistics (LODES) data.

Table 1

Validation Results in Asheville, NC

			Aggregate Trip-Based Model			Tour-Based Model from Passive Data		
Facility Type	*n*	Avg. Count	VHT	RMSE	PRMSE	VHT	RMSE	PRMSE
Freeways	103	22,935.6	62,051.2	3,321.6	14.5%	78,042.0	5,475.1	23.9%
Expressways	6	13,732.2	2,022.9	2,168.2	15.8%	1,965.0	1,984.5	14.5%
Boulevards	15	15,965.1	2,081.2	5,695.2	35.7%	2,302.2	5,920.4	37.1%
Other Major Thoroughfares	337	10,322.2	31,646.6	4,181.5	40.5%	32,980.0	5,113.7	49.5%
Minor Thoroughfares	414	2,938.9	18,360.0	2,026.8	69.0%	18,856.2	2,359.8	80.3%
Total	875	8,433.7	116,162.0	3,250.3	38.5%	134,145.4	4,106.4	48.7%

In the left column, the reference trip-based (four-step) model validation is depicted. In the right column, the passive data tour-based model validation is depicted (which is the demand model based on the synthetic travel data). The top row illustrates the count scatterplots and the bottom row illustrates the maximum desirable deviation tolerances. The points are color coded by facility type. Note that 41 and 47 links in each model, respectively, had percent error greater than 200%. However, these were all on Other Major or Minor Thoroughfares with average weekly daily traffic (AWDT) volumes under 3,000 (shown with a vertical dashed line). For visual clarity, we do not show them.

Figure 1

Validation results in Asheville, North Carolina, after static assignment.

Product Pay-Off Potential

A successful demonstration and reliable analysis of the synthetic travel data during this IDEA project will outline a future, scalable data collection strategy that will allow questions to be asked that currently cannot. It will dramatically increase the value in collecting data for transportation planning with a decrease in cost per household and an increase in frequency and timeliness. Traditional household travel surveys cost on average $151 per household between 1998 and 2008 and usually take two or more years from conception to delivery of data. Recently, costs have increased to $300 to $350 per household, with many surveys costing several million dollars. Using the data synthesis process, it is expected that synthetic travel data can be produced for less than $5 per household at the click of a button and can be updated as often as every month.

Product Transfer

This project aims to refine a data synthesis process that will be provided as software or data as a service. The IDEA project involves working closely with the PSRC, where the project is being implemented with input from a team of experienced travel modelers and transportation engineers and an expert panel of leaders from metropolitan planning organizations and departments of transportation (DOTs) throughout the country (Atlanta Regional Commission, Ohio DOT, Oregon DOT, San Diego's Regional Planning Agency, and San Francisco's Metropolitan Planning Commission). A significant portion of the expert panel's involvement will focus on identifying the earliest use cases for this type of data, providing detailed input on how the data can be adopted by practitioners more quickly, such as performance-based planning with more effective before-and-after studies, toll revenue forecasting, and planning for new transportation technologies such as autonomous vehicles.

CURVEPORTAL FOR AUTOMATED IDENTIFICATION AND EXTRACTION OF HORIZONTAL CURVE INFORMATION

NCHRP-IDEA Project 185

David A. Noyce [Tel.: (608) 265-1882; Fax: (608) 262-5199; Email: noyce@engr.wisc.edu]
Madhav Chitturi [Email: mchitturi@wisc.edu]
Andrea R. Bill [Email: bill@wisc.edu]
University of Wisconsin, Madison, Wisconsin

IDEA Concept and Product

Building on the extensive experience with geographic information systems (GIS), data integration, and safety analysis, the University of Wisconsin Traffic Operations and Safety (TOPS) Lab developed CurveFinder (concept shown in Figure 1), a tool to extract horizontal curve location and geometric information automatically from GIS roadway maps. CurveFinder was successfully used in Wisconsin and Iowa. The CurveFinder algorithm needs to be improved to address accuracy issues with low-quality GIS maps, and made available for public use. The objective of this project is to improve the CurveFinder algorithm and develop a prototype of CurvePortal, which is a web interface for extracting horizontal curve location and geometric information automatically from GIS roadway maps. CurvePortal will provide curve data in GIS format for easy integration with existing asset management, roadway inventory, and crash data sets.

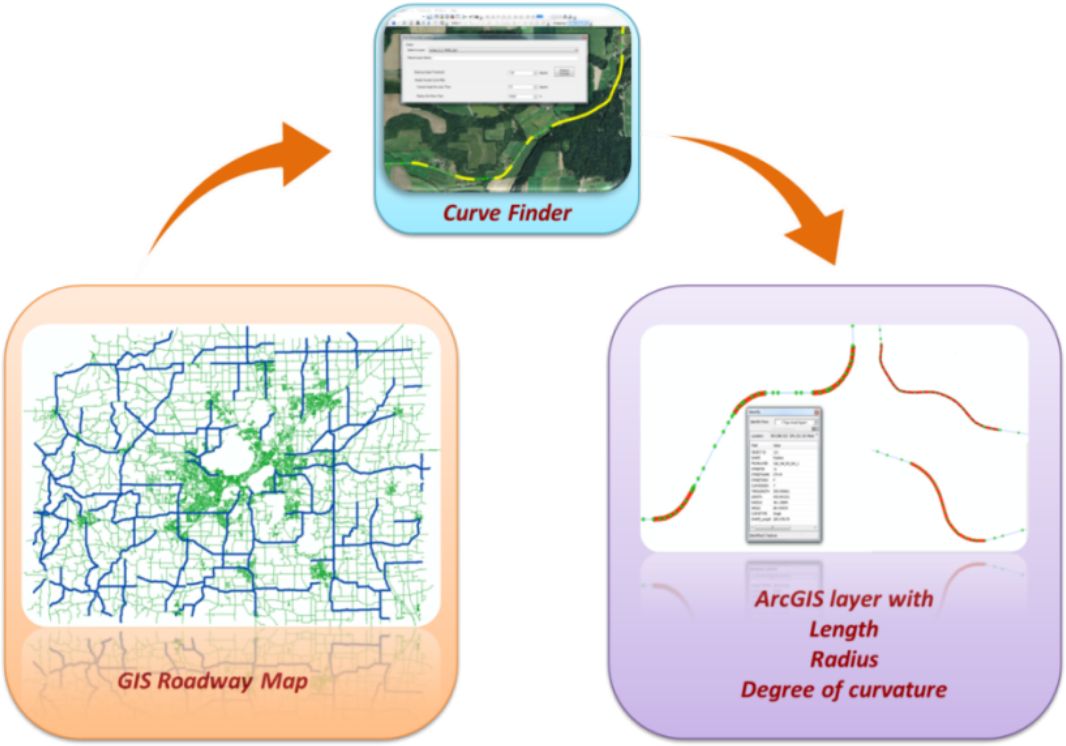


Figure 1

Concept of CurveFinder.

