IDEA

Innovations Deserving
Exploratory Analysis Programs

HIGHWAY

New IDEAS for Highway Systems

Annual Progress Report

December 2019

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NEW IDEAS FOR HIGHWAY SYSTEMS

An Annual Progress Report of the Highway IDEA Program

DECEMBER 2019

TRANSPORTATION RESEARCH BOARD

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP 20-30 IDEAS DESERVING EXPLORATORY ANALYSIS (IDEA) PANEL

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TABLE OF CONTENTS

SECTION 1: Completed IDEA Projects

SECTION 2: Active IDEA Projects

SECTION 3: NSF/NRC-IDEA Cooperative Projects

Project **Page**

INTRODUCTION

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

Highway IDEA is one of three IDEA programs managed by the Transportation Research Board (TRB) to foster innovation in highway and intermodal surface transportation systems. Highway 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.

The Highway IDEA program is 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 systems practice.

The selection of each IDEA investigation is made by consensus recommendations from the Highway IDEA Project Panel, 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 selected to work with the investigator on product development and transfer to highway practice. The products emerging from the Highway 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 2019 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 Highway IDEA program for product transfer. Section 2 presents reports of investigations on projects active or completed during the 2019 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. This 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 Highway IDEA Program (attention: Dr. Inam Jawed), Transportation Research Board, 500 Fifth St. NW, Washington, D.C., 20001. Email: ijawed@nas.edu.

SECTION 1
COMPLETED IDEA PROJECTS

This section presents brief summaries of Highway IDEA projects completed before the 2019 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).

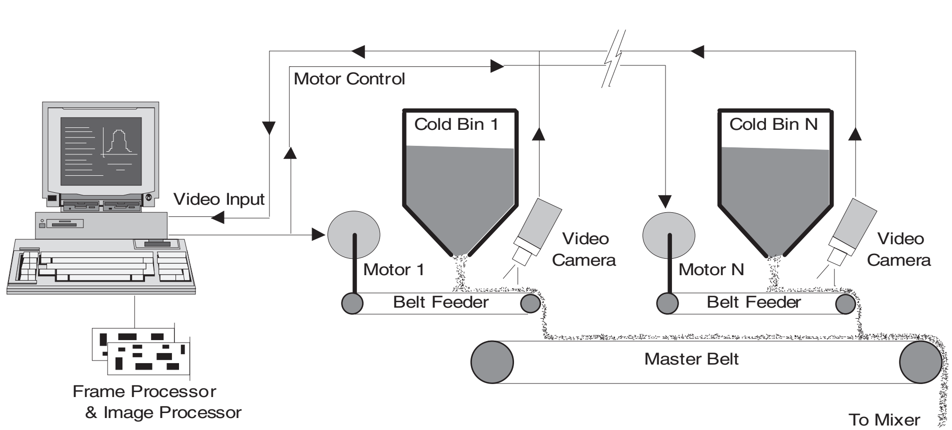


Figure 1

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).

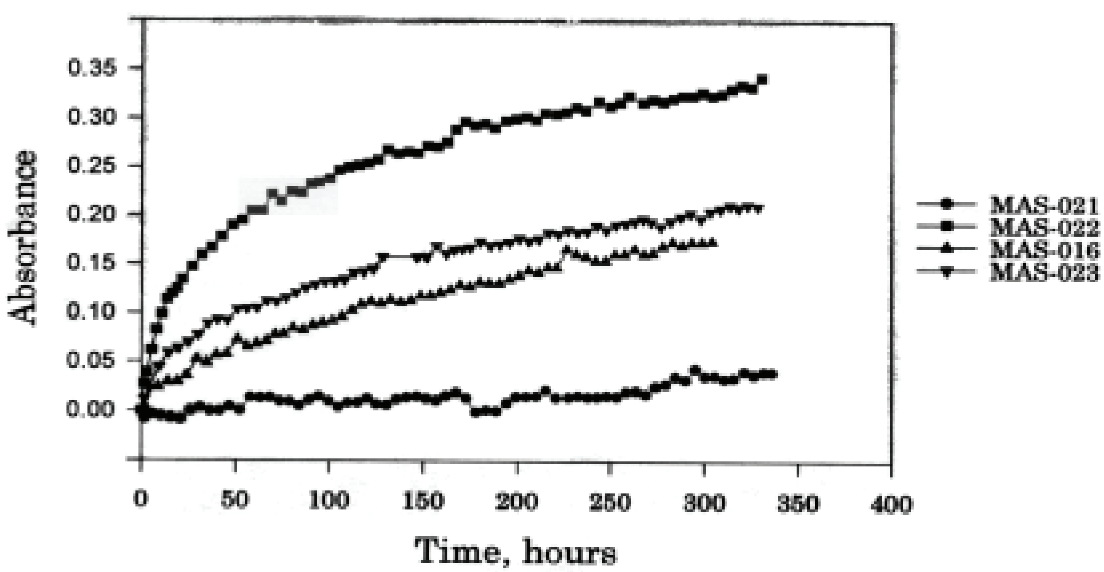


Figure 1

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).

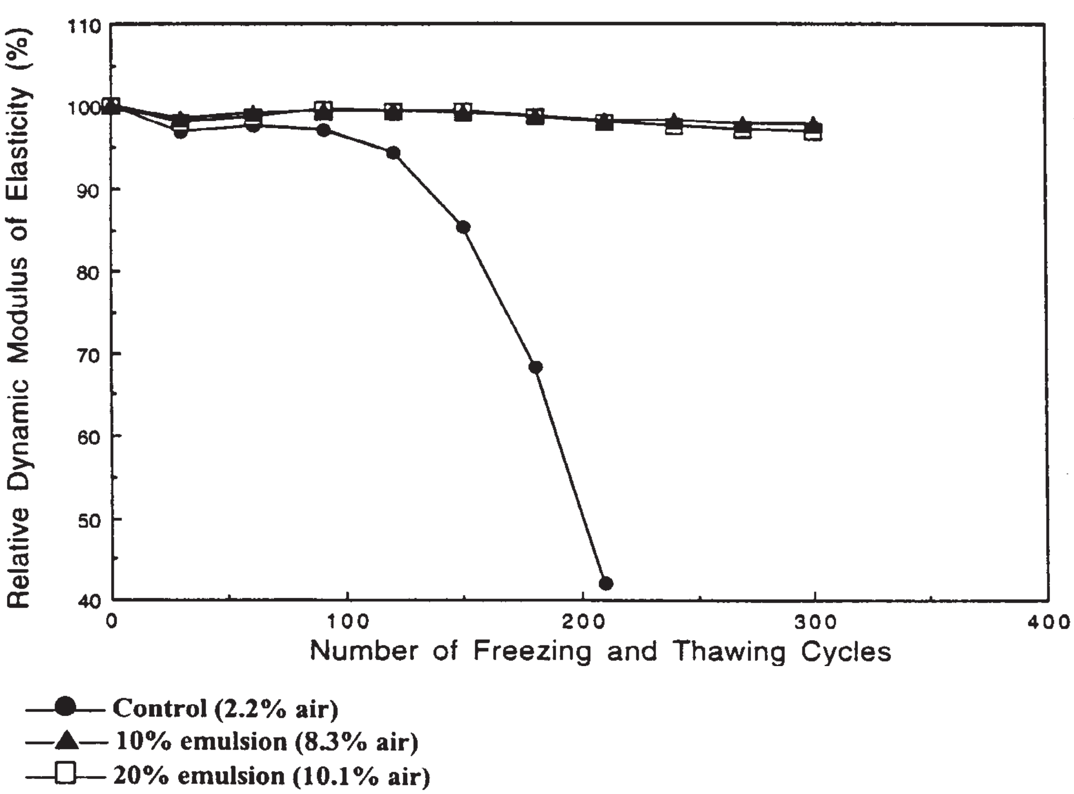


Figure 1

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).

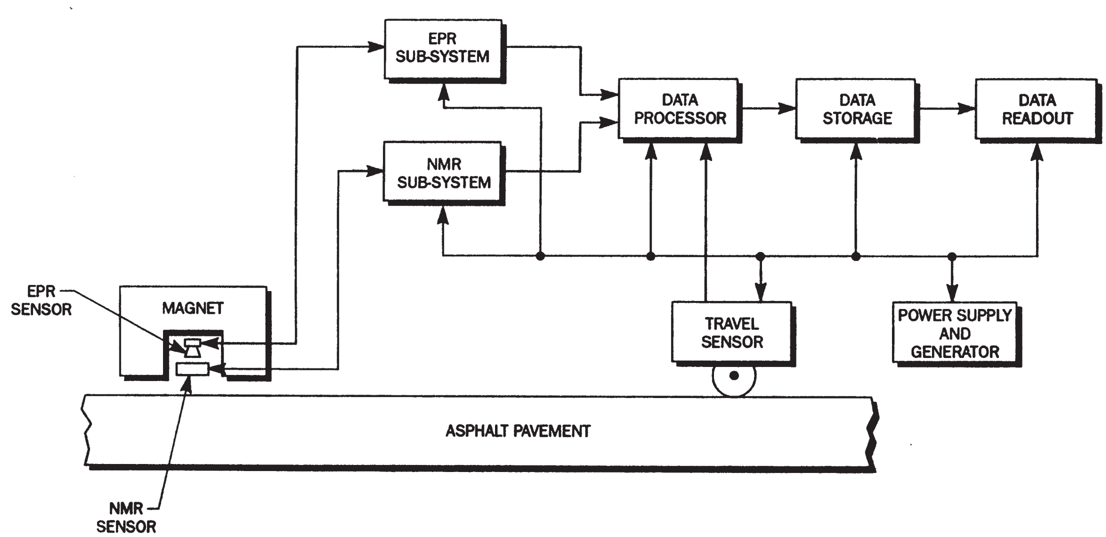


Figure 1

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).

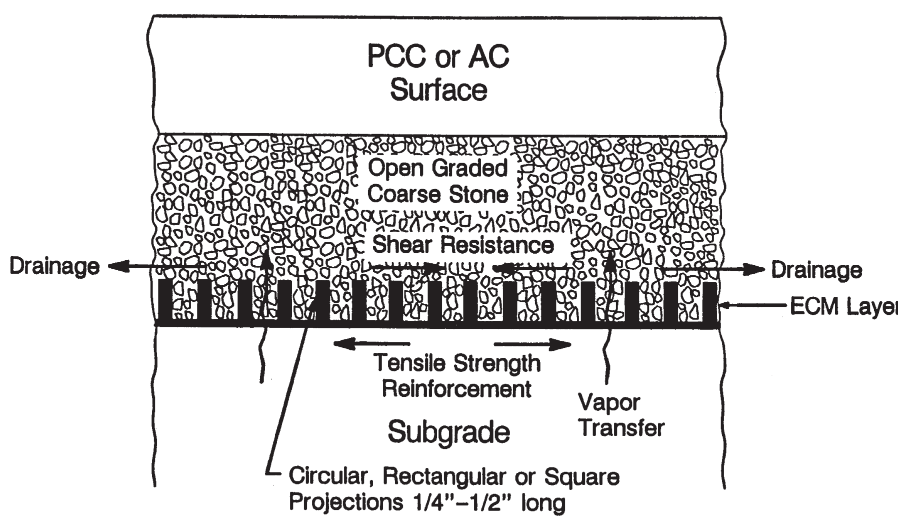


Figure 1

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.

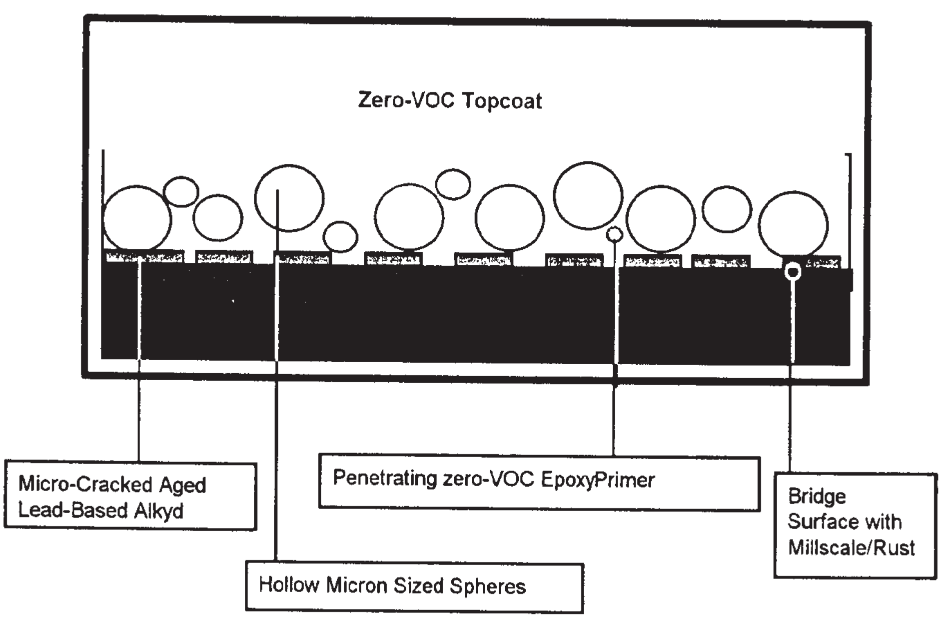


Figure 1

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).

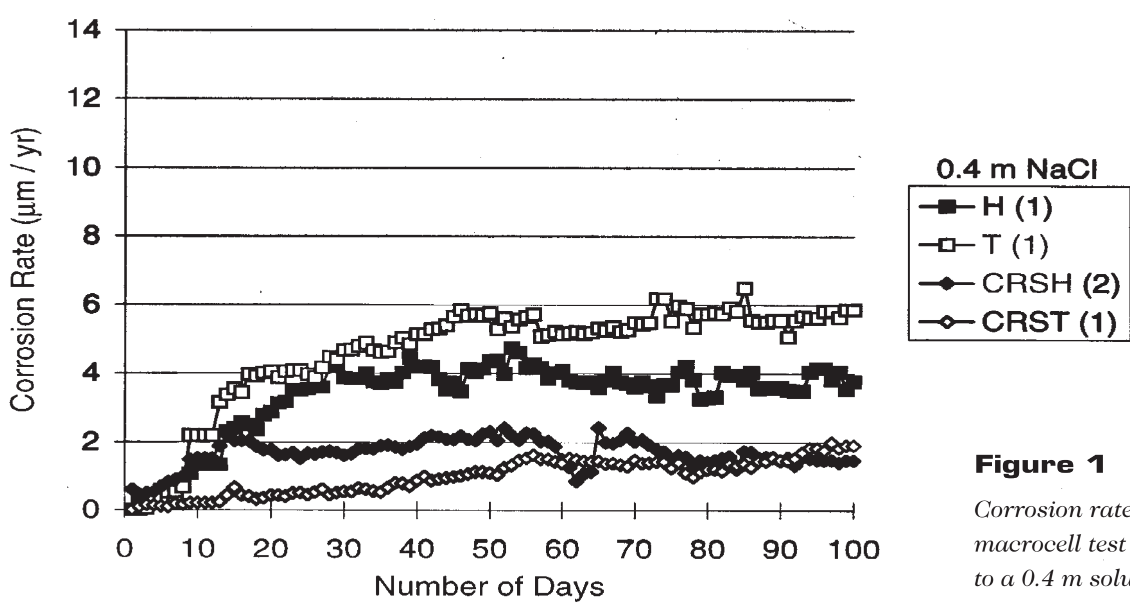


Figure 1

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).

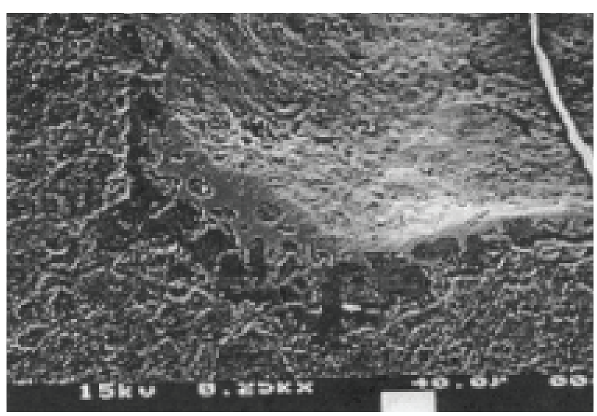


Figure 1

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).

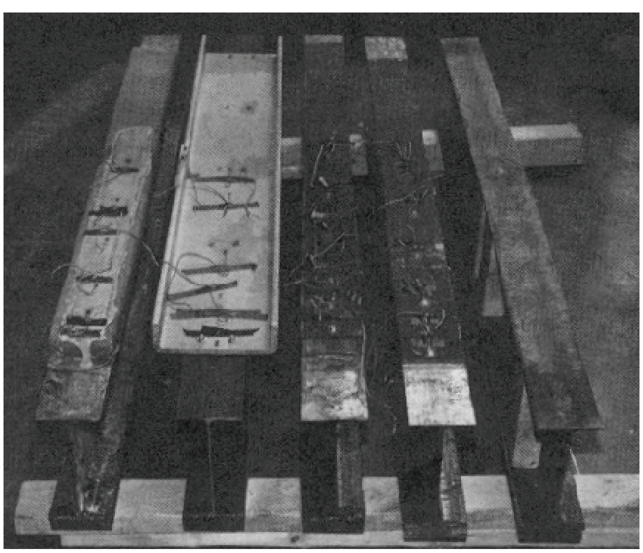


Figure 1

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).

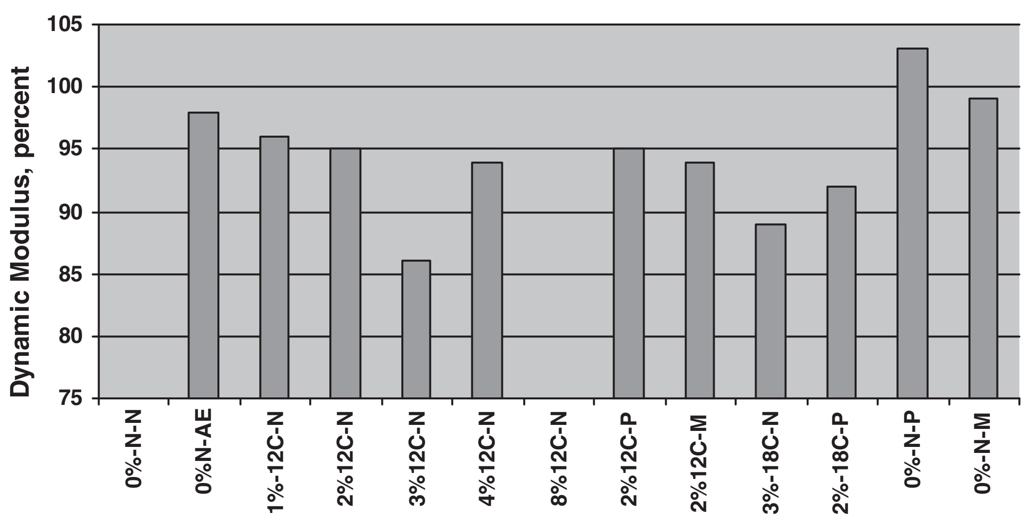


Figure 1

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).

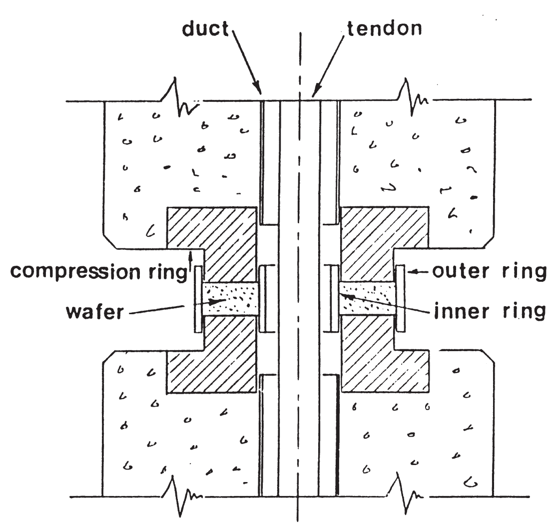


Figure 1

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).