Project Results/Planned Investigation

The investigative approach for the proposed project is divided into the two stages: CurveFinder Improvement and CurvePortal Development and Testing. In Stage 1, the research team has incorporated and validated MIRE compatibility and will improve the CurveFinder algorithm, especially increasing its accuracy when applied on low-quality GIS roadway maps. In addition, more automation features will also be incorporated to enhance CurveFinder's efficiency and accuracy. In Stage 2, the research team will develop a prototype of CurvePortal that can be accessed by interested transportation agencies to upload their GIS roadway shapefiles for curve data extraction. Stage 2 will also involve testing and obtaining feedback from interested states/agencies.

Product Pay-Off Potential

The most profound impact of this innovation is its ability to obtain highway horizontal curve data using existing resources at minimum cost. Horizontal curves have long been recognized as one of the critical locations with regard to roadway departure crashes. FHWA has indicated that horizontal alignment contributes to 76% of single vehicle run-off-road (ROR) crashes in the United States based on 2007 Fatality Analysis Reporting System data. Previous research results also reported that crash rates on horizontal curves are 1.5 to four times higher than the crash rates on roadway tangents. A typical safety countermeasure to prevent roadway departure crashes from occurring in horizontal curves is the installation of warning signs in advance of the curves. The 2009 *Manual on Uniform Traffic Control Devices* (*MUTCD*) mandates horizontal alignment warning signs with advisory speed on roadways with a total volume of daily traffic of more than 1,000. In practice, some locations of high crash rates or severe crash levels lack appropriate curve warning signs or the signs are not placed at a proper location. Knowing the locations and geometric characteristics of curves is essential for improving curve safety. In particular, many states do not have curve data for non-state trunk roads. Considering horizontal curves are the major contributing factor to ROR crashes on rural county and local roads, having a horizontal curve database is essential to reach the Towards Zero Deaths goal adopted by many states and AASHTO. In summary, a complete set of horizontal curve data for all roadways including state trunk roads, county roads, local roads, and even unpaved or gravel roads benefits state and local transportation agencies for performing crash analysis, recommending safety treatments, and meeting the *MUTCD* mandate.

Product Transfer

The proposed CurvePortal will be hosted on WisTransPortal, an online transportation data portal managed by the TOPS lab at the University of Wisconsin–Madison. CurvePortal will be accessible to transportation agencies to upload their GIS roadway map shapefiles to get the horizontal curve data extracted.

DEVELOPMENT OF AN ELECTRICAL RESISTIVITY PUSH PROBE FOR RAPID ASSESSMENT OF GROUND IMPROVEMENT

NCHRP-IDEA Project 186

Mike Mooney [Tel.: (303) 384-2498, Fax: (303) 273-3602, Email: mooney@mines.edu]
Colorado School of Mines, Golden, Colorado

IDEA Concept and Product

This project addresses a limitation in geometric assessment of ground improvement applications such as jet grouting. During the jet grouting process, erosive fluid and grout are used to create columns of cement-grouted soil, aka soilcrete, in the subsurface. Adequate performance of jet-grouted columns requires precisely constructed diameters to match design specifications. Existing geometric verification techniques often require destructive assessment of test columns; for example, excavation or radial coring. These approaches are expensive and time intensive, and are not always adequate because spatial soil variability and inconsistent grouting parameters can result in production columns with different geometries than the test columns. This project seeks to develop a push probe device and delivery system to estimate jet grout column diameter using electrical resistivity. The probe exploits the significant resistivity contrast between fresh soilcrete and in situ soil to image the boundary between the column and soil. The probe and tripod-based deployment system are shown in Figure 1. The

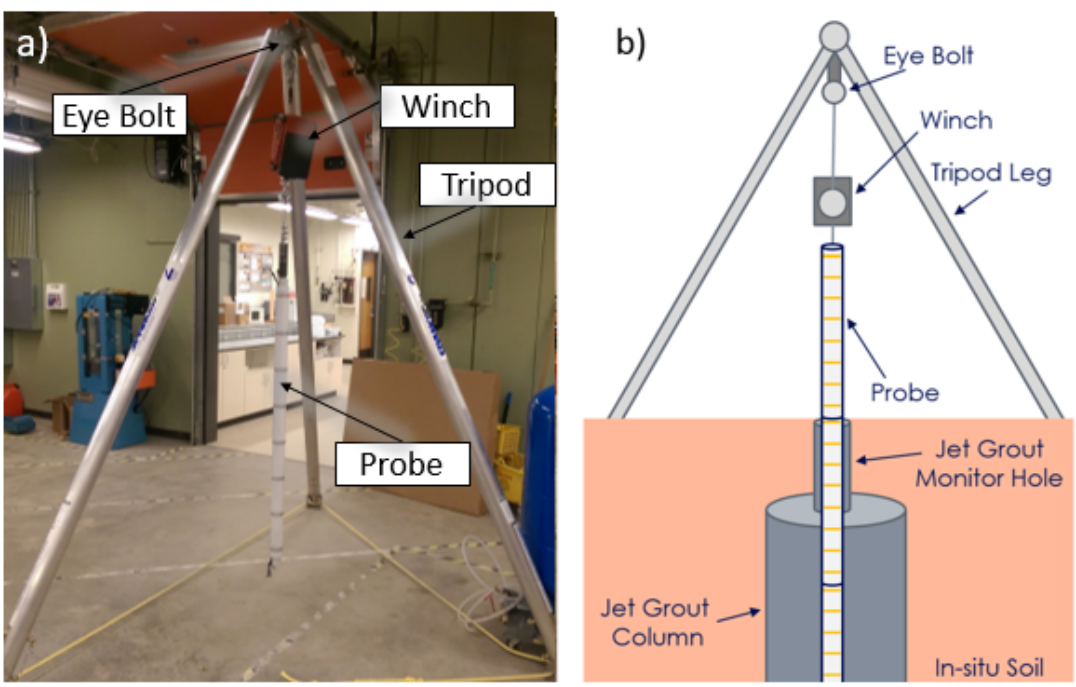


Figure 1

a) Photo of the tripod deployment system and one probe section assembled in the lab, and b) illustration of the probe and tripod deployment system placed in a jet grout column.

goal of this system is to provide a self-contained test setup and methodology that can non-destructively assess the geometry of production jet grout columns immediately after column construction with no additional on-site equipment or personnel support required.

Project Results

The research for this project has two planned stages. The first stage involved the design and construction of the probe and deployment system with initial field testing of the new device. The probe and deployment system have been designed and constructed, and an active search for field test sites is underway. The probe was designed using finite element modeling via COMSOL Multiphysics to inform the necessary electrode spacing and injection/measurement protocols to successfully image the constructible range of soilcrete column diameters in a variety of soil conditions. Example finite element models are shown in Figure 2, where the electrical potential field resulting from current injection across electrodes *A* and *B* is illustrated for a 1-m and 3-m diameter column. The changes in this potential field that result from proportionally more or less soilcrete are characterized by measuring the potential difference across different combinations of electrodes *M1–M30*.

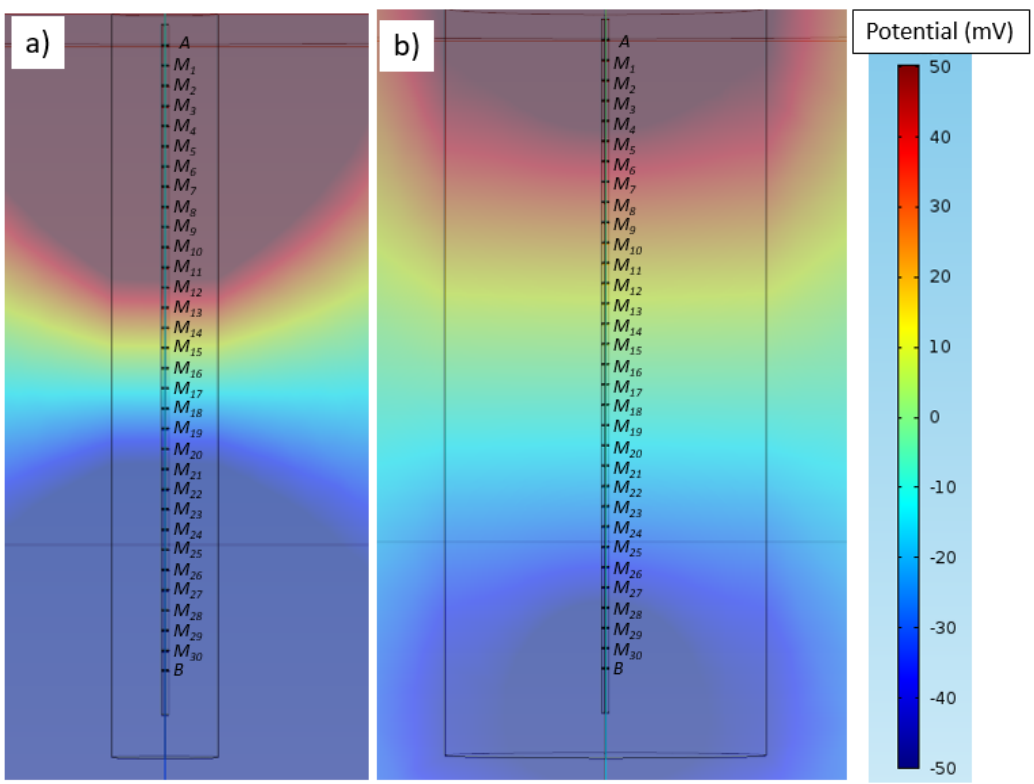


Figure 2

Finite element forward model of the push probe and resulting electric potential field generated by the probe's current injection in a) a 1-m diameter column, and b) a 3-m diameter column.

In addition to the modeling effort to design the probe's electrode geometry, the probe was engineered to be easily deployable and field-ruggedized. The probe is constructed of ultra-high molecular weight polyethylene, which has a high density to overcome the buoyancy effect in soilcrete columns and is resistant to impact and abrasion. The total length of the probe is 20 feet, but it is assembled in 5-foot sections to facilitate handling and deployment. In addition, the probe is outfitted with an onboard inclinometer to assess the verticality of the probe during soilcrete column testing. The probe's tripod deployment system is designed to be placed over the monitor hole after jet grouting (Figure 1b). The probe is lowered into the soilcrete column by a two-man team using a winch and cable system. The same system is used to extract the probe after testing. This design allows the test setup to be easily moved from column to column after construction and requires no on-site equipment; for example, crane or drill rig, for deployment.

Product Pay-Off Potential

This project offers three significant potential benefits. First, the push probe provides a non-destructive assessment of production columns. No existing technique can accurately estimate production column diameter with no lasting column defects. Second, the probe provides test results immediately after construction and prior to soilcrete curing (approximately 30 minutes per column tested). This rapid test procedure provides contractors with sufficient time to remix/regrout production columns if the desired diameter is not achieved. Third, the probe's deployment system does not require any on-site equipment; for example, crane or drill rig, and can be readily moved from column to column immediately after construction.

Product Transfer

This project aims to produce a testing device, deployment system, and data analysis routine. The system would be marketed to jet grout contractors, departments of transportation (DOTs), and potentially to third party consultants who could provide on-site testing services during jet grout column construction. We are actively pursuing jet grout construction sites in collaboration with Hayward Baker, Moretrench, Kiewit, Bauer, Malcolm Drilling, and Nicholson Construction. We are also seeking test sites from the Army Corps of Engineers and several DOTs including Florida, Minnesota, Indiana, and California. These test sites will provide critical data sets to assess the probe's column accuracy for column diameter prediction. In addition, the test site collaborators will provide feedback on the probe's ease of deployment and test time requirement.

A LOW-COST MOBILE PROXIMITY WARNING SYSTEM IN HIGHWAY WORK ZONES

NCHRP-IDEA Project 187

Yong Kwon Cho [Tel.: (404) 385-2038; Email: yong.cho@ce.gatech.edu]
Georgia Institute of Technology, Atlanta, Georgia

IDEA Concept and Product

A wireless equipment-worker proximity detection and alert sensing system has been investigated for proactive safety warnings at dynamic roadway work zones at grade. The system utilizes portable mobile devices (e.g., smartphones) carried by pedestrian workers as Personal Protection Units (PPUs) and low-cost Bluetooth beacons that can be attached to equipment as Equipment Protection Units (EPUs) for proximity detection and alert with audible sound and vibration through mobile devices. An equipment operator and pedestrian workers will be simultaneously warned in real time through their PPUs. Further, the operator can identify the location of workers in proximity around the vehicle through his PPU display (Figure 1). Unlike existing commercial proximity alert systems, this system requires minimal infrastructure (no need of cell service) and maintenance, and is economically viable and easy to set up and use by utilizing many smart functions of mobile devices and low-cost Bluetooth wearable gears such as smartwatches and earpieces.

Figure 1

Concept of a mobile proximity safety warning system.