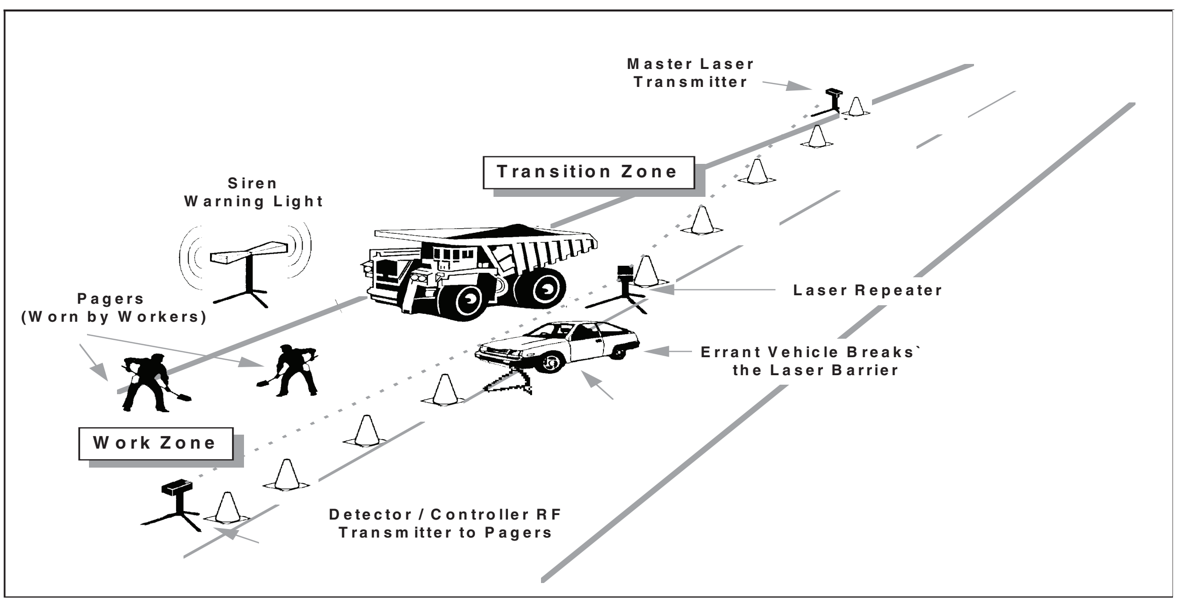


Figure 1

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).

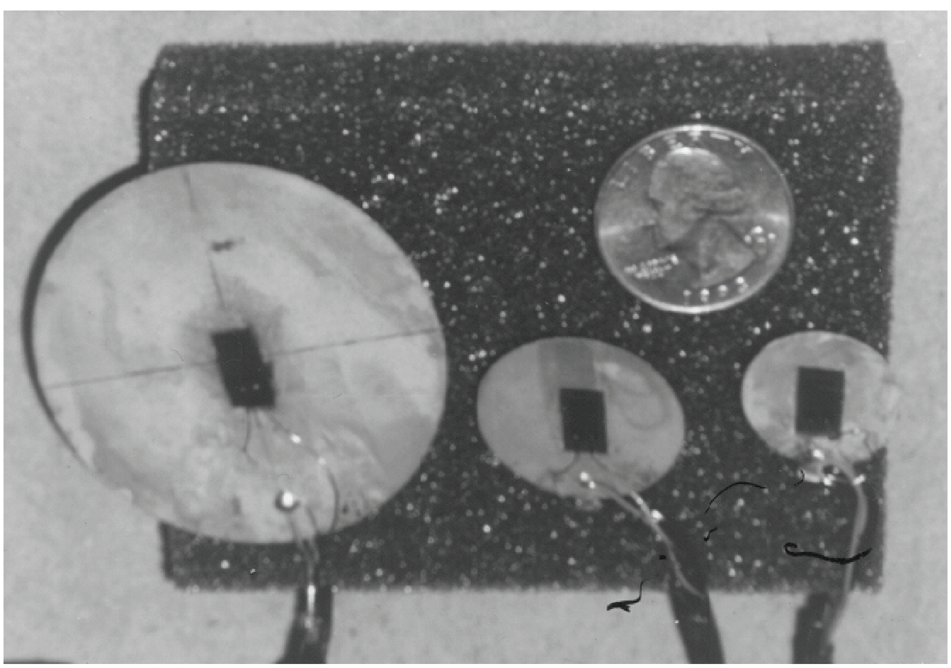


Figure 1

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.

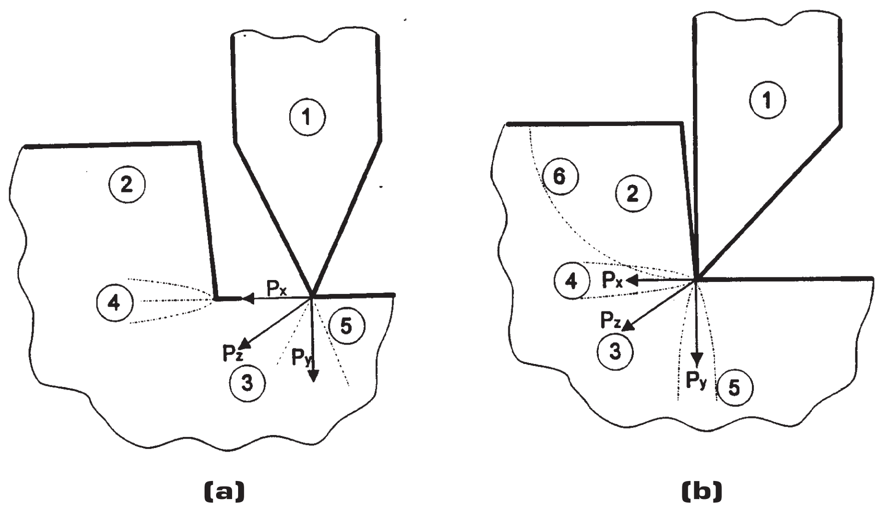


Figure 1

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).

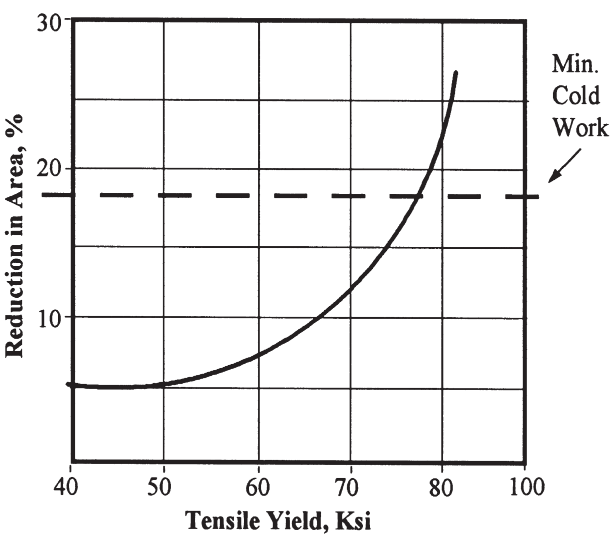


Figure 1

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

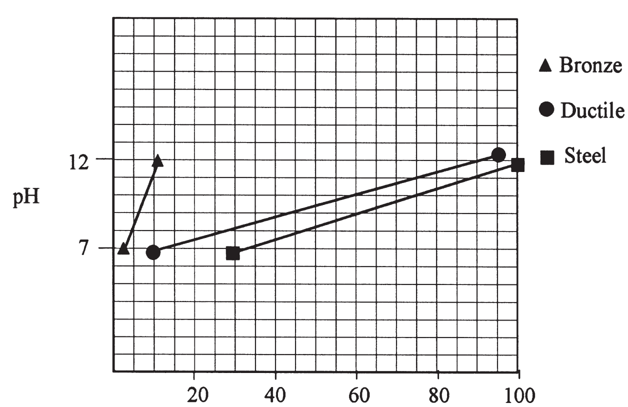


Figure 2

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.

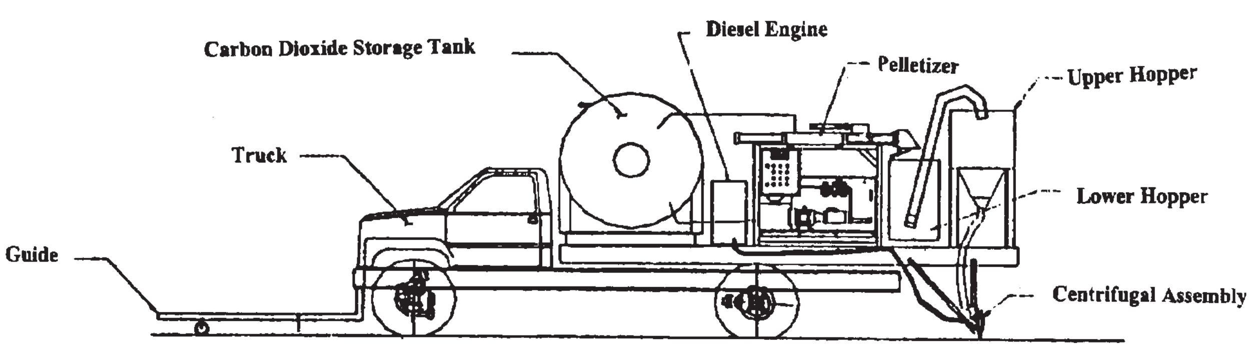


Figure 1

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).

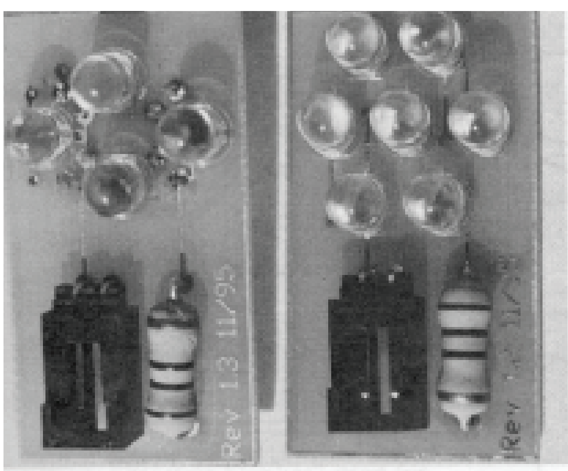


Figure 1

High- and low-intensity LED devices.

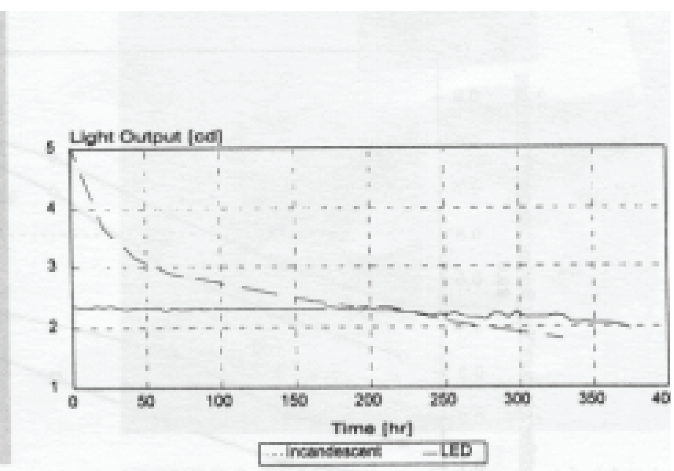


Figure 2

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).

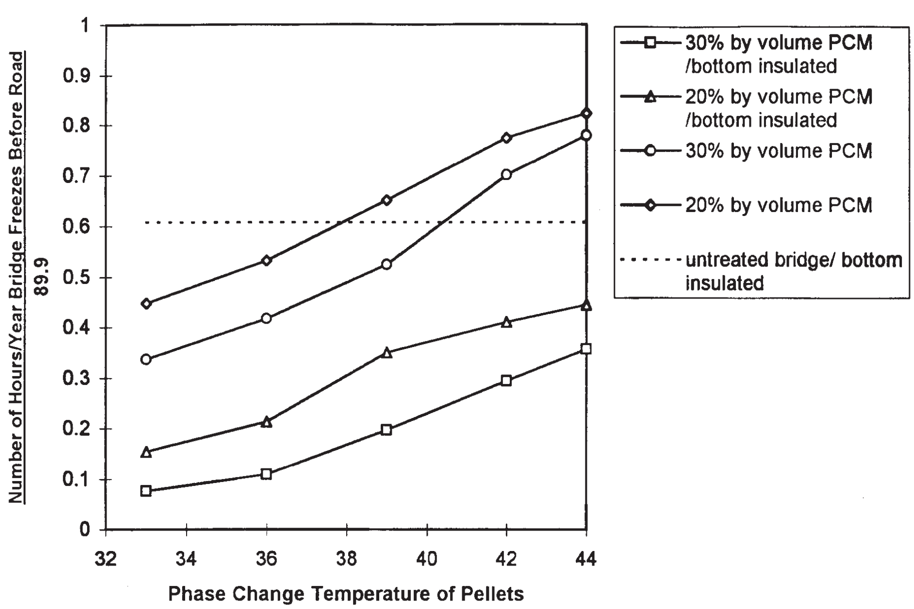


Figure 1

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).

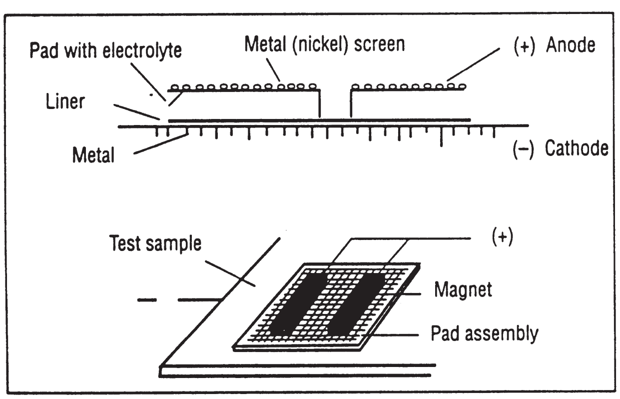


Figure 1

"Electric blanket" used for electrochemically assisted paint removal.

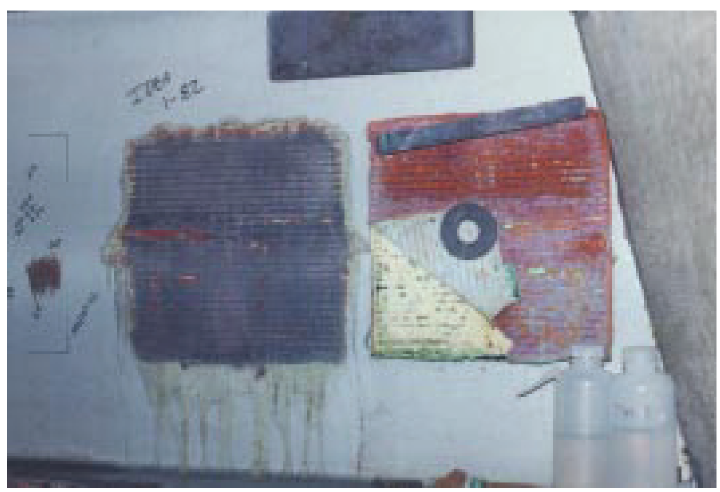


Figure 2

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).

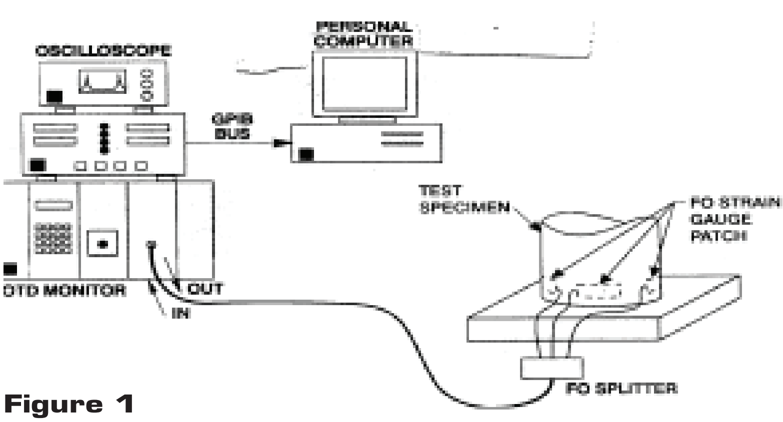


Figure 1

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

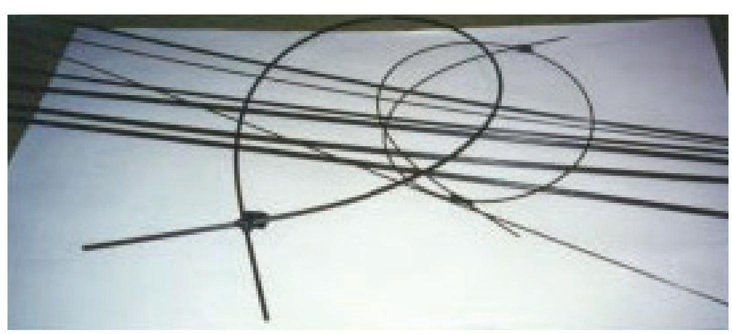


Figure 1

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).

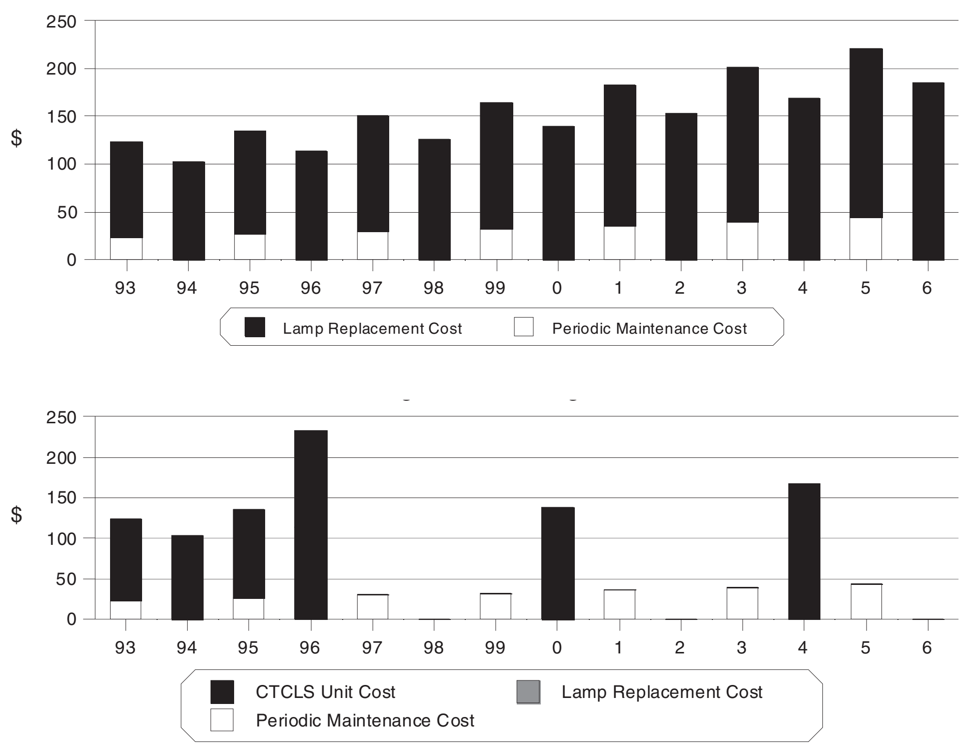


Figure 1

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).

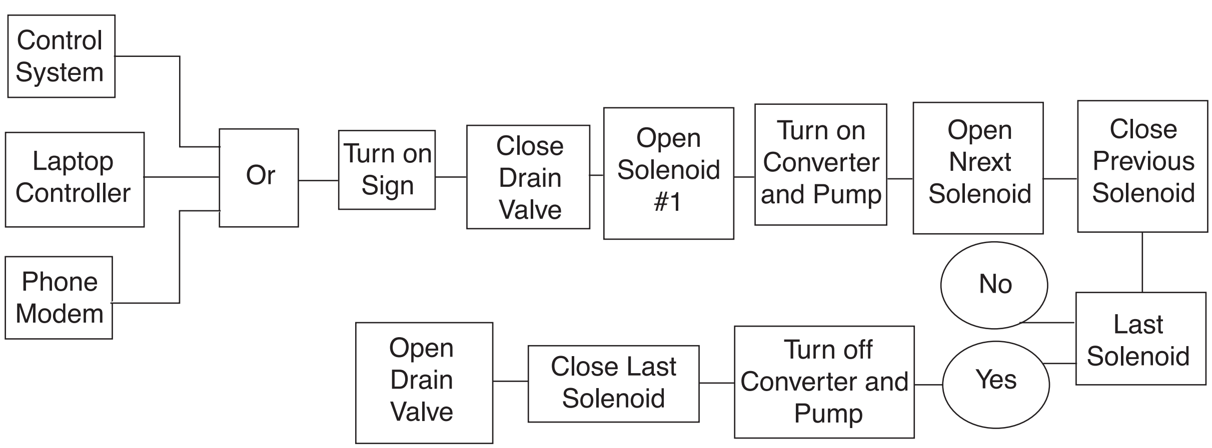


Figure 1

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).

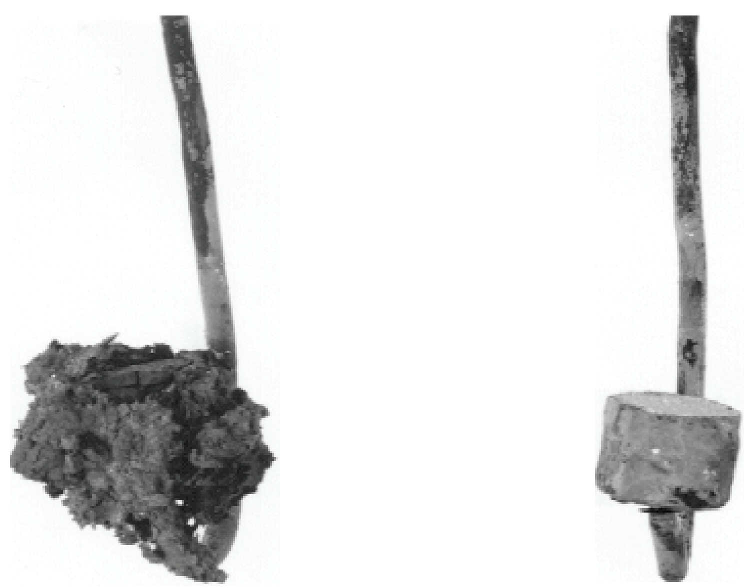


Figure 1

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

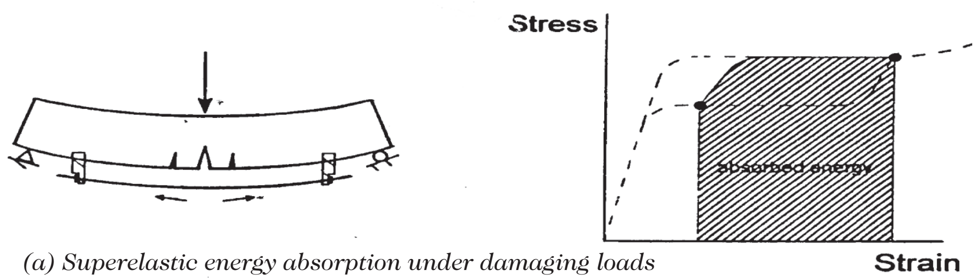
SUPERELASTICITY-BASED MATERIALS FOR BRIDGE REHABILITATION

NCHRP-IDEA Project 29

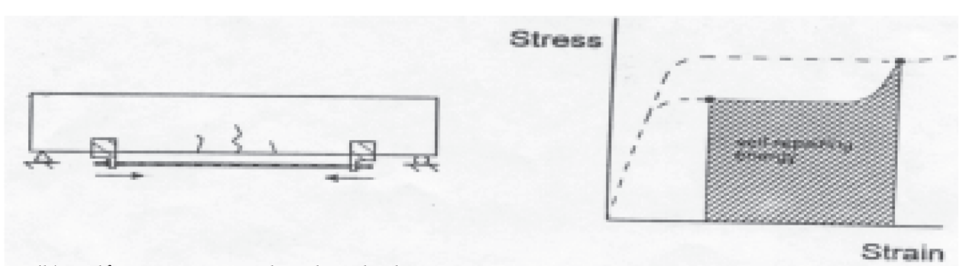
Jer-Wen Hsu and Ken Ostowari [Tel.: (517) 349-5653, Fax: (517) 349-5653]
DPD Inc., Lansing, Michigan

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).

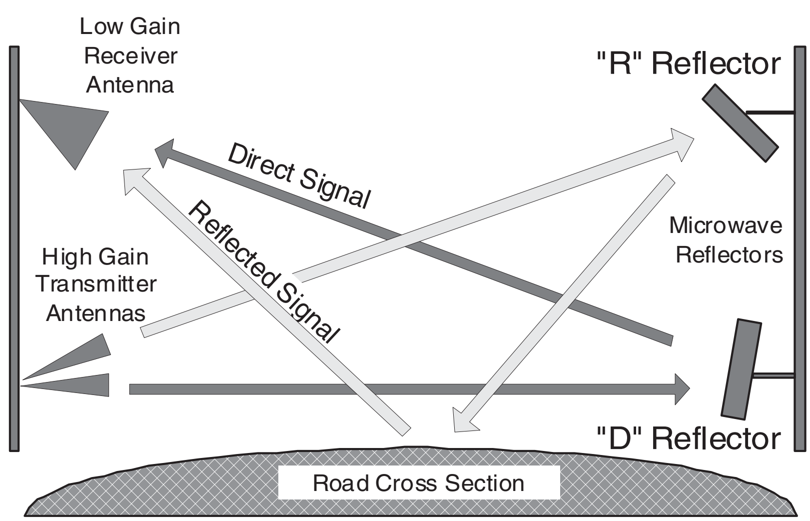


Figure 1

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).

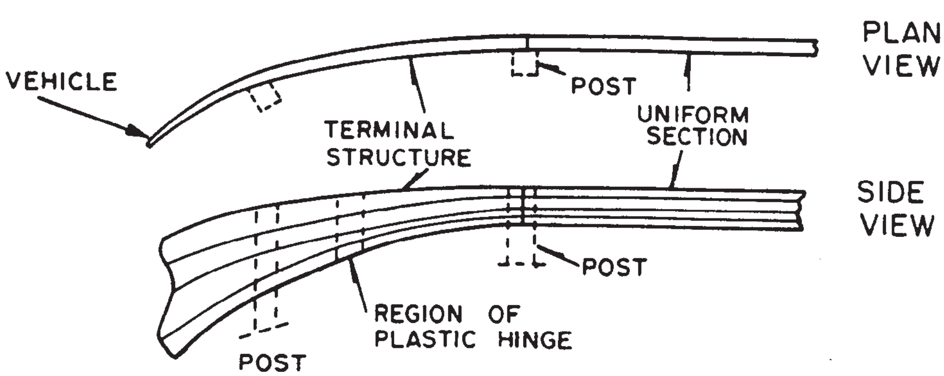


Figure 1

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).

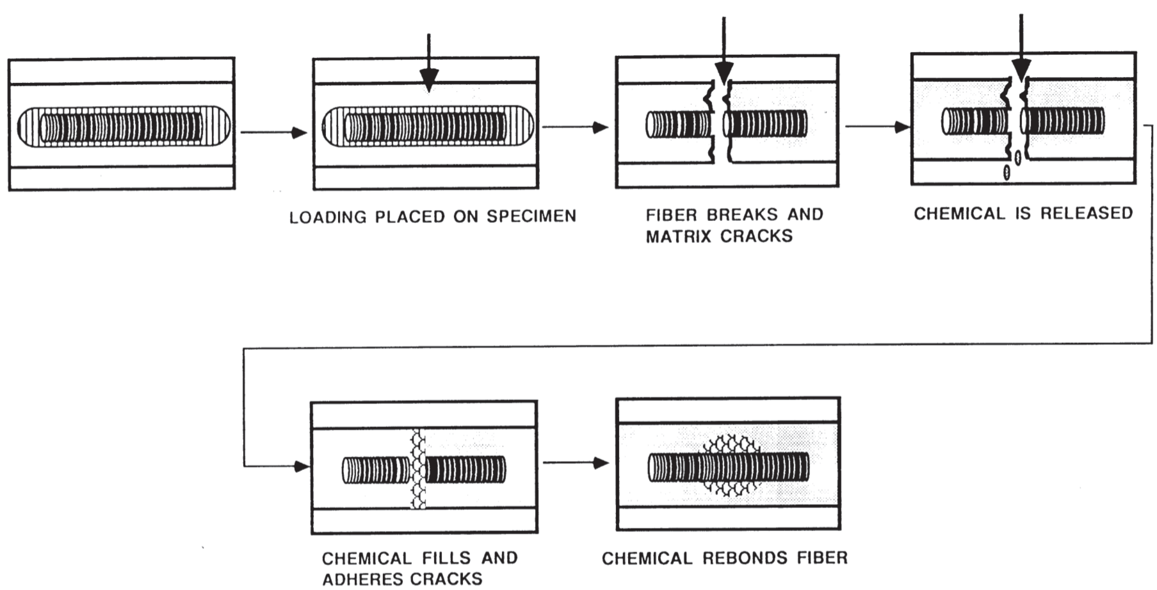


Figure 1

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).

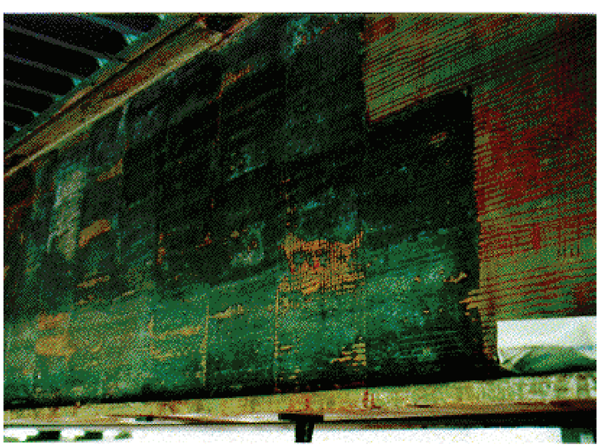


Figure 1

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).

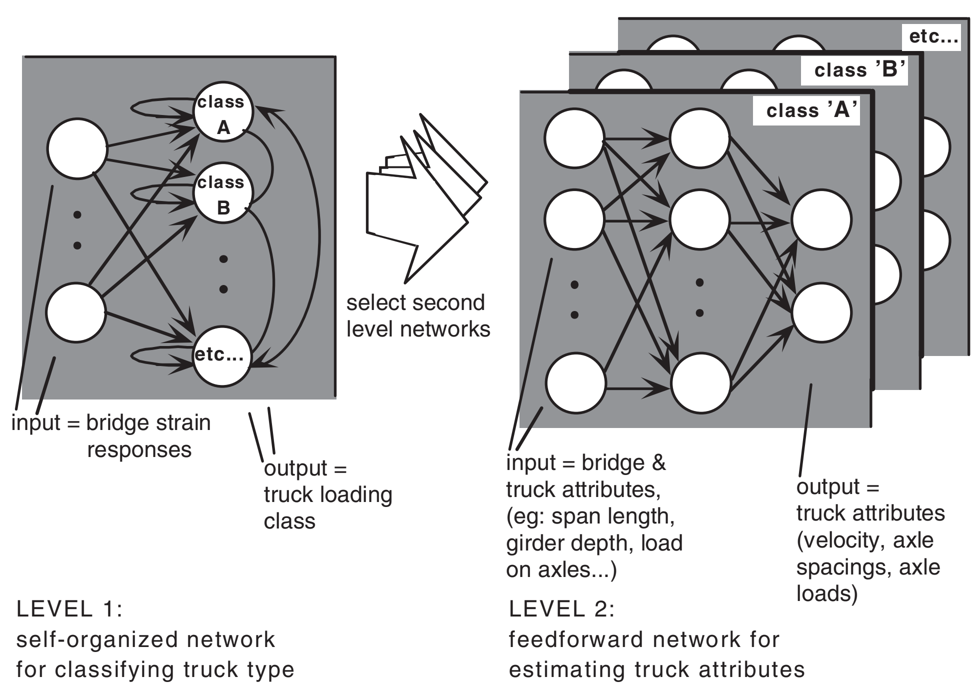


Figure 1

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).

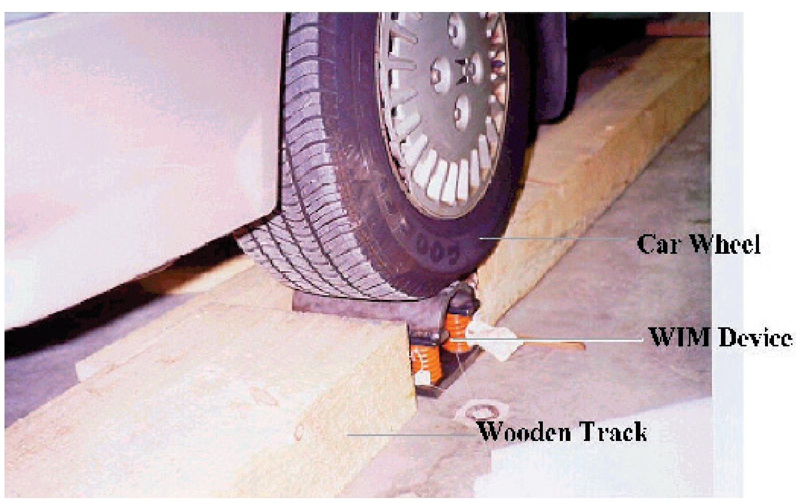


Figure 1

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

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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).

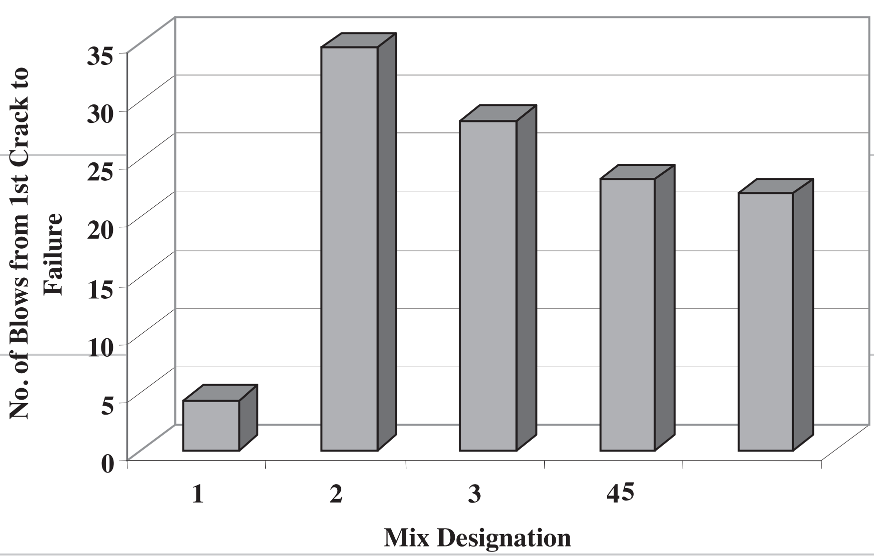


Figure 1

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

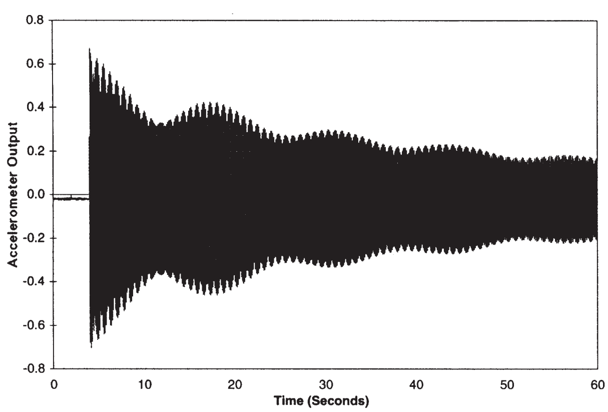
Truck-mounted RoadWriter™ prototype system in field operation.

DAMPER SYSTEMS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

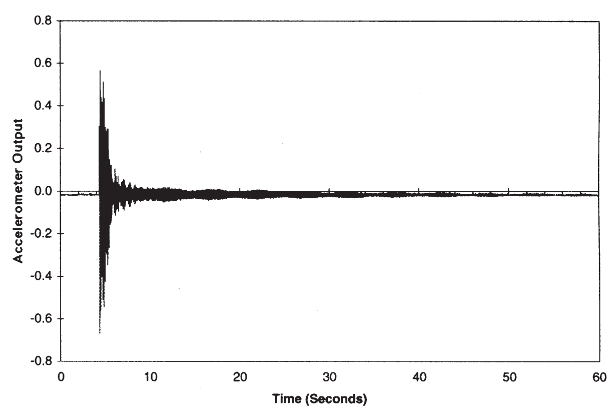
NCHRP-IDEA Project 50

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).



(a)



(b)

Figure 1

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

APPLICATION OF ADVANCED COMPOSITES TO STEEL BRIDGE RETROFITTING

NCHRP-IDEA Project 51

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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

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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

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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).

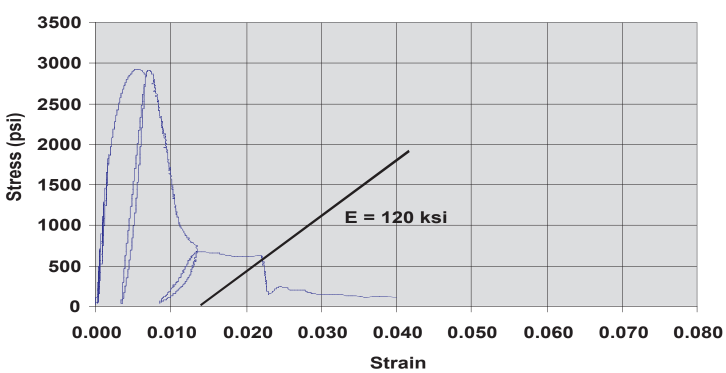

Figure 1

Stress strain response—compression test.

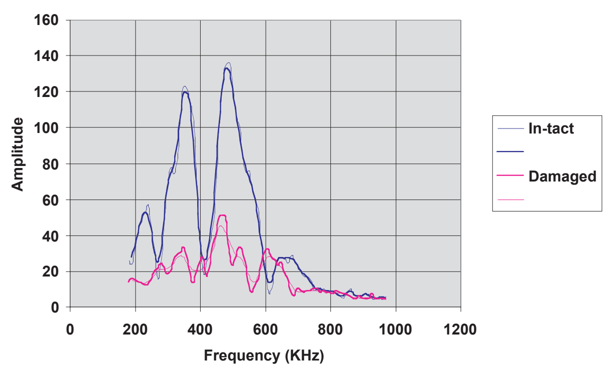

Figure 2

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

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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

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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).

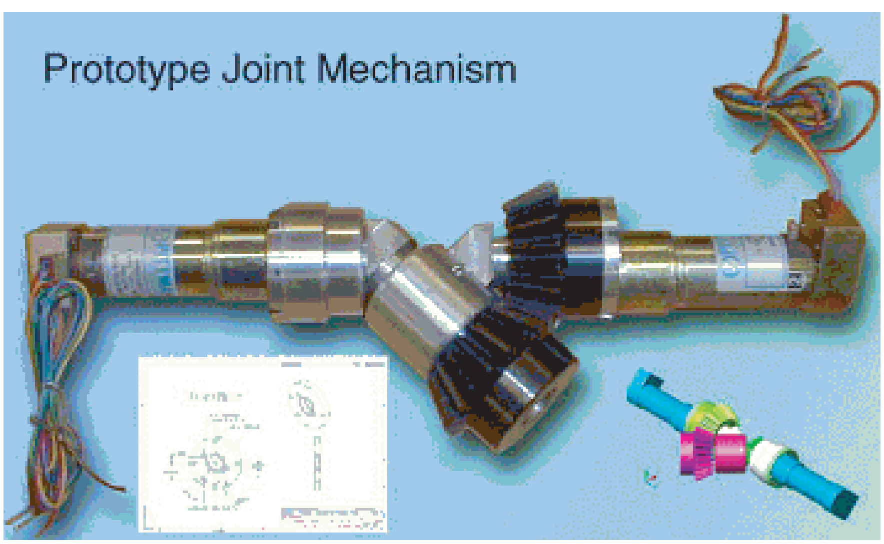

Figure 1

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

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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

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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).

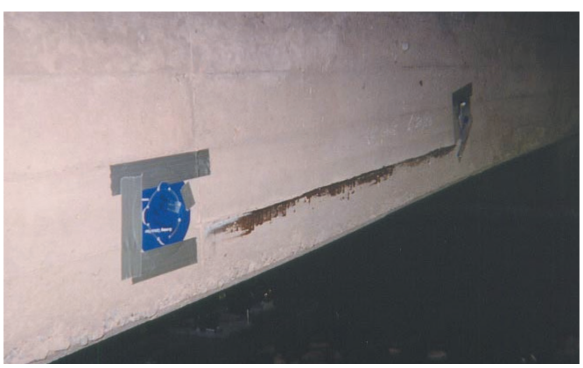

Figure 1

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).

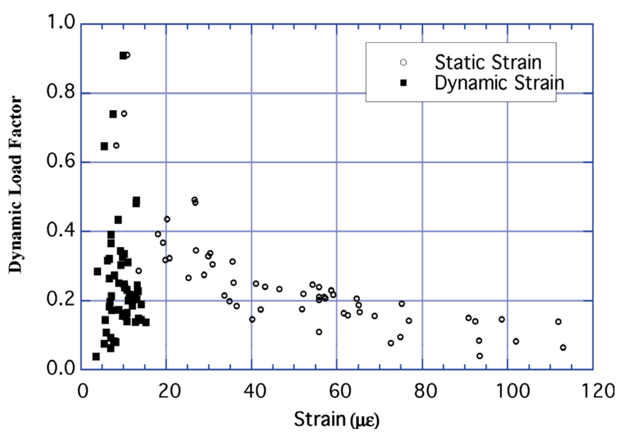

Figure 1

DLF vs. static and dynamic strain.