Project Results

The proposed research encompasses two distinct work stages: (1) system development and prototyping, and (2) field testing and validation for industry acceptance. During the first stage, an extensive literature review has been conducted on commercially available proximity sensing systems and Bluetooth Low Energy (BLE) technology. Based on the literature review, a mobile application for a proximity alert sensing system for pedestrian worker's PPU and an equipment operator's PPU has been developed, and a field trial was conducted at a district of Georgia Department of Transportation (GDOT). Figure 2 shows the testbed. Through this test, the research team identified that the connection was successfully established for mobile devices to communicate with the sensors in real-time. In addition, the alert efficiency of the BLE system was augmented by connecting additional BLE wearable devices to the system, such as smart watches and Bluetooth ear pieces. A web-based database has been configured for a cloud communication; in this configuration, real-time proximity-related personnel data can be stored and remotely monitored. Currently, a new communication protocol between a pedestrian worker's PPU and an operator's PPU is under investigation. The operator's PPU will also have a function of displaying directions of pedestrian worker's location when his or her proximity is detected.

During the second stage, the prototype system developed from the first stage will be further tested under variable real-world field conditions in highway construction work zones to validate effectiveness through industry observations. The hardware configuration methods and software will be continuously improved through a combination of industry feedback and simulated laboratory tests.

Figure 2

Field trial at GDOT district's equipment yard.

Product Pay-Off Potential

The preliminary results of our study at the first stage show that a Bluetooth-based, mobile, real-time, pro-active proximity detection and alert system has high potential to promote safety in roadway construction work zones in terms of accuracy, cost, and user friendliness. Furthermore, there is a clear benefit with regard to the simplicity of hardware configuration. Basic required components are smartphones (or tablets) and Bluetooth beacons that can be attached to any solid surface of the equipment body. The portability and simplicity of the proposed system will allow broader onsite adoption of the proposed technology and proactive safety practices between equipment and pedestrian workers at roadway construction work zones. Furthermore, our preliminary interviews with insurance and construction companies indicate that the contractors using this safety technology would get direct or indirect insurance premium benefits and increase the probability to win a bid when their bid is competitive as a result of their additional safety technology.

If successful, this research will provide highway construction safety and project managers with a comprehensive understanding of the job site hazard in dynamic construction work zones. Furthermore, with the aid of the proposed system, state transportation agencies can formulate a more efficient way of regulating work zone safety guidelines; therefore, a lower rate of accidents and near-misses yields not only an improvement of worker's safety but also a decrease of project delays resulting from safety-related accidents.

Product Transfer

Our research team has been continuously working with state DOTs in construction technology applications. We will test and demonstrate our proposed system to state DOTs and construction contractors. Their support will allow us to utilize a large assortment of test beds at their working sites to analyze the effectiveness of our design and potential prototype. Their feedback throughout the entire process will ensure that the outcome of this project is practical and industry driven. The progress and outcomes of the proposed system will be posted at our Robotics and Intelligent Construction Automation Lab (RICAL) webpage (rical.ce.gatech.edu) for public dissemination.

A CLASS OF V-CONNECTORS FOR BRIDGE DECK PIER AND PIER-FOOTING JOINTS ALLOWING INTEGRATED DESIGN AND SEISMIC ISOLATION WHILE ENABLING ACCELERATED BRIDGE CONSTRUCTION

NCHRP IDEA Project 188

Su Hao [Tel.: (949) 679-9047; Fax: (855) 207-9835; Email: hao@suhao-acii.com]
ACII, Inc., Irvine, California/Wilmette, Illinois

IDEA Concept and Product

This research develops a class of innovative devices, termed "V-connectors" for use as the joints between bridge pier and superstructure or between pier and footing, facilitating accelerated bridge construction (ABC) and providing robustness for required seismic resistance.

Figure 1 illustrates the basic configuration of the proposed V-connector, which is an assembly of the five basic elements to be manufactured: two V-shape guiding tubes (VGT) that are respectively mounted into the two connected structural parts, a bridge's deck and pier in this figure; a vertical stabilization-pin, abbreviation "SBP," with its two ends inserted respectively into the two VGTs; a damping cone around the pin within the lower VGT; and a washer. While as a seal to prevent dirt fell into VGT, the major function of the washer is to provide selectable friction-induced energy dissipation when a bridge is struck by earthquakes (see the hysteretic loops on the right of Figure 1). However, it is optional because the friction between the contact-surface pair of the connected structural parts may perform the same function. Also, the damping core is optional if the friction-induced dissipation is sufficient for the system.