THE HYBRID-COMPOSITE BEAM SYSTEM

NCHRP-IDEA Project 60

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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

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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).

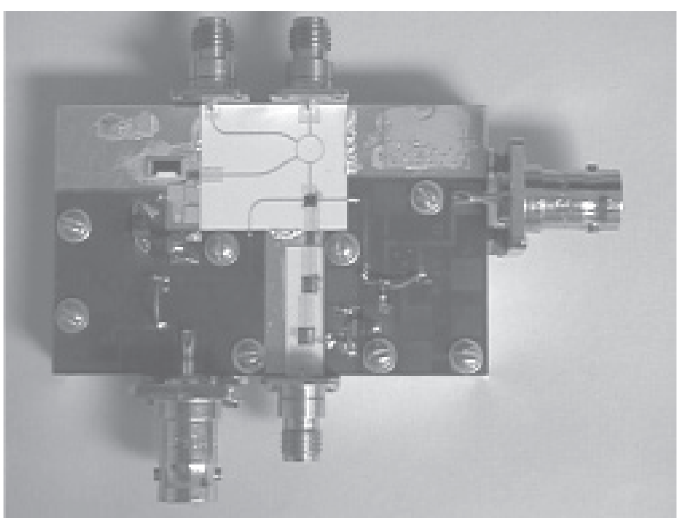

Figure 1

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).

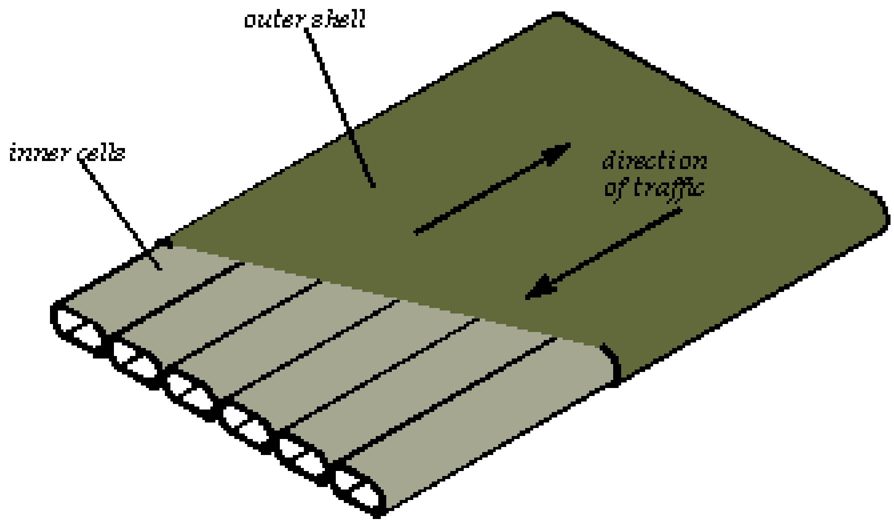

Figure 1

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).

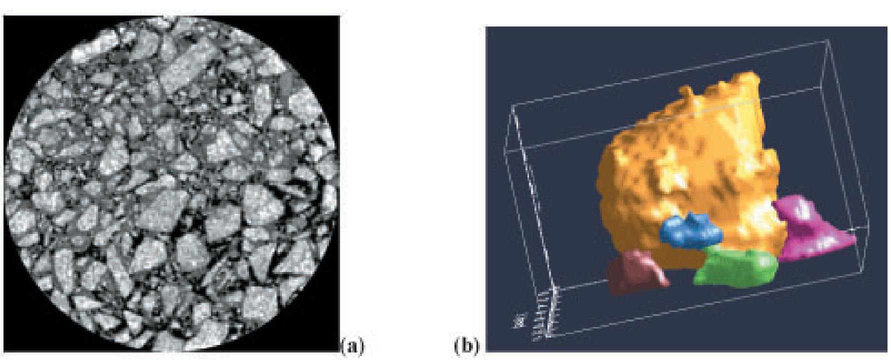

Figure 1

(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

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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.

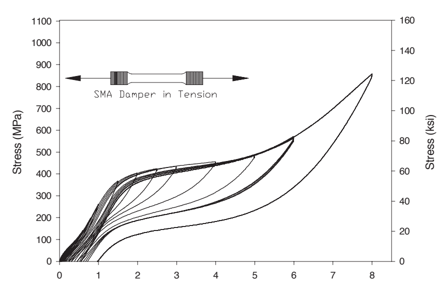

Figure 1

(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

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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.

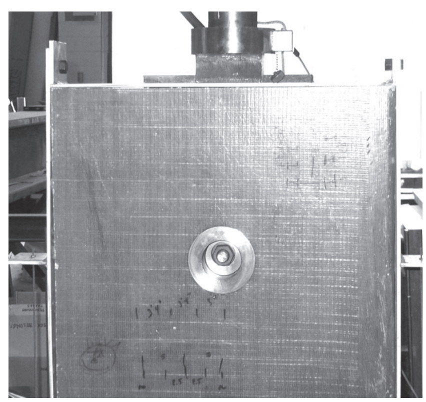

Figure 2

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

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University of New Mexico, Albuquerque, New Mexico, and

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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).

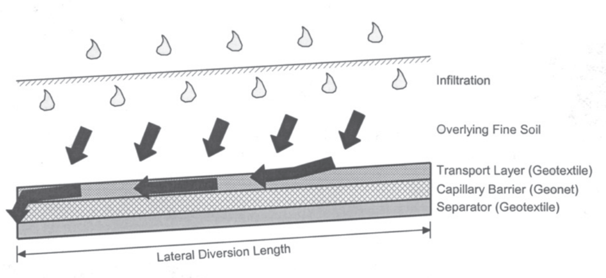

Figure 1

Geocomposite capillary barrier drain.

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

NCHRP-IDEA Project 69

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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).

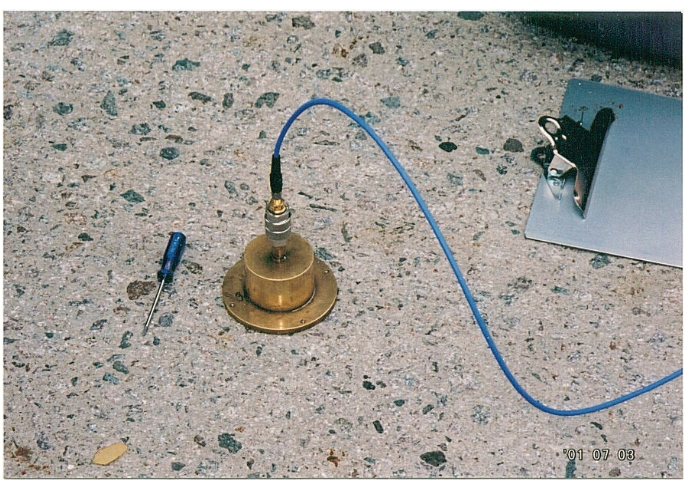

Figure 1

CSP probe.

FLAMESPRAY COATING AS AN ENVIRONMENTALLY ACCEPTABLE PAVEMENT MARKING TECHNIQUE

NCHRP-IDEA PROJECT 70

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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

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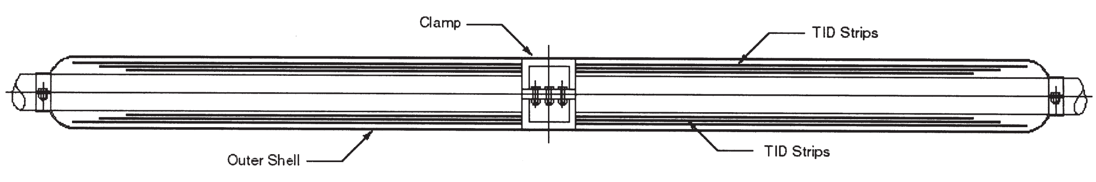
Habib Tabatabai
University of Wisconsin, Milwaukee, Wisconsin

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).



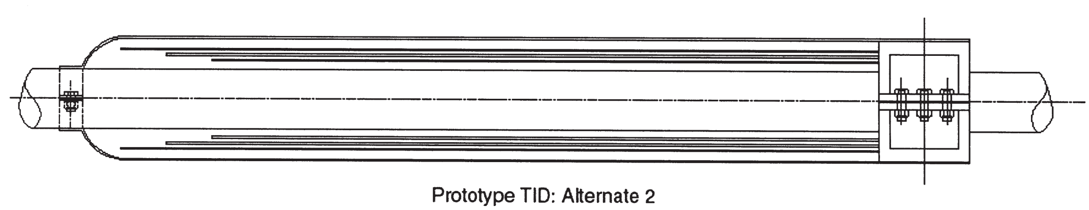


Figure 1

Tuned Induced Damper (TID) system.

IMPROVED FILTRATION OF WASH WATER GENERATED DURING BRIDGE MAINTENANCE PAINTING

NCHRP-IDEA Project 72

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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

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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).

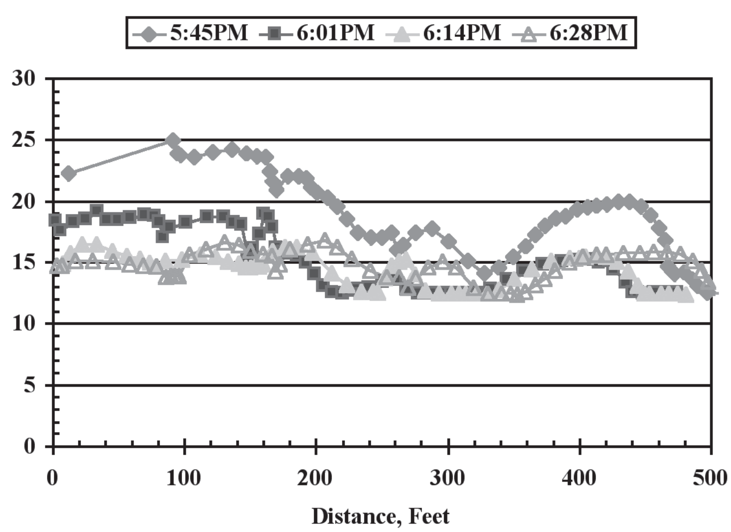

Figure 1

Temperature ranges for four runs on an existing pavement.

ADHESION TOOL FOR OVERCOATING RISK-REDUCTION ANALYSIS

NCHRP-IDEA Project 74

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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

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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

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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

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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).

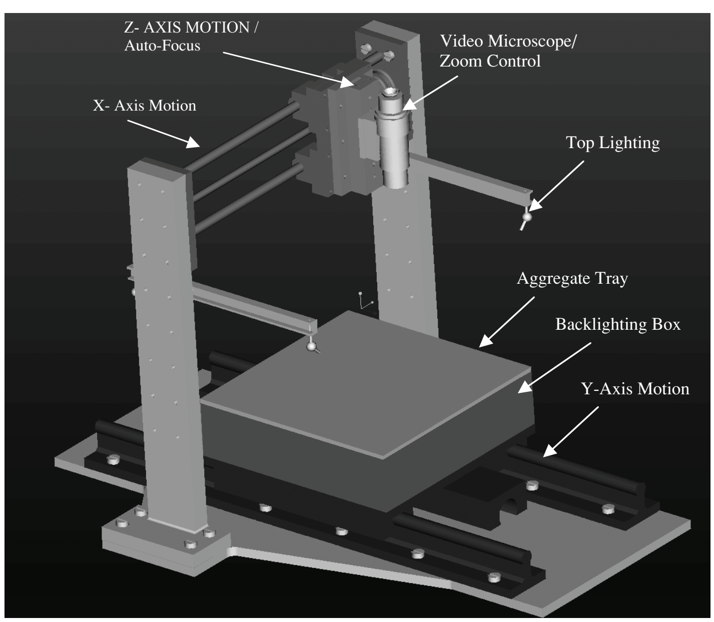

Figure 1

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

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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.

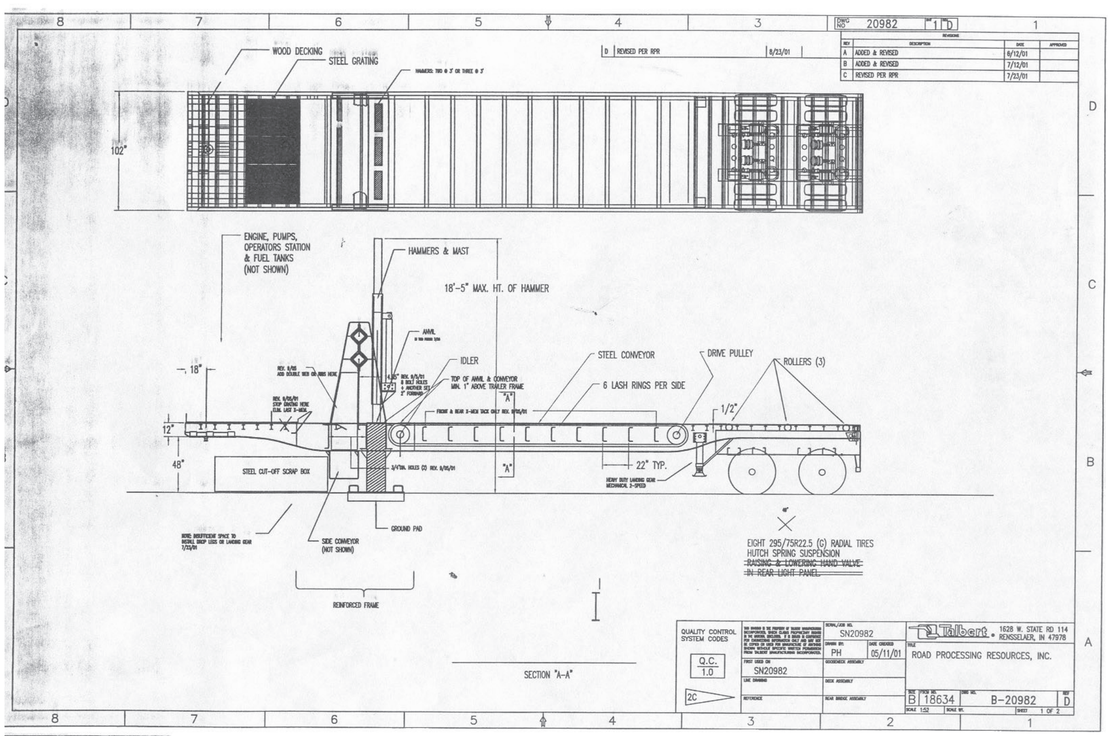

Figure 1

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

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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

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

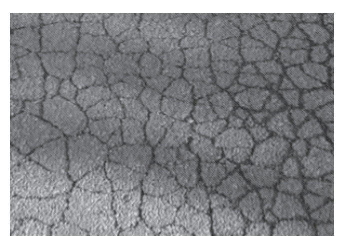
This project developed an automated real-time crack detection and analysis system based on image processing and computer vision techniques. The system consists of a personal computer, a frame grabber with two on-board processors, a distance sensor and a video camera mounted on top of a van. The images 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)

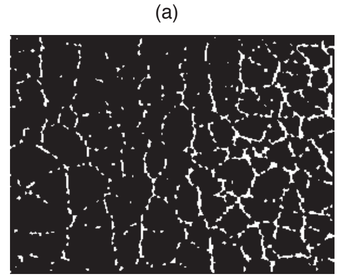
(b)

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

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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).

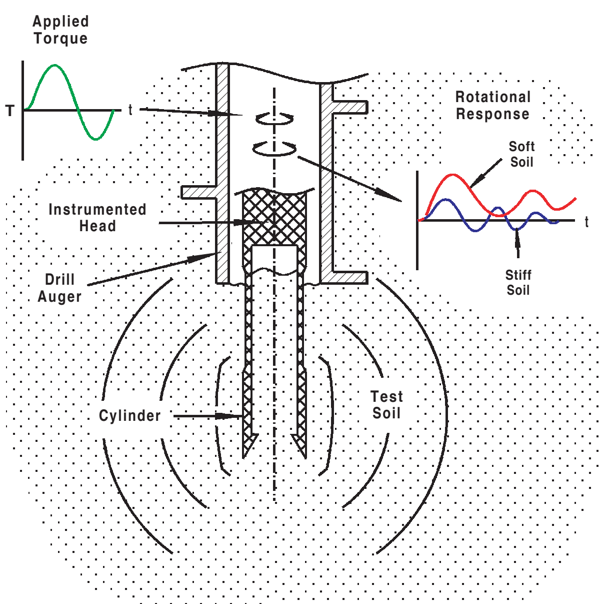

Figure 1

Basic idea of impulse shear test.

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

NCHRP-IDEA Project 83

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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.

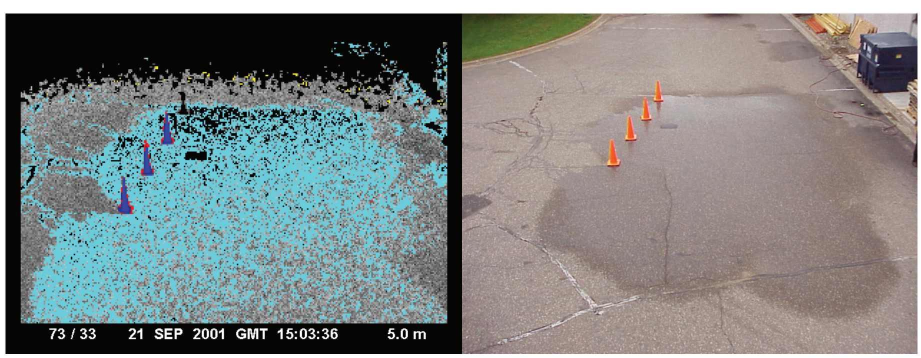

Figure 2

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

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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

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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

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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

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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).

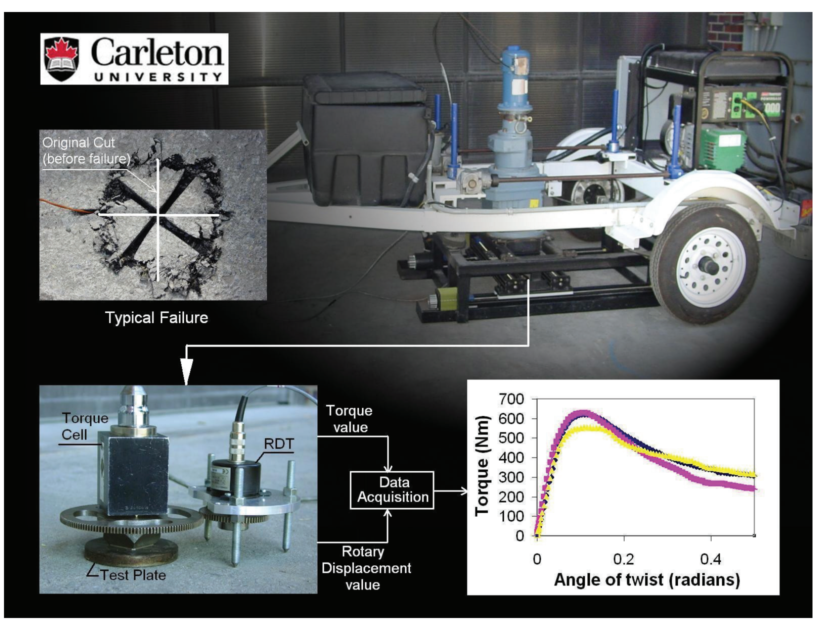

Figure 1

The InSiSST™ system.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION

NCHRP-IDEA Project 88

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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.

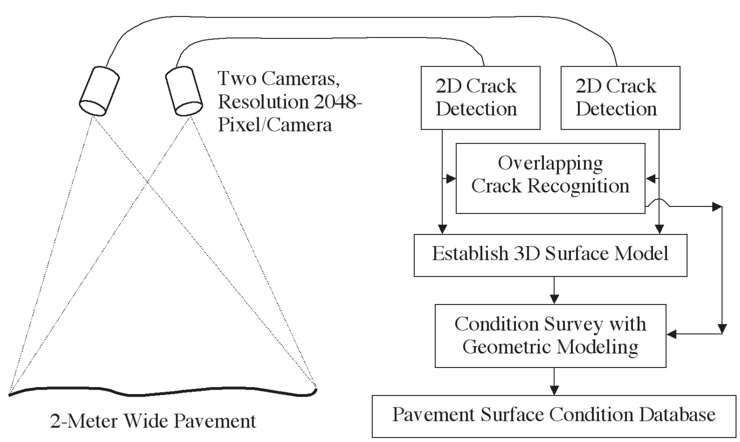

Figure 2

General procedures for automated condition survey with stereovision.

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

NCHRP-IDEA Project 89

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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).

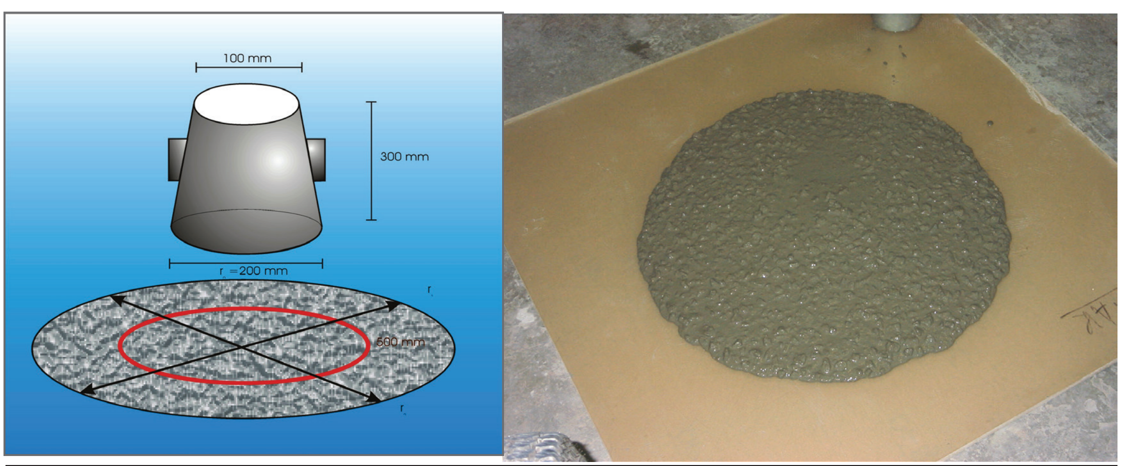

Figure 1

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

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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).

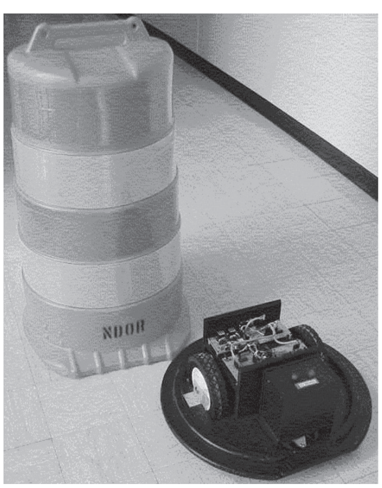

Figure 1

A robotic highway safety marker.

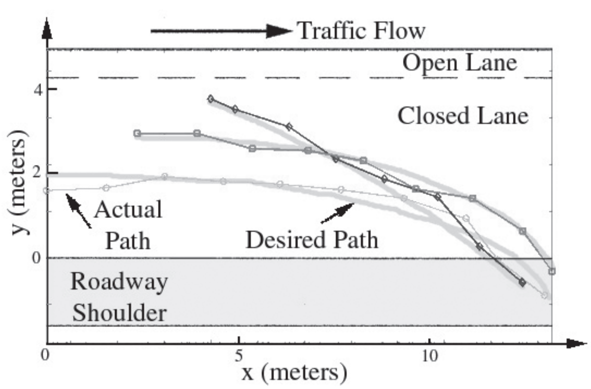

Figure 2

Desired and actual paths during field test.

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 91

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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).

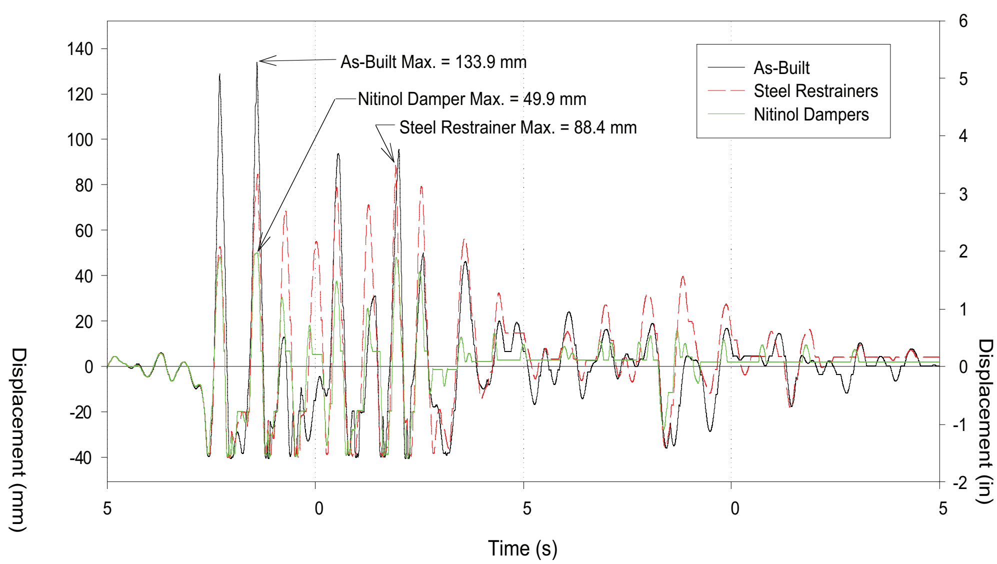

Figure 1

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

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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).

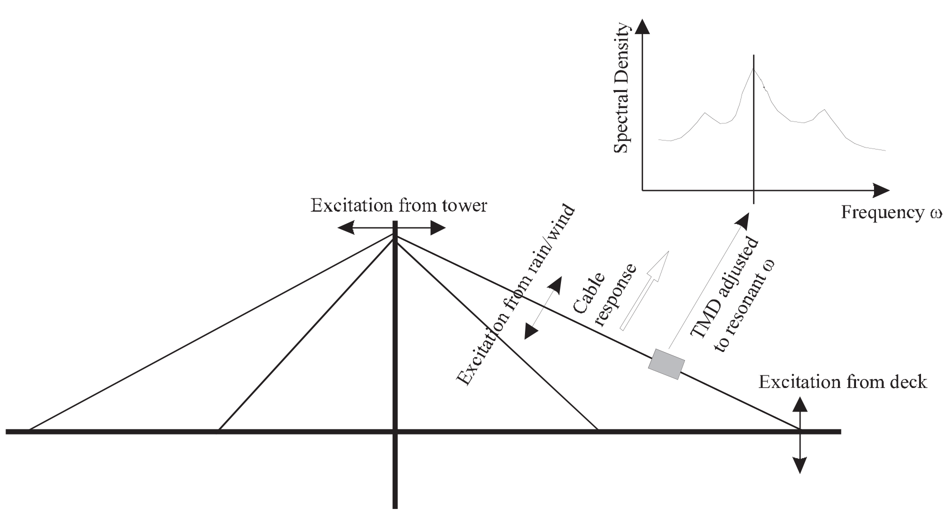

Figure 1

Sketch of cable vibration control strategy.

ADVANCED RELOCATABLE TRAFFIC SENSOR SYSTEM (ARTS)

NCHRP-IDEA Project 93

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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).

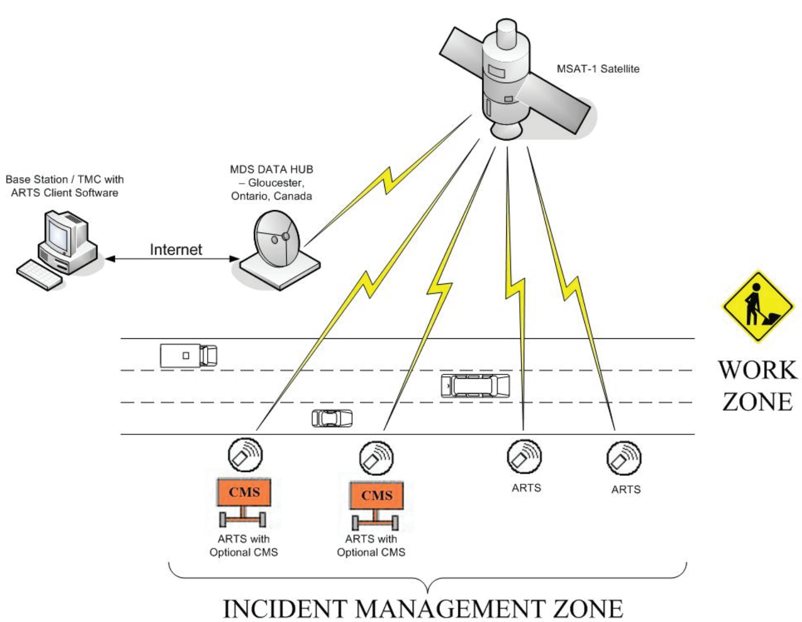

Figure 1

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

LIQUEFACTION MITIGATION USING VERTICAL DRAINAGE: FULL-SCALE TESTING

NCHRP-IDEA Project 94

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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).

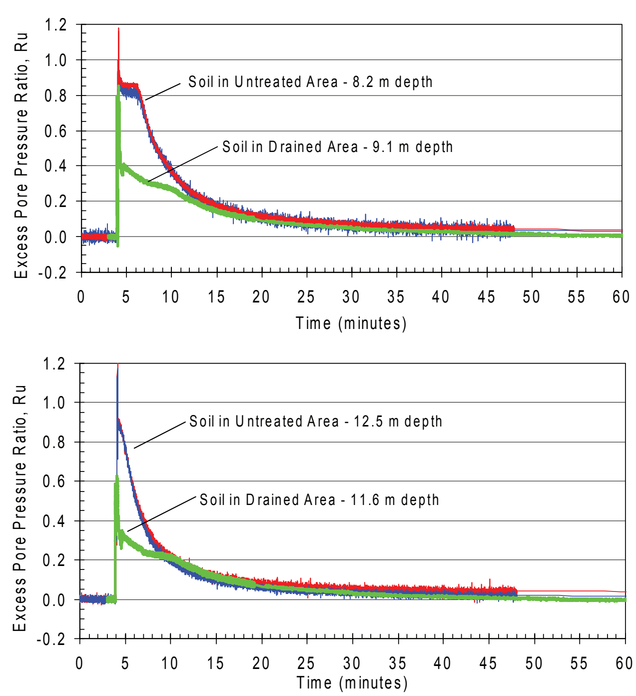

Figure 1

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

pore pressure

CONCRETE ROAD RECYCLER—HAMMER-ANVIL TEST

NCHRP-IDEA Project 95

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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.

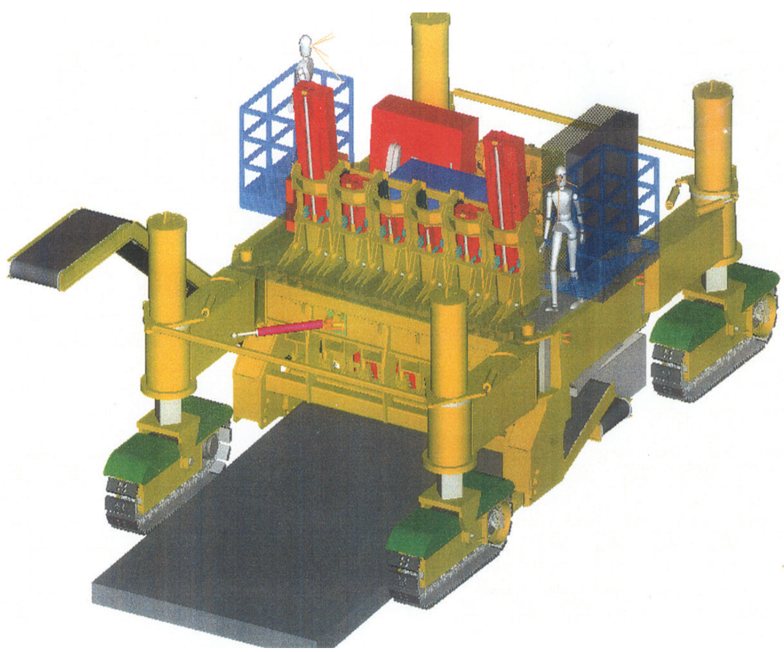

Figure 1

USING ULTRASOUND OF MHZ FREQUENCY FOR TESTING CONCRETE

NCHRP-IDEA Project 96

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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

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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).

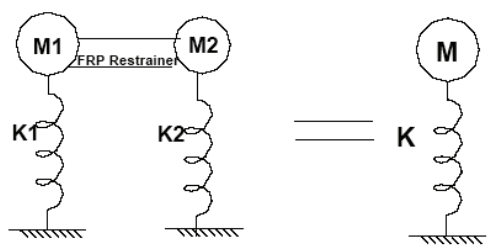

Figure 1

New restrainer design method.

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

NCHRP-IDEA Project 98

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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).

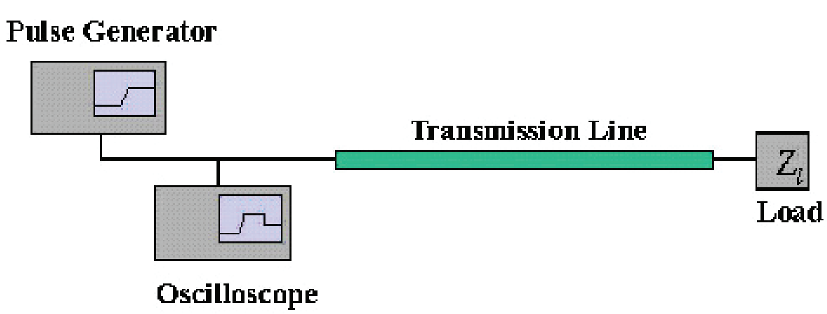

Figure 1

Time domain reflectometry measurement apparatus.

DEVELOPMENT OF ASPHALT BINDER CRACKING DEVICE

NCHRP-IDEA Project 99

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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)

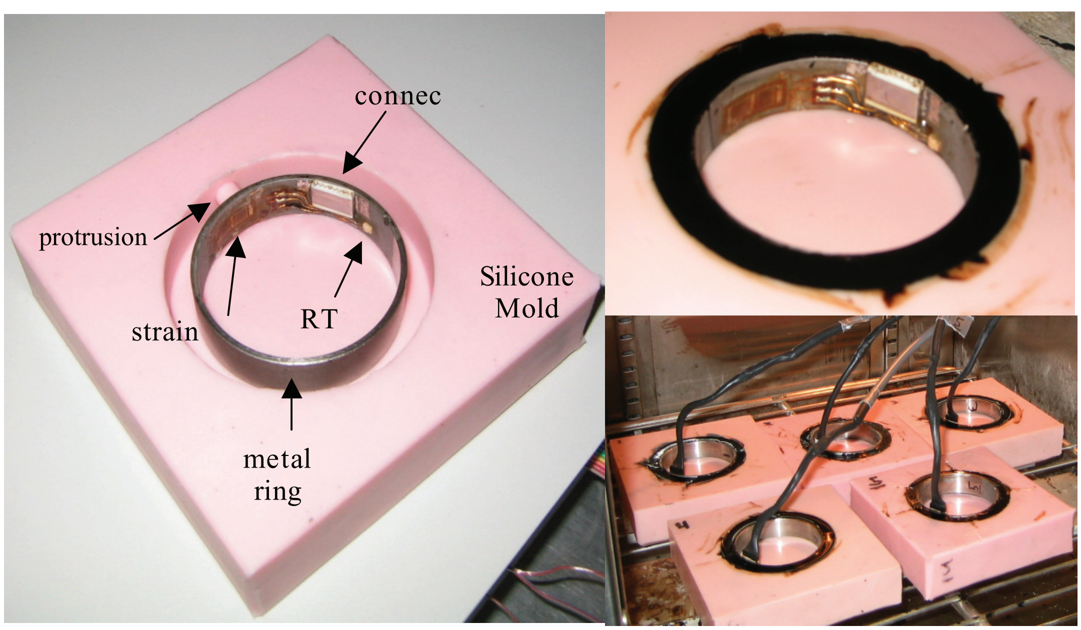

Figure 1

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

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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

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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).

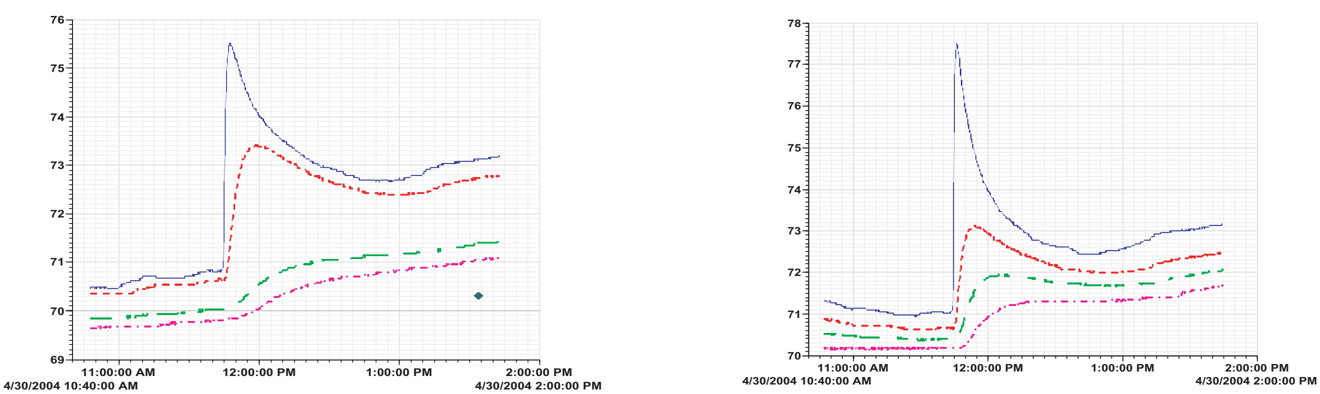

Figure 1

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

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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).

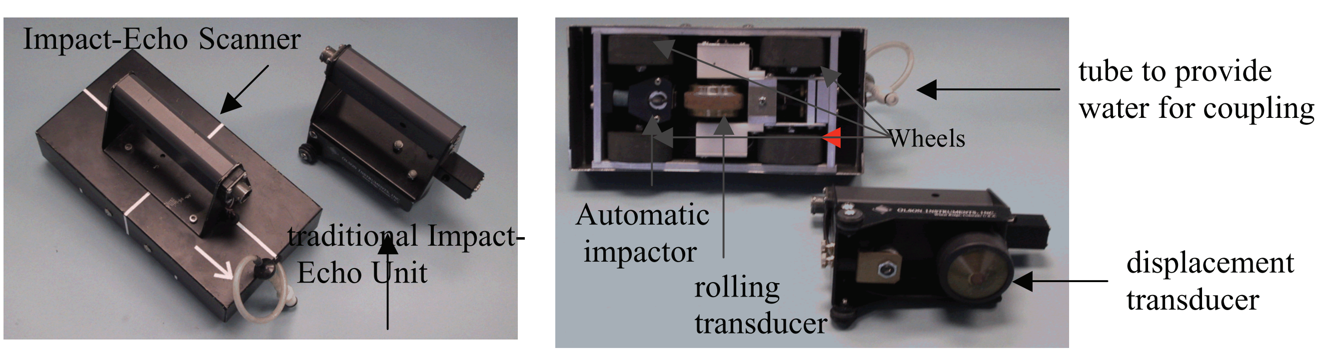

Figure 1

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

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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

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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

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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

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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

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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

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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).