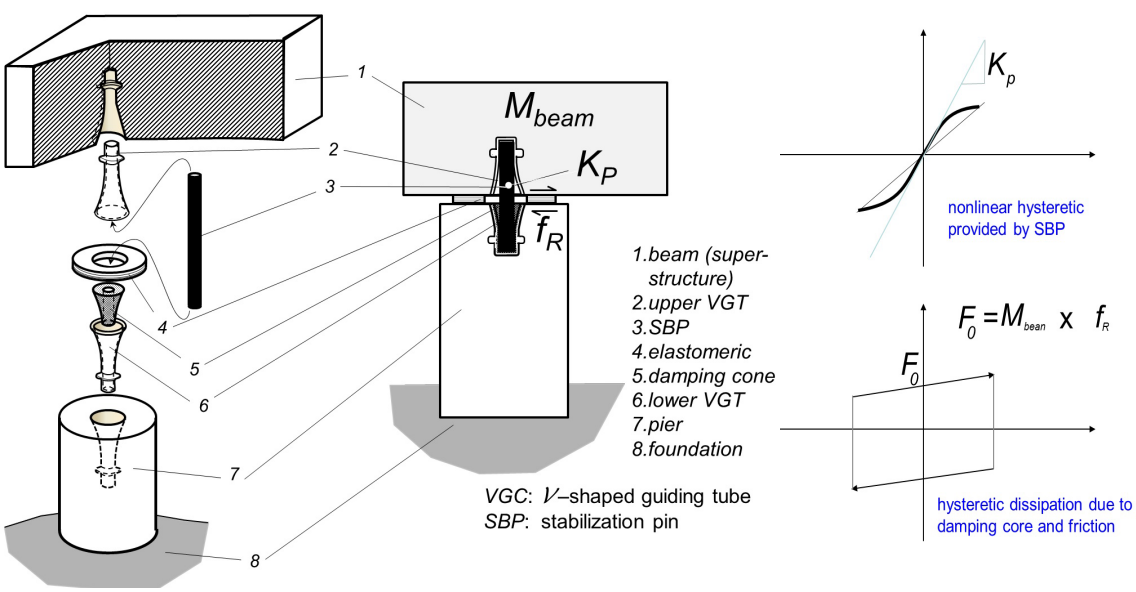


Figure 1

Concept of the V-connector

Project Results/Planned Investigation

The project work is being carried out in two stages. Work in Stage 1 focuses on the analysis and design of the V-connector family. The analysis involves two tasks: (i) development of a theoretical model to obtain the generalized principle of the relationship between key design parameters and the connector's performance for seismic protection; and (ii) establishing the numerical model that is able to screen and quantify the design parameters for a regular bridge at a site with seismic parameters given by the AASHTO LRFD Manual Section 3. The connectors are to be designed with the following two options: (i) work with partner state departments of transportation (DOTs) to identify at least one bridge project that could use the product and then design the connector for that particular bridge based on the theoretic model and numerical analysis developed earlier in the project; or (ii) design the connector to fit the bridge types listed by the AASHTO LRFD Manual. A set of designed connectors will be fabricated for shake-table tests. Contacts with a connector manufacturer and state DOTs will be made to discuss connector manufacturing and identify suitable bridge sites. Work in the second and final stage will involve shake-table tests and completing at least one set of connector design, based on original design and shake-table test results. The connector will be manufactured and implemented on an actual bridge under construction. Two tasks of the designated analysis have been completed: (i) a two-degree theoretical model based on the one-degree model currently applied by the AASHTO LRFD manual, whereby the key is to using a hysteretic curve to determine the damping coefficient; and (ii) 3D-finite element models for screening optimized design parameters with the best performance. To finalize the test specimen parameters that would cover generalized applications, a set of design data for the V-connectors for a three-span notional bridge has been identified in which the major effort is to utilize the shear reinforce ring, a key-feature of this proposed idea, to maximize the connectors' loading capacity while minimizing its weight and volume. The IDEA concept and some preliminary results were presented at the 2015 National Bridge ABC Conference and the 2016 TRB Annual Meeting. Also, in collaboration with Tennessee D0T, this V-connector development has been submitted to the FHWA EDC-4 program.

Product Pay-Off Potential

A modern strategy to achieve ABC is "modular bridge"—building components off-site and then assembling the bridge on-site, for which "assembly precision" and "connection strength" are the two main challenges in practice. This is because whereas a bridge's component, such as a beam, can be from tens to hundreds of feet long, a common connector, such as a pin, has the dimension of inches, implying the precision requirement at the scale at the order of one-tenth of an inch. It is not trivial to manufacture a 100-foot-long beam with such a precision at specified locations; enforced assembling for cases without satisfactory precision consumes extra time and labor in addition to causing additional residual stress and detriment in robustness.

Therefore, for situations that require high strength at connections, such as in an active seismic zone, the construction method termed CIP (cast-in-place) becomes the primary option for concrete bridges, which disables ABC while introducing significant extra costs as a result of the necessary form work. Additionally, resonated vibration of the entire bridge may occur when it is with high pier or piers with uneven heights. This issue leads to the development of seismic isolation design, utilizing isolation bearings as the connectors between the beam and pier. Being a flexible connection, an isolation bearing is able to shift a bridge's natural frequency when struck by an earthquake, while reducing the transmission of inertia force flow. However, such flexibility may also compromise the robustness needed for a bridge under

some situations. For example, during the 2011 Sandai Earthquake, numerous bridges survived the 8.9 magnitude earthquake, but their superstructures were washed out by the following tsunami.

The developed V-connectors family aims at achieving the permanent robustness as a CIP structure while possessing the temporal, restorable flexibility as that which a conventional seismic isolation bearing has. Additionally, the V-geometry by such a connector enables a modular bridge's fast on-site assembling with regular manufactural precision for a bridge's component. The connecting mechanisms illustrated in Figure 1 imply that the connector is also able to accommodate the temperature and live load-induced beam's deformation. In summary, the *payoff to practice* by applying the developed V-connector products family can be briefed as the following properties:

- Sustainability and integrity: Exceptional capability to protect a bridge from the damages caused by seismic events and by a hurricane or tsunami while provide robust connection under regular conditions.
- Efficiency: With least requirement for maintenance during day-to-day operation, as compared with other kinds of bearings.
- Cost-effectiveness: Competitive manufacturing cost, convenience for accelerated construction and replacement.

Product Transfer

State departments of transportation and conventional manufacturers will be approached for testing and implementing the product.

A NOVEL VISION SENSOR FOR REMOTE MEASUREMENT OF BRIDGE DISPLACEMENT

NCHRP-IDEA Project 189

Maria Q. Feng [Tel.: (212) 854-1182, Fax: (212) 854-6267, Email: mfeng@columbia.edu]
Columbia University, New York City, New York

IDEA Concept and Product

This project develops a camera-based vision sensor for remote, long-distance measurement of multi-point bridge displacements with high accuracy. Despite recent advances made in this emerging sensor technology, the current systems suffer from significant measurement errors in outdoor environments resulting from changes in illumination and/or background, heat haze-induced image distortion, and wind-induced camera vibration. This project represents the first effort to systematically address these field measurement errors by implementing three major innovative approaches: (1) a novel template matching algorithm that overcomes the interference of environmental noise to robustly track the displacement of a "natural" marker (such as a rivet on the bridge) and achieve sub-pixel measurement accuracy; (2) an advanced digital filtering approach that compensates for image distortions caused by heat haze; and (3) a patent-pending vibration cancellation technique that minimizes errors caused by wind and traffic-induced camera vibration. As a result of these innovations, the proposed vision sensor system will be able to simultaneously and accurately measure bridge displacements at multiple points using one camera from a long distance, without requiring physical access to the bridge to install artificial targets as done in a conventional approach.

Project Results

This project is executed in two stages. Stage 1 focuses on developing the three innovative-approaches to improve the accuracy of the remote measurement of multi-point bridge displacements in outdoor environments without using artificial tracking markers. The robust template matching algorithm is integrated with the heat haze filtering and the camera vibration cancellation technique to systematically address all sources of environmental noise that deteriorate measurement accuracy. Laboratory tests are carried out to evaluate the effectiveness of the developed algorithms and techniques using simulated environmental noise including low-lighting, shadowing, heat haze, change in illuminating light, and background conditions. Figure 2 shows the superior performance of the OCM algorithm over a conventional UCC mothed in tracking a natural target (bolt) of a structural model in dim light.

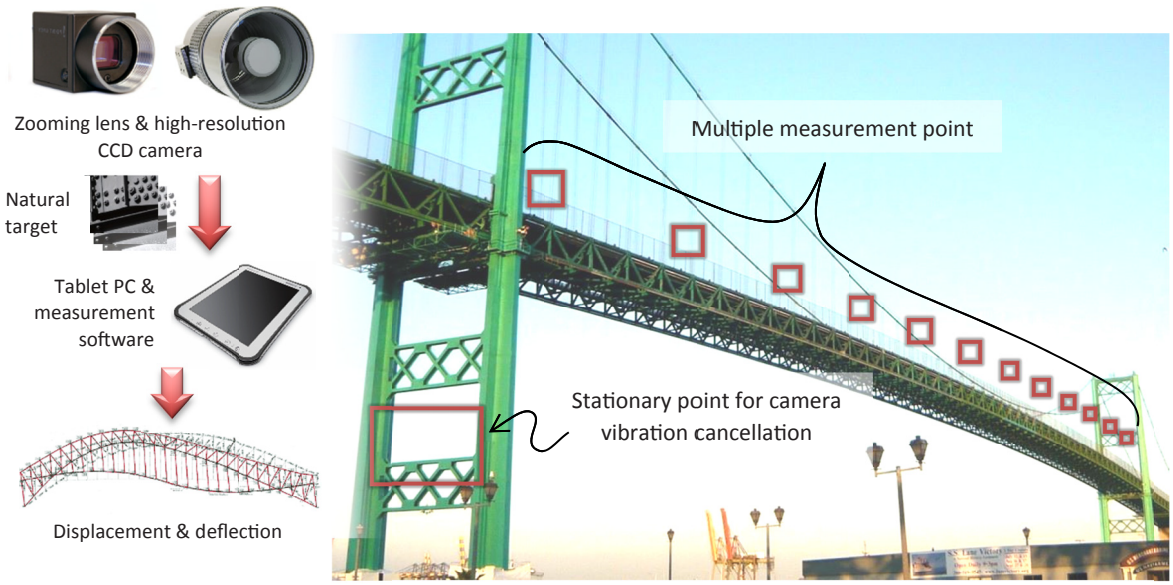


Figure 1

Vision sensors for remote multi-point measurement of bridge displacements.

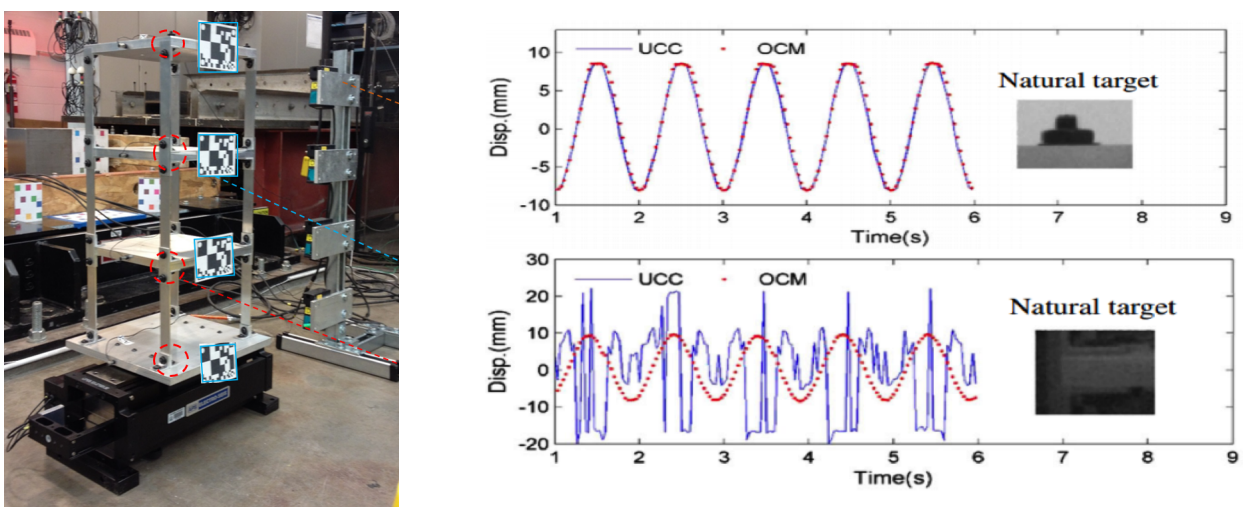


Figure 2

Evaluation tests of the OCM algorithm against environmental noise (Top: natural light, Bottom: dim light).

Stage 2 work will first develop a prototype vision sensor system by incorporating the algorithms developed in stage 1 and then perform bridge field evaluation tests. Advanced computational techniques will be applied to reduce the image processing time to realize real-time online measurement. In addition, a user-friendly interface will be built into the software package. The performance of the prototype vision sensor system will be evaluated on bridges in terms of its long-distance, multi-point measurement accuracy in presence of various sources of field environmental noise.

Project Pay-Off Potential

Measurement of bridge static deflections and dynamic displacements can play an important role in ensuring the bridge functionality and structural integrity. The advanced vision sensor system proposed in this project will deliver a low-cost tool for fast, remote, and accurate measurement bridge displacement in field conditions. The near-term target is the application in load testing for bridge ranking, with a goal of making the load testing fast and affordable and thus widely implementable. In fact, the proposed vision sensor system will be applicable to measure static deflections and dynamic displacements of any structures. In the long term, the project team will investigate the application of the system in other highway transportation structures such as sign- and light-supporting structures, whose excessive deflections are causing safety concerns. Furthermore, the technology can be expanded to 3-D measurement by using two cameras in a stereoscopic configuration, depending on the application requirements. In addition, the system can be developed for permanent installation at bridge sites for long-term continuous monitoring. The novel algorithms and software package developed in this research can be integrated into existing, ubiquitously available security cameras to explore their potential dual usage for measuring structural deflections and dynamic displacements for long-term monitoring of structural integrity and safety.

Product Transfer

Successful completion of this project will deliver a low-cost, high-accuracy, easy-to-use vision sensor system for remote, multi-point measurement of bridge displacements from a long distance. The project team will continue working with the California Department of Transportation (DOT) (Caltrans), New York City DOT, and others on the implementation of the system for bridge field tests and long-term structural health monitoring. Beyond the IDEA project, efforts will be made to initiate trial projects at state DOTs and build strategic partners for wide implementation of the technology.

SELF-DE-ICING LED SIGNALS FOR RAILROADS AND HIGHWAY INTERSECTIONS

NCHRP IDEA Project 190

Hongyi Cai [Tel.: (785) 864-2597; Fax: (785) 864-5631; Email: hycai@ku.edu]
University of Kansas, Lawrence, Kansas

Steven D. Schrock [Tel.: (785) 864-3418; Fax: (785) 864-5631; Email: schrock@ku.edu]
University of Kansas, Lawrence, Kansas

Eric J. Fitzsimmons [Tel.: (785) 532-0889; Fax: (785) 532-7717; Email: fitzsimmons@ksu.edu]
Kansas State University, Manhattan, Kansas

IDEA Concept and Product

This project will develop a new type of self-de-icing LED signal for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The snow-clogged signal lights can decrease the performance of signalized intersections and railroads and may result in collisions in inclement weather conditions. The self-de-icing LED signal light will adopt two innovations of "Heated Lens Lighting Arrangement" (Figure 1) and "Heat Arrangement of LED Arrays in Low Profile" (Figure 2) to harvest both the light and the heat generated by the same LED for illumination and heating of the signal lens.