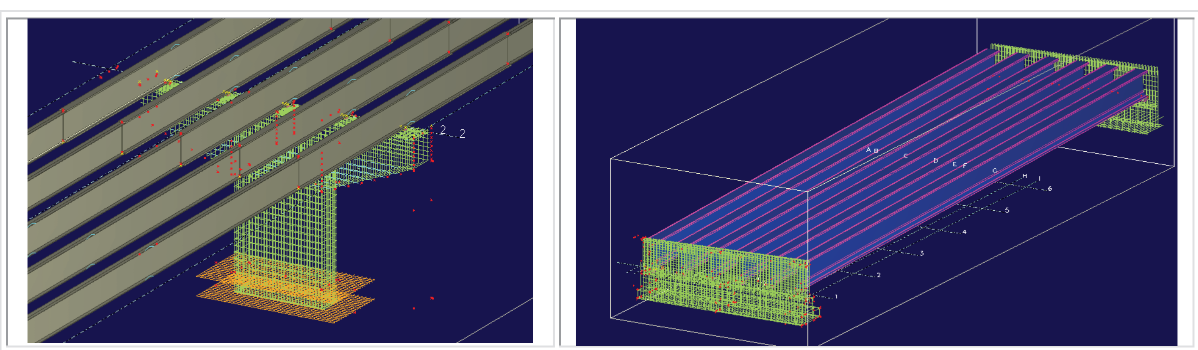

Figure 1

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

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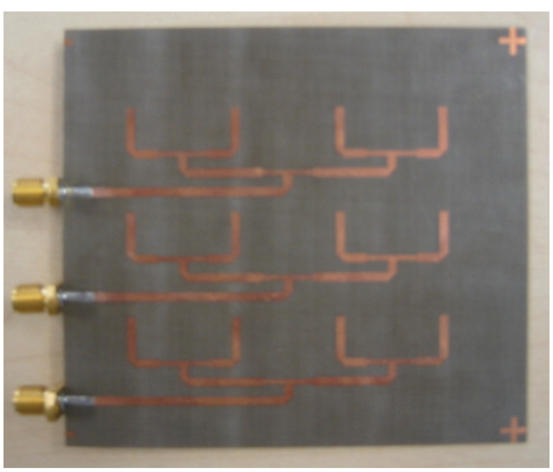
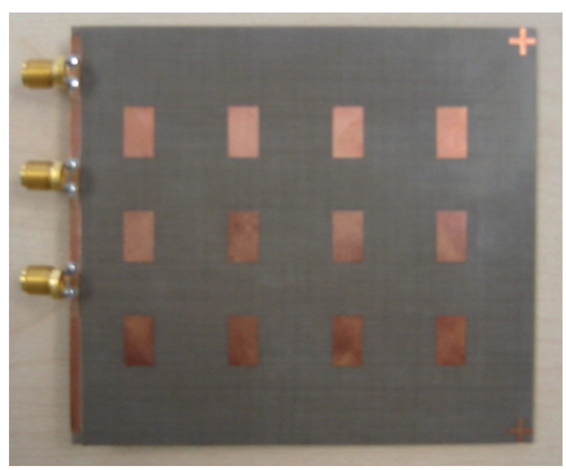
This project developed a nondestructive method for the condition evaluation of fiber-reinforced polymer (FRP) concrete bridge members using a smart antenna array to detect microwave signals (Figure 1). The system consisted of three modules: a controller and a power supplier, a transceiver, and array 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

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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).

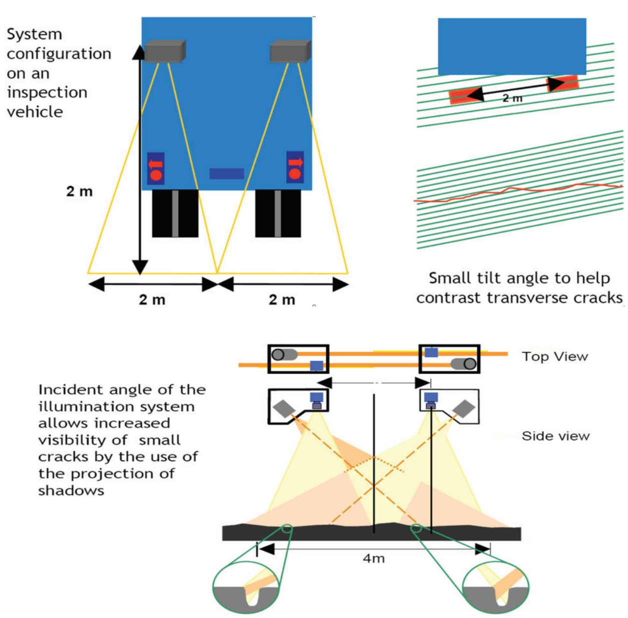

Figure 1

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

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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

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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)

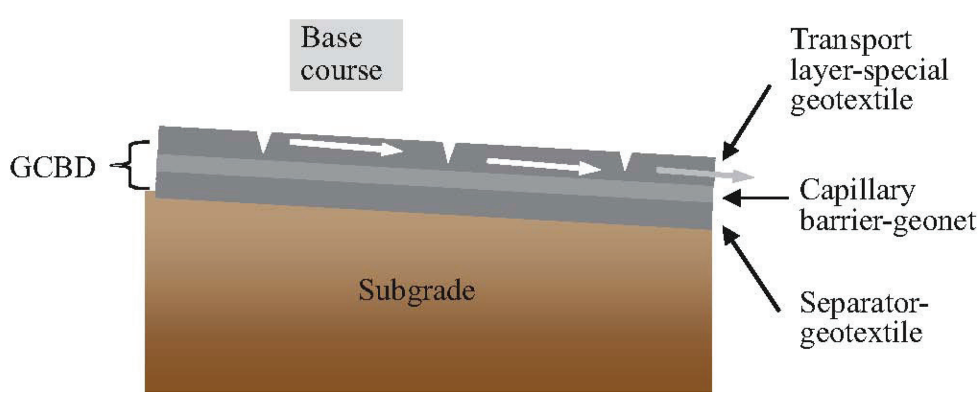

Figure 1

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

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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

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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).

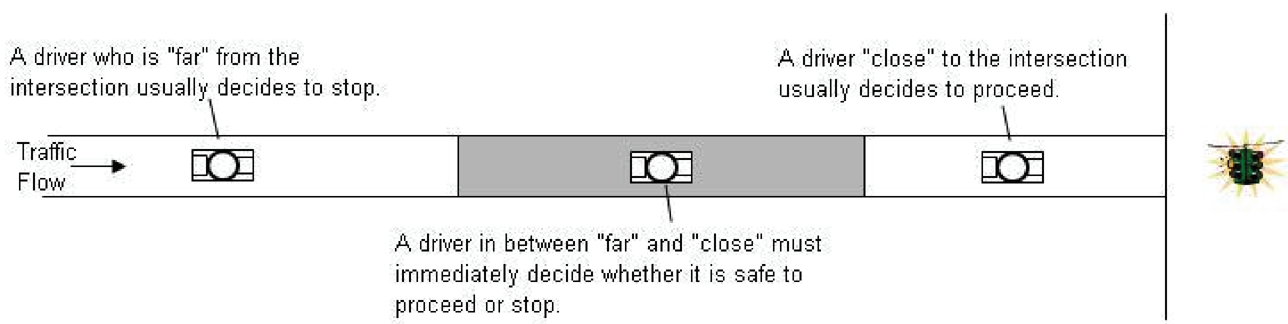

Figure 1

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

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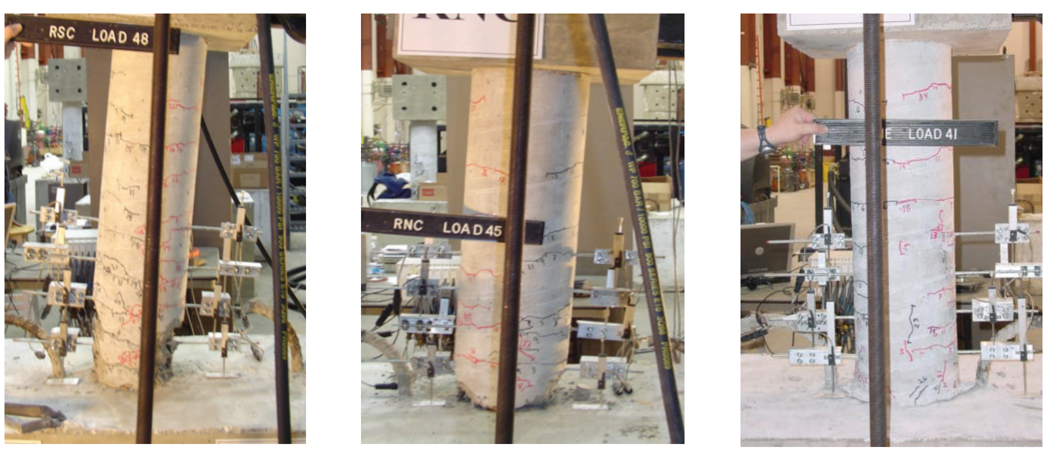
This project evaluated the application of superelastic shape memory alloy (SMA) reinforcement in combination with engineered cementitious composites (ECC) in bridge columns to minimize earthquake damage. Based on initial evaluation, Nitinol SMA and ECC compositions were selected for application in bridge 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

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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)

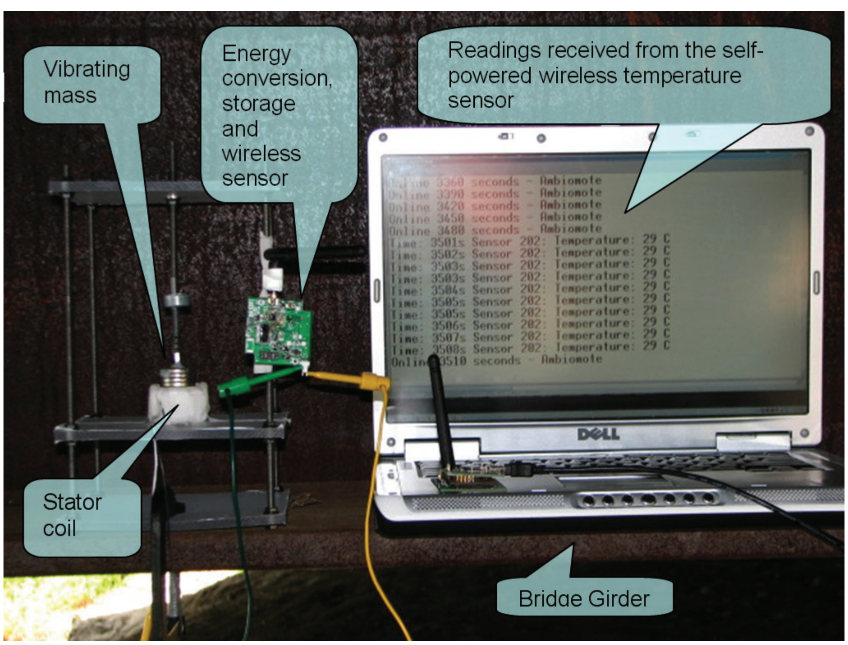

Figure 1

Prototype of the self-powered wireless sensor.

THE BCD: A NEW INSTRUMENT FOR COMPACTION CONTROL

NCHRP-IDEA Project 118

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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).

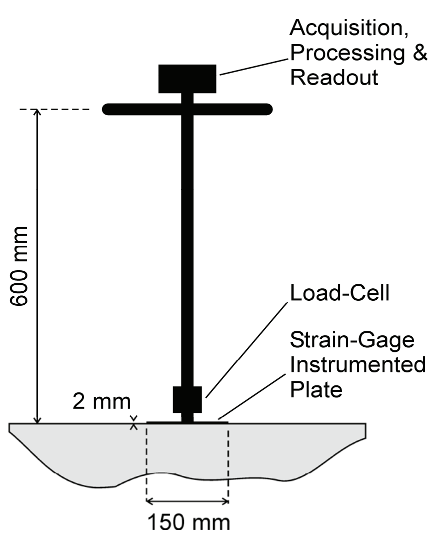

Figure 1

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

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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

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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).

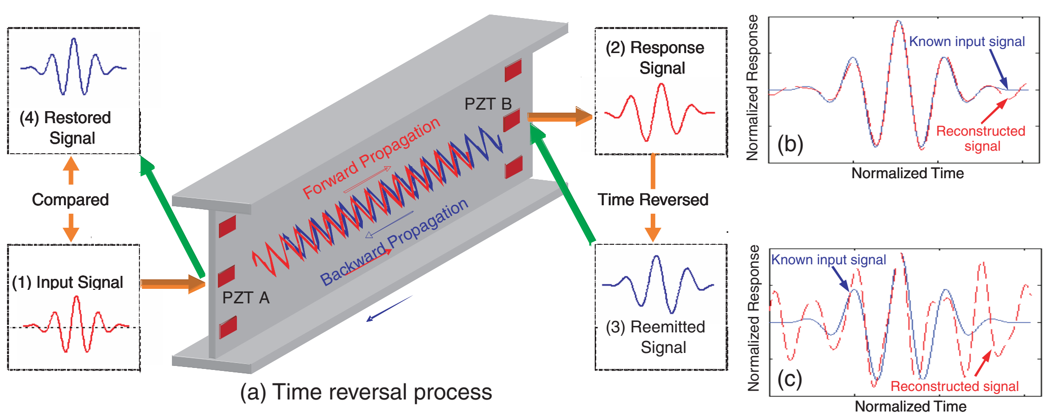

Figure 1

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

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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

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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.

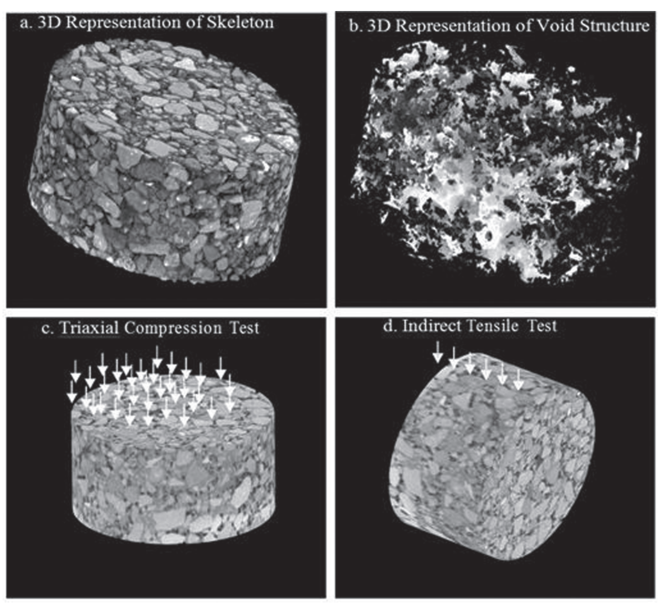

Figure 1

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

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Paul Fuchs [Tel.: (703) 737-3871, Fax: (703) 737-6381,
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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)

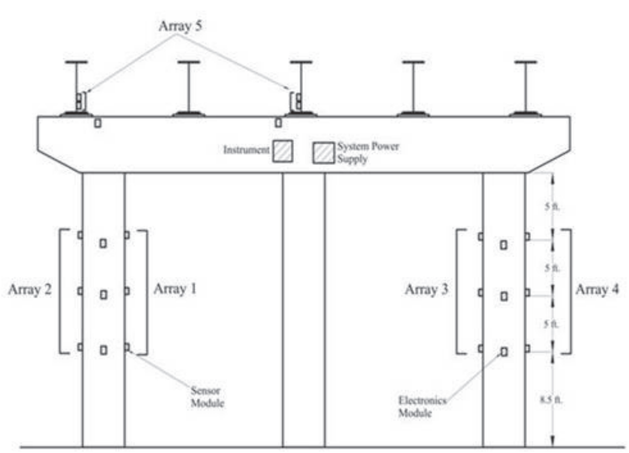

Figure 1

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

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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)

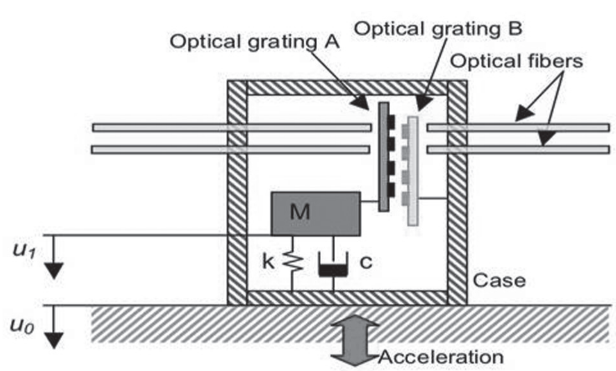

Figure 1

Design of fiber optic accelerometer.

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

NCHRP-IDEA Project 125

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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.

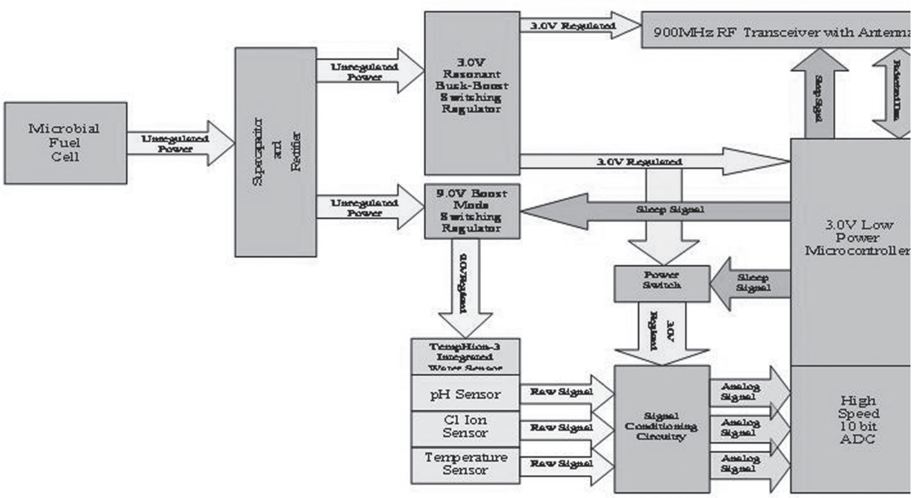

Figure 1

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

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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

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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).

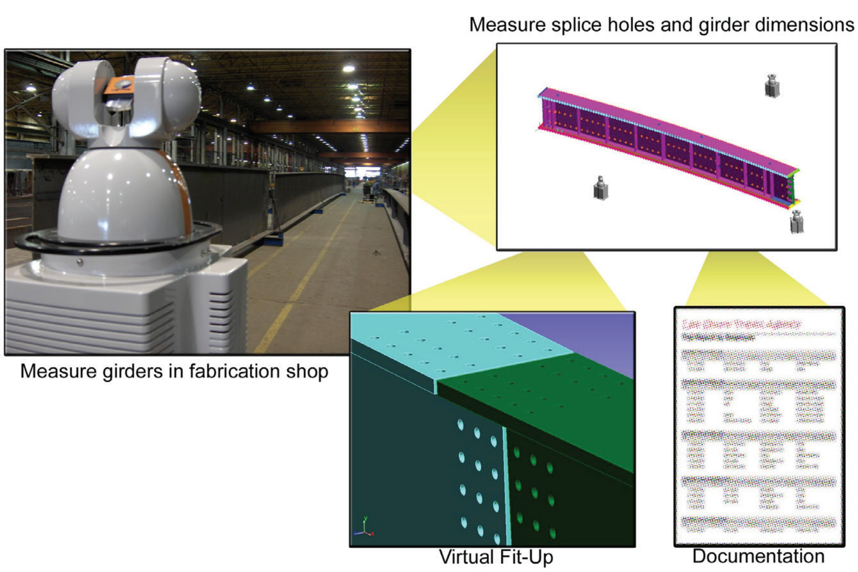

Figure 1

System concept for laser measurements of steel bridge girders.