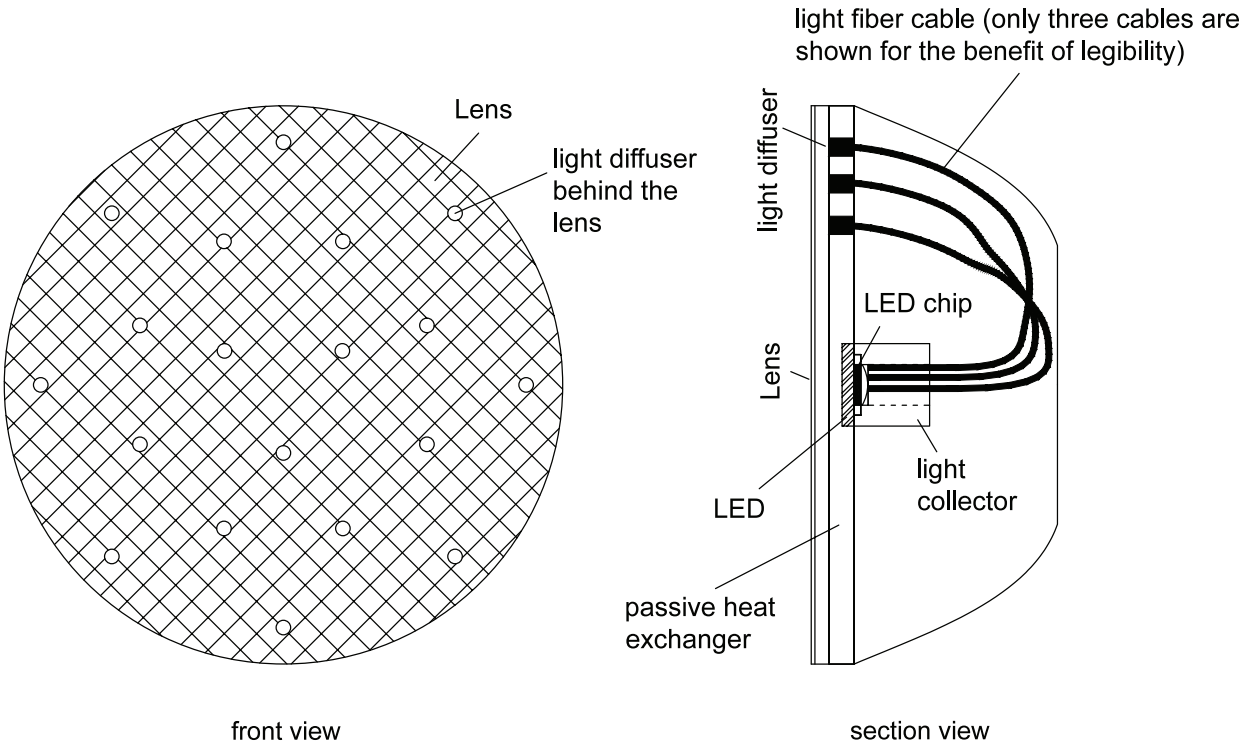


Figure 1

The concept of the self-de-icing LED signal light—"Heated Lens Lighting Arrangement." The heat generated by the LED is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions. The otherwise trapped LED light is re-directed to the front lens using a bundle of light fibers.

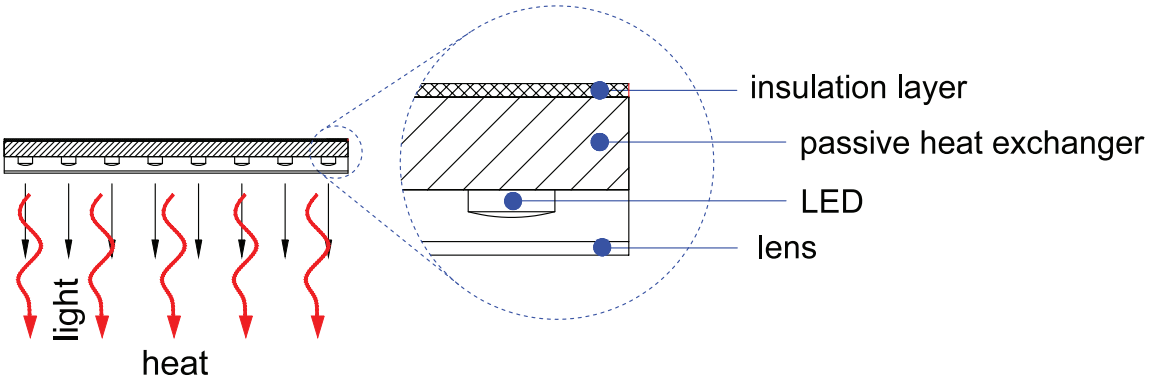


Figure 2

A new system architecture of the self-de-icing LED signal light—"Heat Arrangement of LED Arrays in Low Profile" to harvest both the light and the heat generated by the same LEDs via a mingled path for lighting and heating uses.

Project Results

The investigative approach for the proposed project is divided into the three stages, as follows. Work in Stage 1 will focus on laboratory research and development and tests of the prototype self-de-icing LED signals. The research team will develop and test three prototypes of the self-de-icing LED signals in red, green, and yellow light colors, including highway intersection traffic lights (12 in.), railroad wayside signal lights (5½ or 8 in.), and railroad at-grade crossing signal lights (6 or 12 in.). The research team will test their best thermal and lighting performance to meet all requirements. Work in Stage 2 will focus on testing the three prototypes that will be mounted in closed-course settings. The research team will evaluate the thermal and lighting performance of the prototypes over one winter season in this manner. Work in Stage 3 will focus on the field tests of the prototypes on identified highway signalized intersections and rail track sections. The prototypes will be installed on pole-mounted signals as backup to the existing primary signals. At each test site, a security video camera will be mounted on a pole top facing the prototype signals at a close distance to monitor their real-time performance for melting snow and de-icing in wintery conditions. Later, the research team will visit the test sites again to conduct a real-time performance measurement of those prototype signals under wintery conditions with heavy snow and ice, and hold an on-site demonstration to the project partners for final evaluation for their future implementation in practice.

Product Pay-Off Potential

Once validated, the self-de-icing LED signal light is expected to be a viable replacement of the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emergent LED signal lights using additional heat generators and control sensors. If the self-de-icing LED signals are implemented in practice significant benefits, including safety and efficiency, cost savings, and environmental sustainability, are expected to the transportation agencies, districts and cities, the railroad companies, and the driving public in the snow-belt states. This system will not alter the function and sizes of the existing signal lights. There will be no need to add additional wiring inside and outside of the existing signal controller cabinets, and no need to change anything outside of the signal housing. The self-de-icing LED signal lights could save on annual maintenance costs.