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

NCHRP-IDEA Project 128

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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

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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)

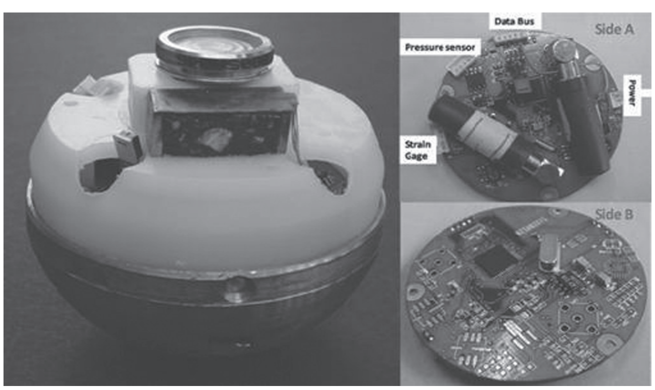

Figure 1

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

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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)

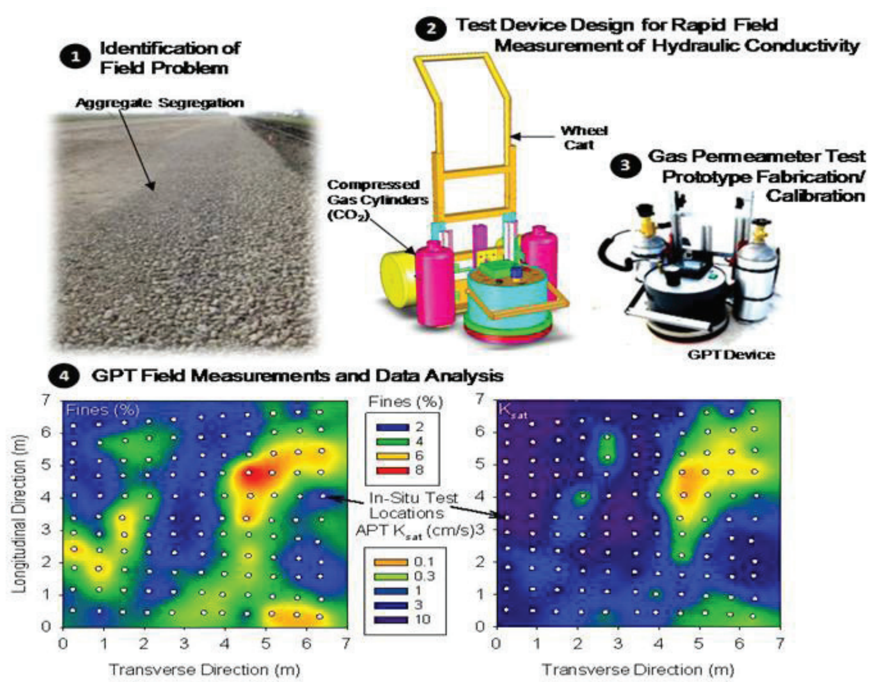

Figure 1

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

SMART SENSOR FOR AUTONOMOUS NOISE MONITORING

NCHRP-IDEA Project 131

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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)

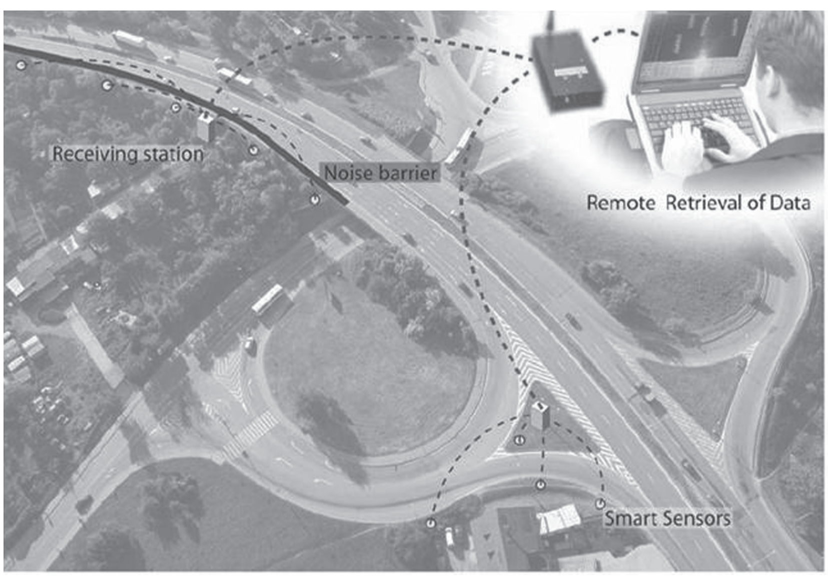

Figure 1

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

VEHICLE-MOUNTED BRIDGE DECK SCANNER

NCHRP-IDEA Project 132

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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)

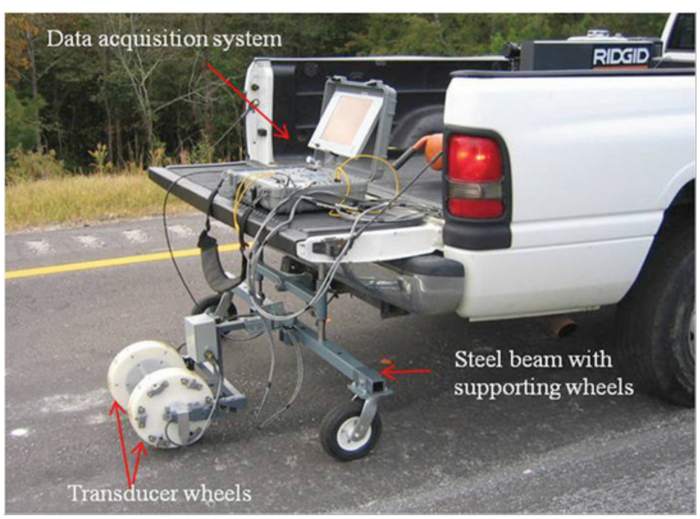

Figure 1

Bridge deck scanner (BDS) prototype.

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

NCHRP-IDEA Project 133

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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)

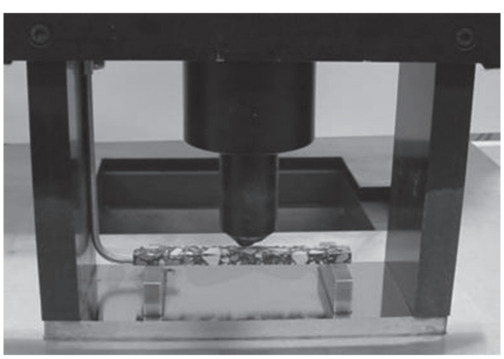

Figure 1

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

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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)

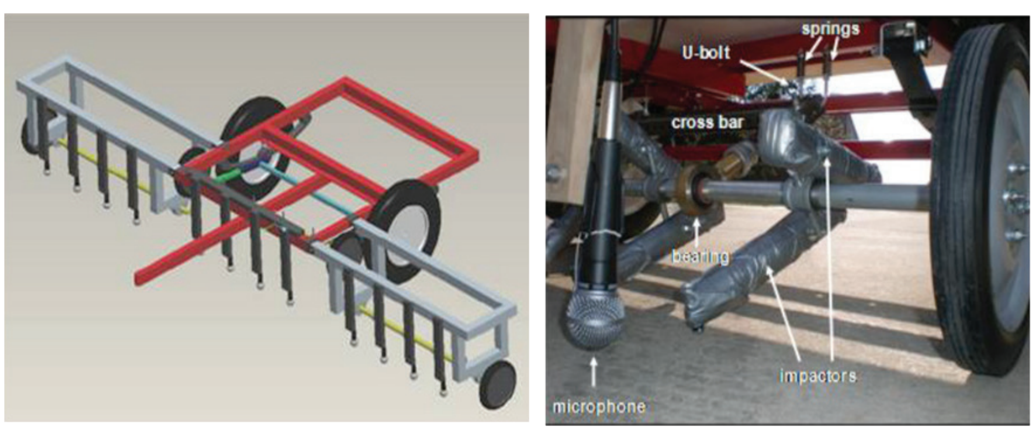

Figure 1

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

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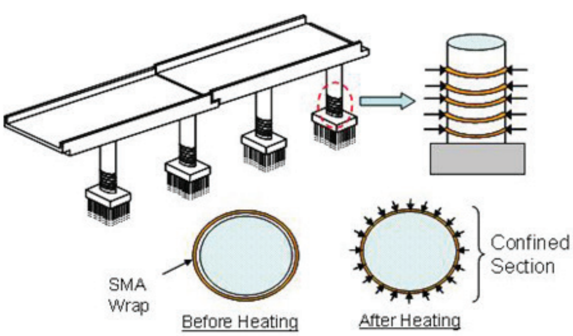
This project developed a system for the active confinement of reinforced concrete bridge piers using shape memory alloys (SMAs). A material testing program determined the stress-strain behavior of concrete cylinders actively confined with SMAs. Figure 1 illustrates the procedure for applying active confinement 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)



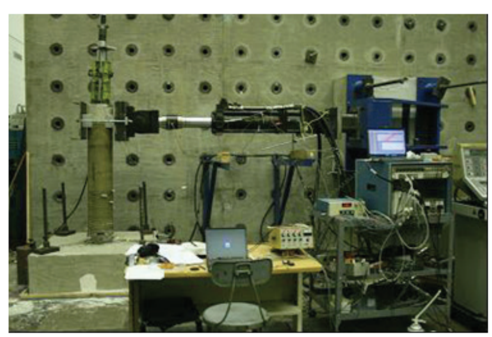


Figure 1

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

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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. (Final Report NTIS # PB2016-100666)

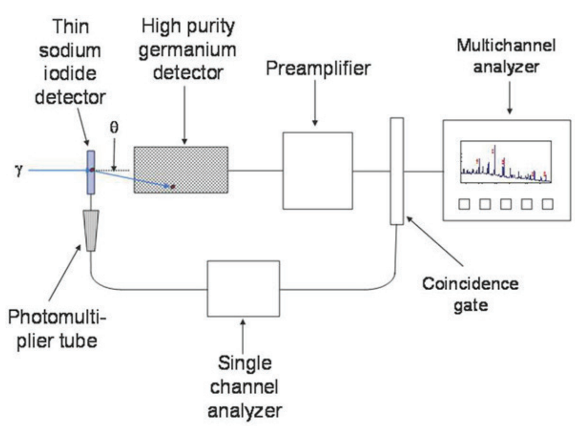

Figure 1

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

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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)

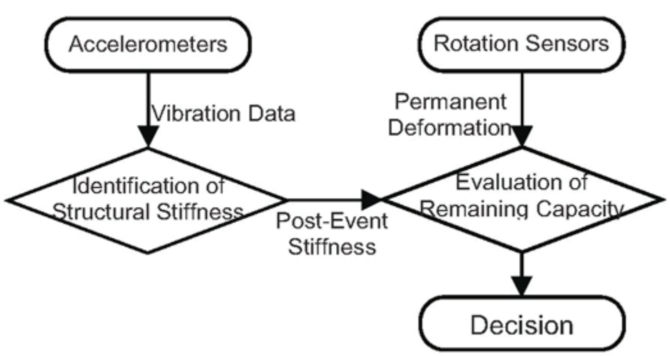

Figure 1

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

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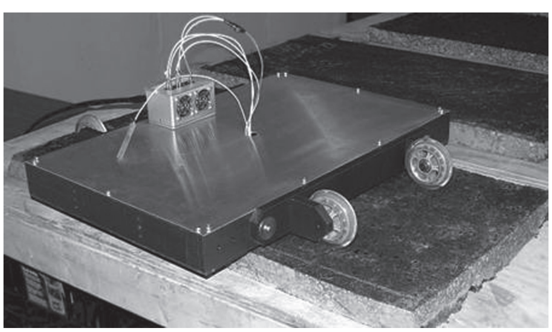
Hot-mix asphalt (HMA) density is one of the best predictors of pavement quality and durability. The goal of this project was to develop a method for measuring HMA density via an array of sensors capable of rapidly inspecting large areas (Figure 1). Research performed in the project demonstrated desired 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)



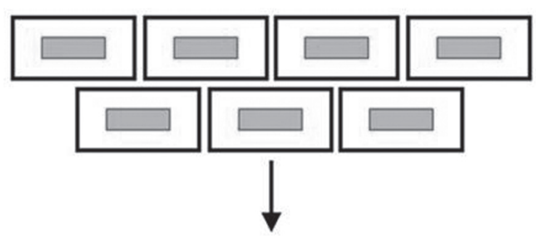


Figure 1

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

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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).

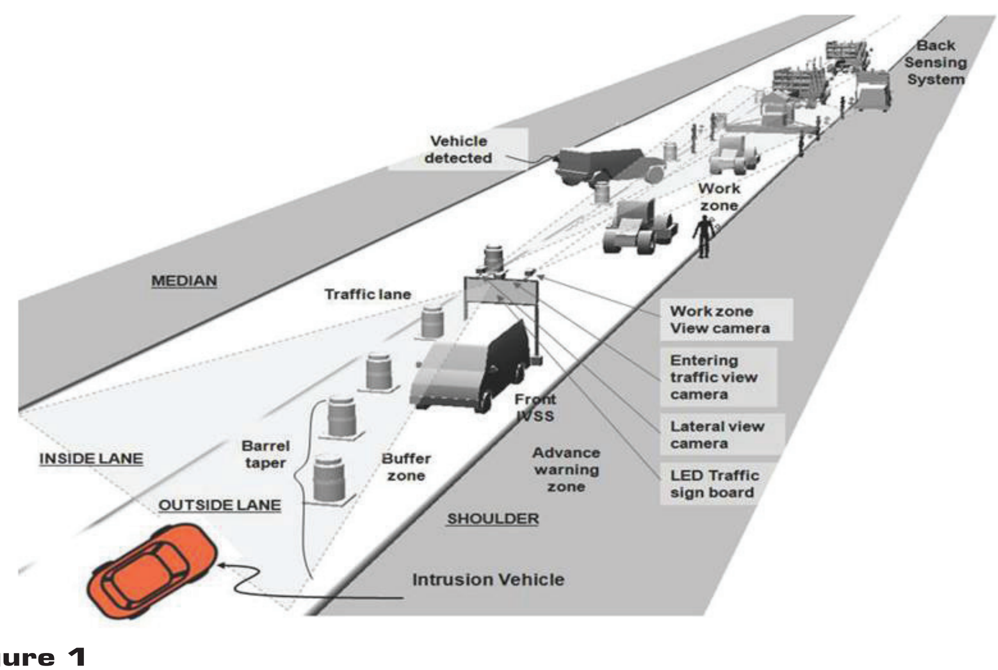

Figure 1

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

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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

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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)

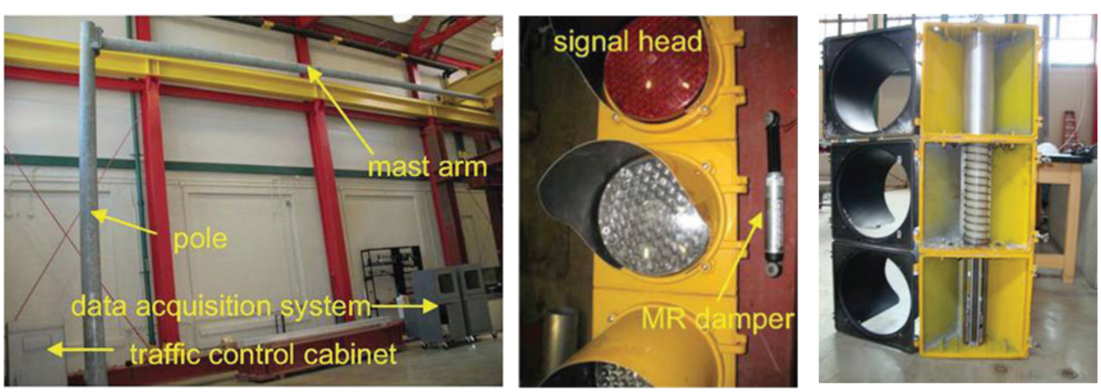

Figure 1

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

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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).

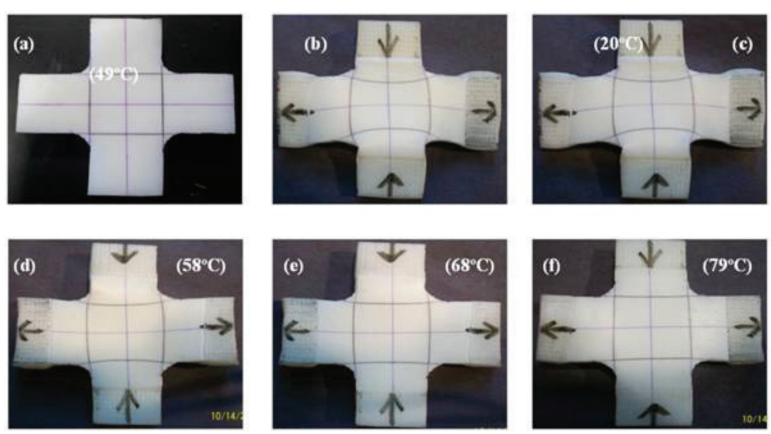

Figure 1

(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

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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).

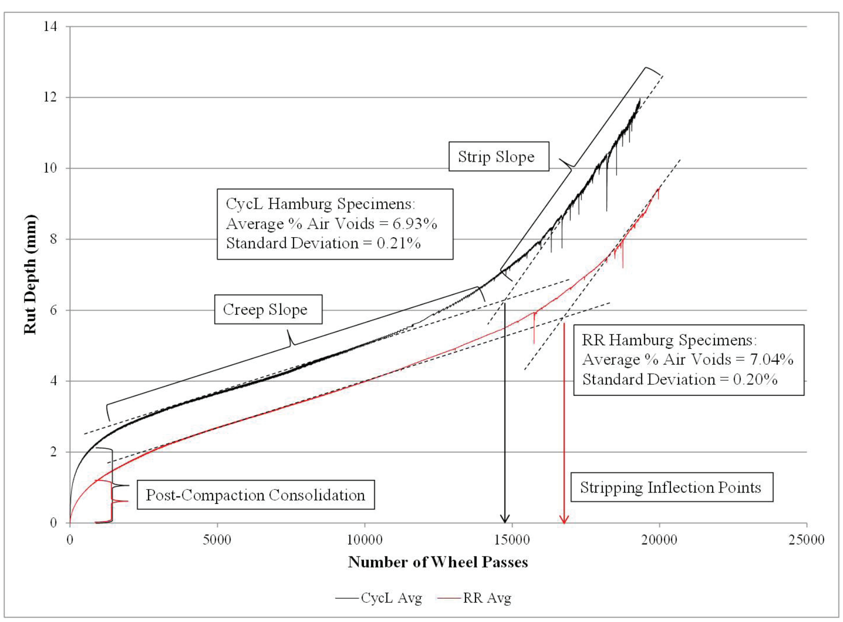

Figure 1

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

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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)

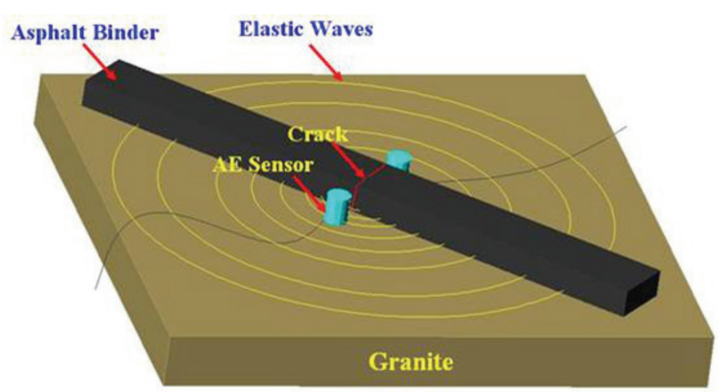

Figure 1

Schematic representation of AE asphalt binder sample during the test.

EXTRACTION OF LAYER PROPERTIES FROM INTELLIGENT COMPACTION DATA

NCHRP-IDEA Project 145

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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).

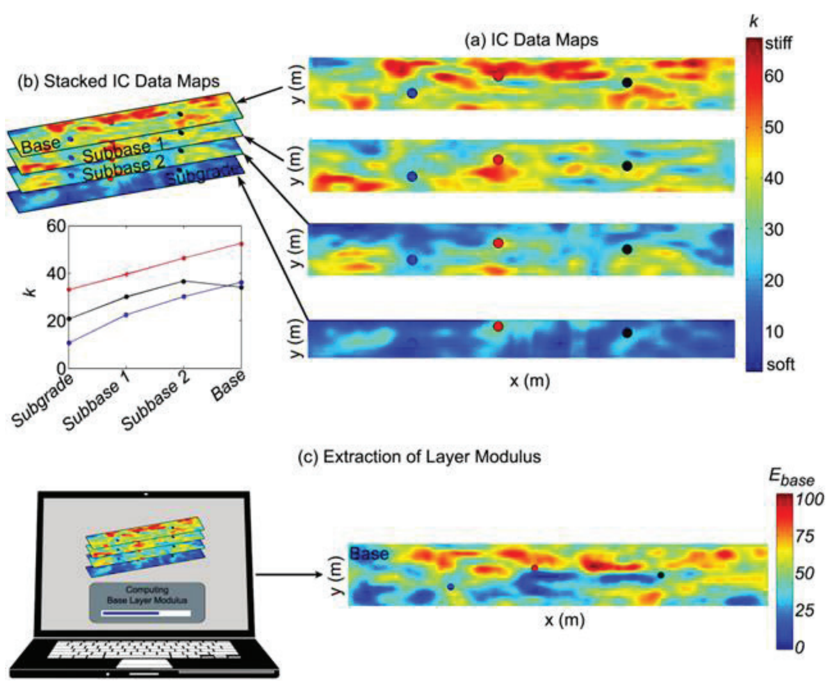

Figure 1

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

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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).