Product Transfer

A nonprovisional patent application (No. PCT/US14/53503) was filed on August 29, 2014, for the innovation of "Heated Lens Lighting Arrangement." A provisional patent application was filed on April 15, 2016, covering a second innovation of "Heat Arrangement of LED Arrays in Low Profile." The research team and the University of Kansas Innovation and Collaboration (KUIC) have been reaching out to the signal industry for patent licensing. Pilot replacement programs are planned to displace the existing signals with the self-de-icing LED signals in some collaborative state departments of transportation (e.g., Kansas, California, Michigan, New Jersey, Pennsylvania, Wisconsin, Maryland, Colorado, Minnesota, or Iowa), the Union Pacific Railroad, and the Burlington Northern and Santa Fe Railroad. Once validated, the self-de-icing LED signals are expected to be installed at highway intersections, Class I railroads, commuter railroads, and short line railroads in cold weather zones.

SECTION 3
NSF/NRC-IDEA COOPERATIVE PROJECTS

The projects described in this section were funded jointly by the IDEA Program and the National Science Foundation (NSF) under a collaborative arrangement between NRC/TRB and NSF. The projects were funded in two separate yet interrelated parts. The basic science part (theoretical investigations and analytical verifications) was supported by an NSF grant, while the IDEA funds and contracts were used to develop and test the research product in a practical setting and to transfer results to highway applications.

CONTROL SYSTEM FOR HIGHWAY LOAD EFFECTS

NSF/NCHRP-IDEA Project 1

Andrzej S. Nowak [Tel.: (313) 764-8495, Fax: (313) 764-4292]
University of Michigan, Ann Arbor, Michigan

The project developed and field tested an integrated monitoring system for highway load effects control (Figure 1). The system includes a weigh-in-motion (WIM) truck weight measurement, fatigue load spectra measurement, and failure detection systems. The integrated system coupled with analytical procedures (development of load spectra, component-specific diagnostic test, prediction of remaining fatigue life) was applied for monitoring and providing bridge loading diagnostics. The system proved to be effective on truck parameters (weight, axle loads, speed, lane position, multiple presence) and load effects (girder moments and shears, component-specific strain and stress, fatigue load spectra) for estimating the health and remaining life of the bridge.

The system has the potential to serve as an efficient control measure to monitor highway loads for bridge diagnostics (evaluation of site-specific bridge condition) and management. The results of this project are on the way to implementation by the Michigan Department of Transportation (MDOT). The project team works closely with the technical staff of MDOT. The field work was carried out on bridges selected in coordination with MDOT. Some of the most efficient results that have already been implemented include WIM measurements and proof load testing. The developed procedures have been used by MDOT for evaluation of selected partially deteriorated bridges. The investigators are extending the project to focus on developing a remote-sensing device for measuring lane-specific truck parameters to arrive at practical procedures for active and passive control of truck load effects and to improve prediction of life expectancy and reliability of bridge structures based on WIM measurement.

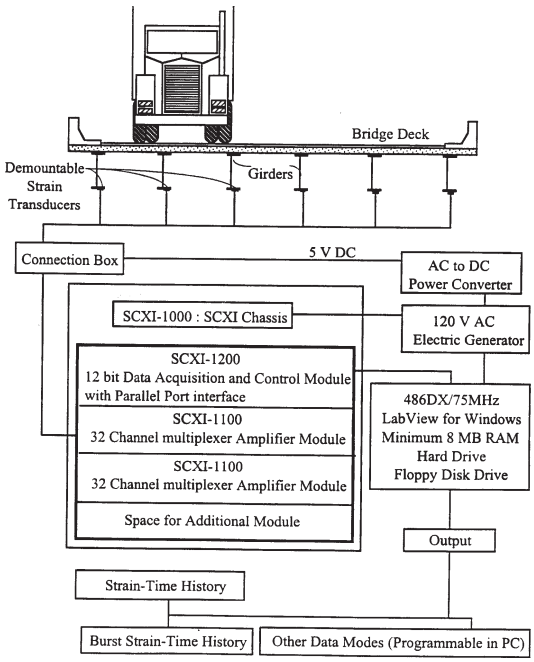


Figure 1

Data acquisition and control system.

PULSE-ECHO TOMOGRAPHIC MICROWAVE IMAGING SYSTEMS FOR QUANTITATIVE NDE OF CIVIL STRUCTURES AND MATERIALS

NSF/NCHRP-IDEA Project 2

Hua Lee [Tel.: (805) 893-4480, Fax: (805) 893-3262], University of California, Santa Barbara, California

The objective of this research is to develop pulse-echo tomographic imaging techniques for quantitative nondestructive evaluation (NDE) of civil structures and materials. Pulse-echo impulse radar provides a means of detecting voids, cracks, and the condition of concrete reinforcement bars. The ability to recognize and identify the constitution of detected objects is also useful for NDE of civil structures. Classification of the material type permits the confirmation of design specifications and a more accurate evaluation of unknown areas.

Pulse-echo radar transmits a pulse and performs time-delay estimation on the received echoes to form the time-delay profile. A Fourier transform is used to decompose the returns into their frequency components. The frequency components are individually back-propagated to create a wavefield of the area. The wavefields are then superimposed to reconstruct the image area. A singular value decomposition of the wavefield at a target is used to generate a signature vector that minimizes the sum of all distances from each wavefield to its projection onto the vector. Signatures of different materials are stored in a database for comparison to the signatures of unidentified targets. Matches are performed by computing the magnitude of the inner product with each signature in the database. Objects are identified by matching multiple signatures from the target and applying majority rule.

The investigators successfully developed and implemented the image reconstruction algorithm for the data acquisition system and operating configuration. The utilization of wavefield statistics for accurate image formation was optimized and pattern recognition techniques were evaluated. Matching and recognition experiments were performed to demonstrate the application of the technique to evaluate civil structures.

Five classes of materials were used to test the object recognition method. The five targets included an air void, air permeated concrete, a full water occlusion, the air portion of an air/water mix, and the water portion of the air/water mix. All targets were embedded in concrete. The results showed that the technique identified all targets correctly. In fact, the object recognition scheme was able to correctly identify all classes of test objects with as few as 5 test set vectors.

The technique is being used in industrial applications at the Special Technologies Laboratories of the University of California, Santa Barbara. The California Department of Transportation is planning to use the technology in conjunction with the Lawrence Livermore National Laboratory system for bridge inspection. Cooperation for implementing the technology will be available from the NSF University/Industry Research Center on High-Speed Image Processing.

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.

www.national-academies.org