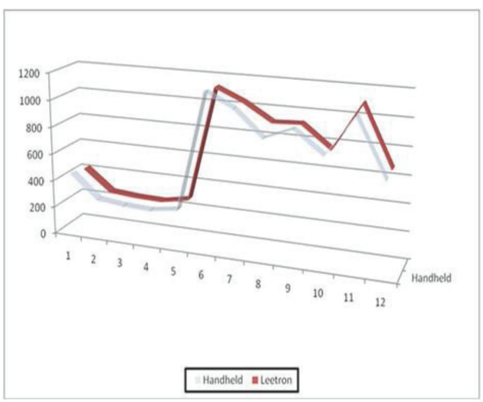

Figure 1

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

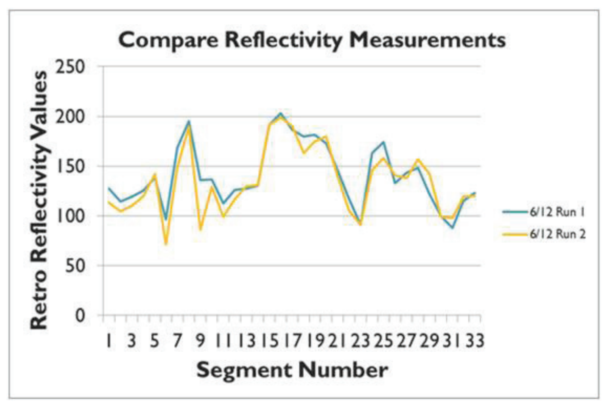

Figure 2

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, up-front 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)

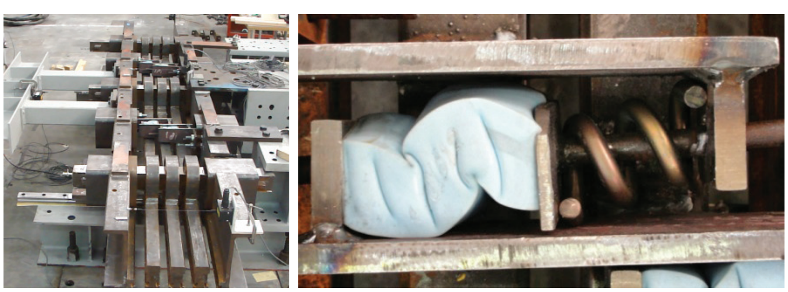

Figure 1

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)

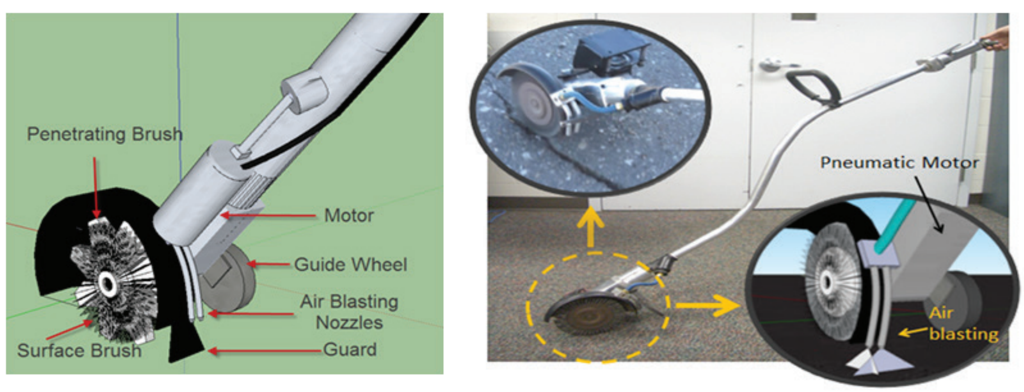

Figure 1

Crack cleaning device concept and product.

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

NCHRP-IDEA Project 149

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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. (Final Report NTIS # PB2016-100667)

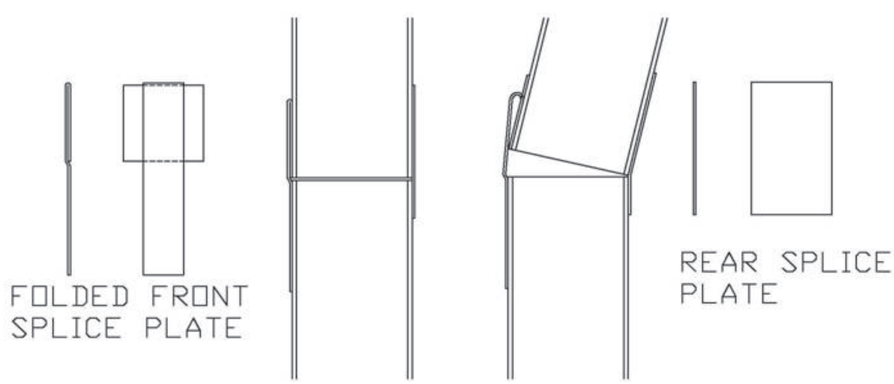


Figure 1

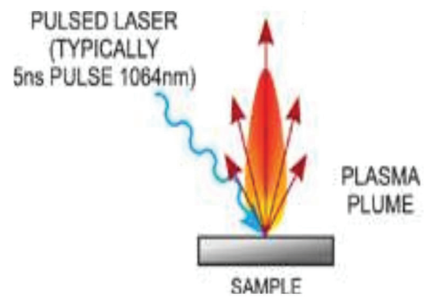
Schematic of bent plate design.

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)

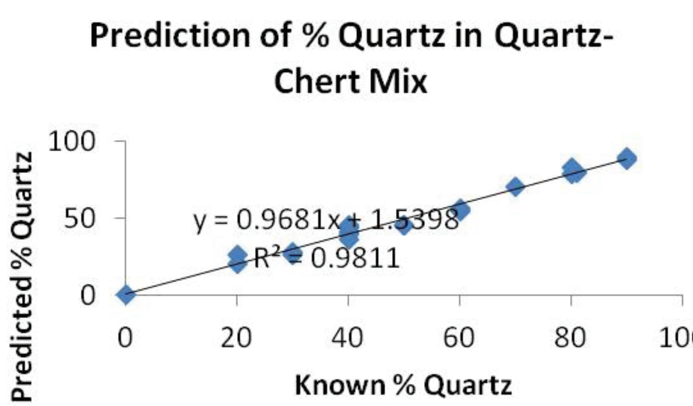


Figure 1

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

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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)

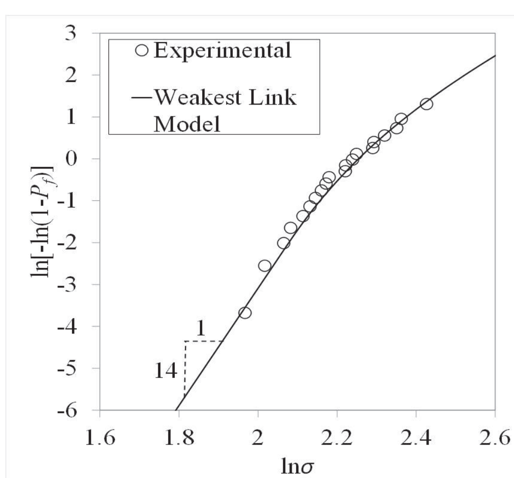

Figure 1

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

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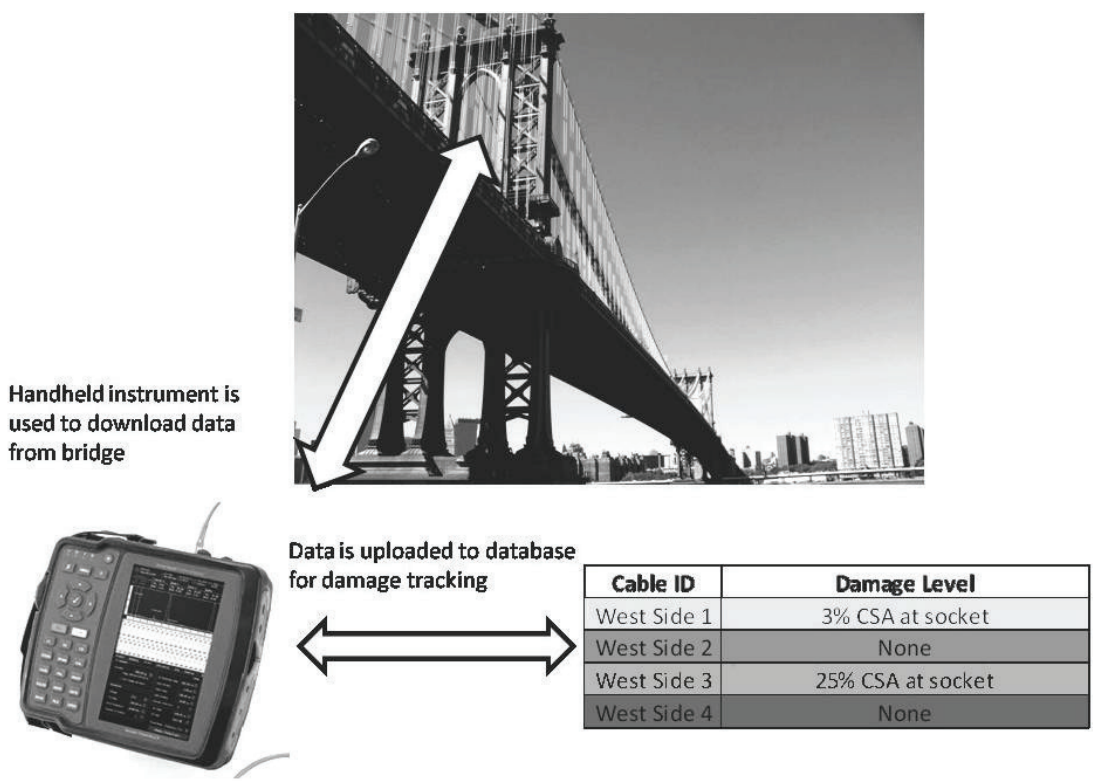
This project developed and demonstrated the application of a rapid and reliable non-destructive method, based on long-range ultrasound, of inspecting bridge cables for corrosion, wire breaks, and other structural flaws (Figure 1). Cable inspection tests, performed in controlled laboratory environment 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)

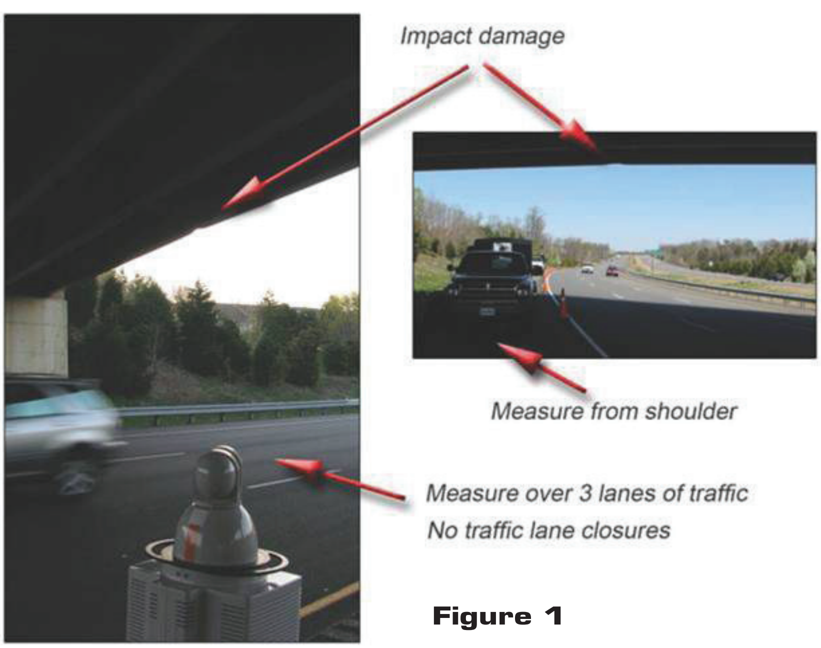


Figure 1

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

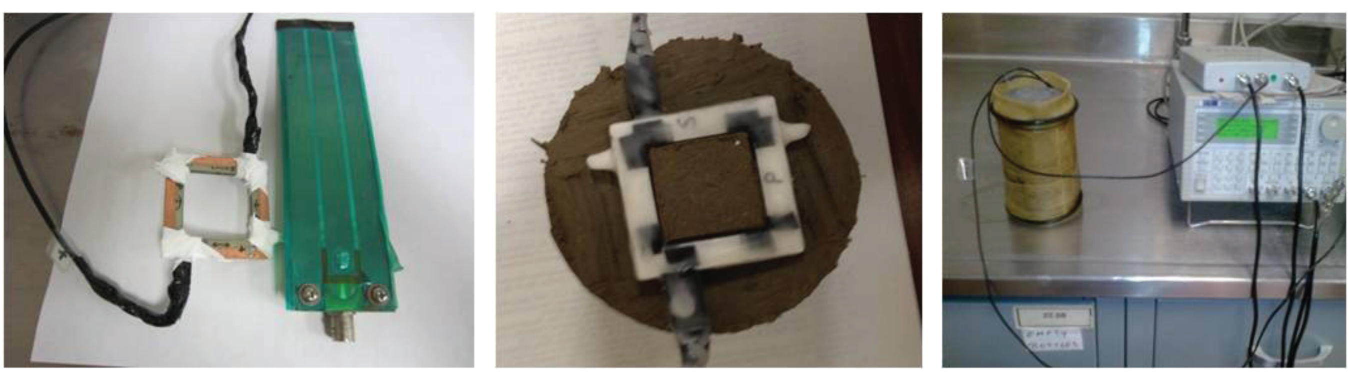
AN INNOVATIVE HYBRID SENSOR FOR RAPID ASSESSMENT OF SULFATE INDUCED HEAVING IN STABILIZED SOILS

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 uninhibited 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. Additional 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

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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).

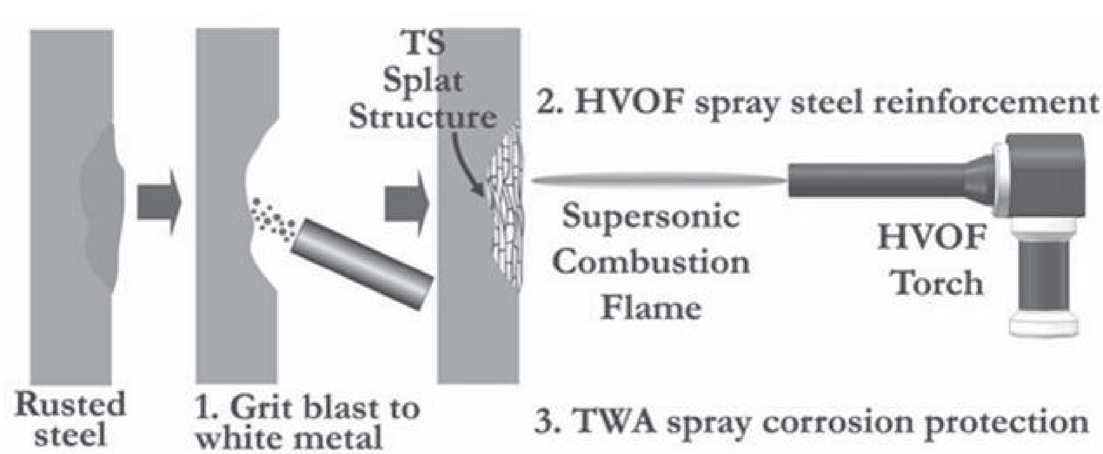

Figure 1

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

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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. (Final Report NTIS # PB2016-100668)

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

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Illinois Institute of Technology, Chicago, Illinois

The project was aimed at developing and demonstrating the application of a low-cost, environmentally safe, polymer-based coating system for the corrosion protection of structural steel in highway facilities. A promising ϖ-conjugated polymer, which was also an intrinsically conducting polymer (ICP), was developed and incorporated in the primer layer of the proposed two-layer coating system. The ICP-based primer demonstrated three major anti-corrosion mechanisms: (i) ennobling substrate surface, (ii) reducing coating delamination, and (iii) smart self-healing initiated corrosion. The two-layer coating system was made by coating the primer with a robust polyurethane layer and subjected to ASTM tests B117 (Salt Spray Test), D5894 (Cyclic Salt Fog and UV Exposure Test), and D4541 (Pull-Off Strength of Coatings). Results indicated that this two-layer system possessed long-term durability, was able to provide long-term corrosion protection to steel substrate, and had strong long-term adhesion to the substrate steel surface. Two best-performing coating systems, each with an ICP-based primer layer, were then selected for field evaluation. Two field sites were selected for evaluating the performance of the selected coatings. Coated steel panels were exposed to the field corrosive conditions on a wooden stand at a 45° angle with respect to the ground surface. Figure 1 shows the field testing stacks and the SEM images of the substrate-primer-topcoat interfaces for two of the systems after 12 months of field exposure. After 12 months of field testing, the coating system including an ICP-based primer (made by mixing ICP in a regular epoxy matrix) and a polyurethane topcoat continued showing anti-corrosion performance comparable to that of the system with a zinc-rich primer and a polyurethane topcoat. (NTIS Report Number: PB2017-101834)

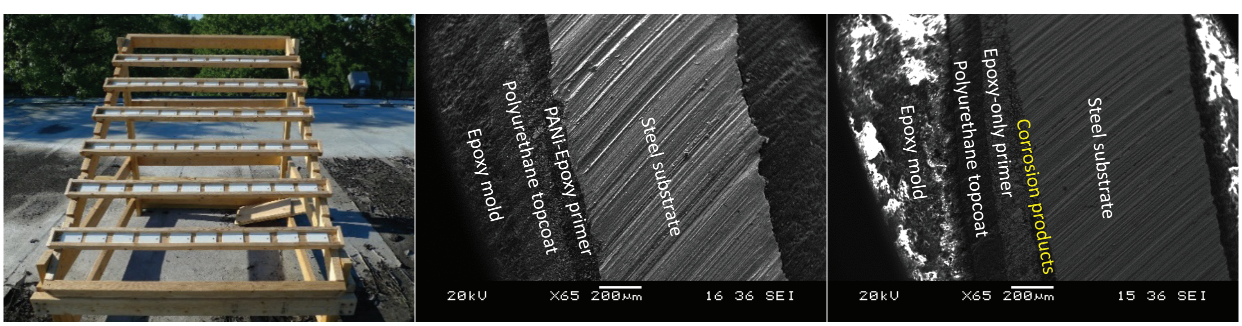

Figure 1

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

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

NCHRP-IDEA Project 158

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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. (Final Report NTIS # PB2016-100669)

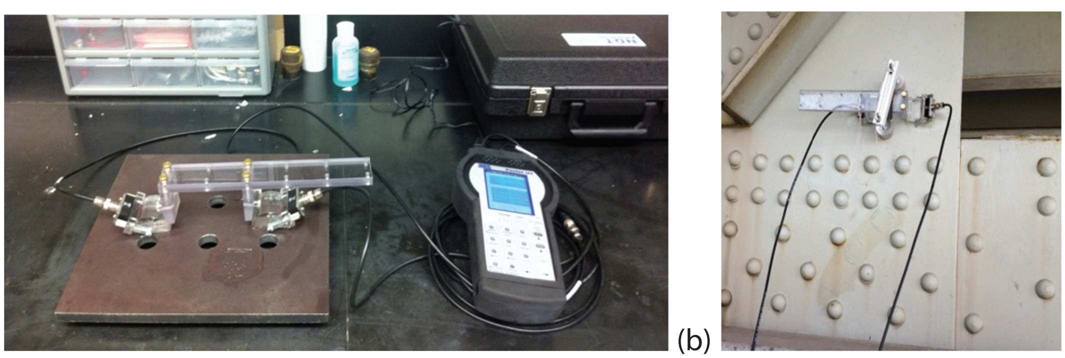
(a)

(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

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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

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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. (Final Report NTIS # PB2015-100844)

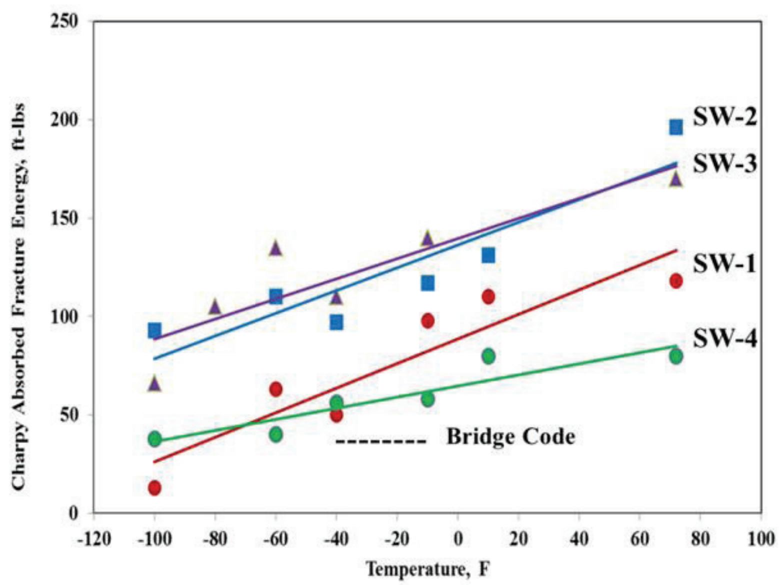

Figure 1

Charpy absorbed fracture energy of experimental super-weathering steels.

TOOLS FOR DETERMINING YIELD STRESS OF IN-SERVICE GUSSET PLATES

NCHRP-IDEA Project 161

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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. (Final Report NTIS # PB2015-102648)

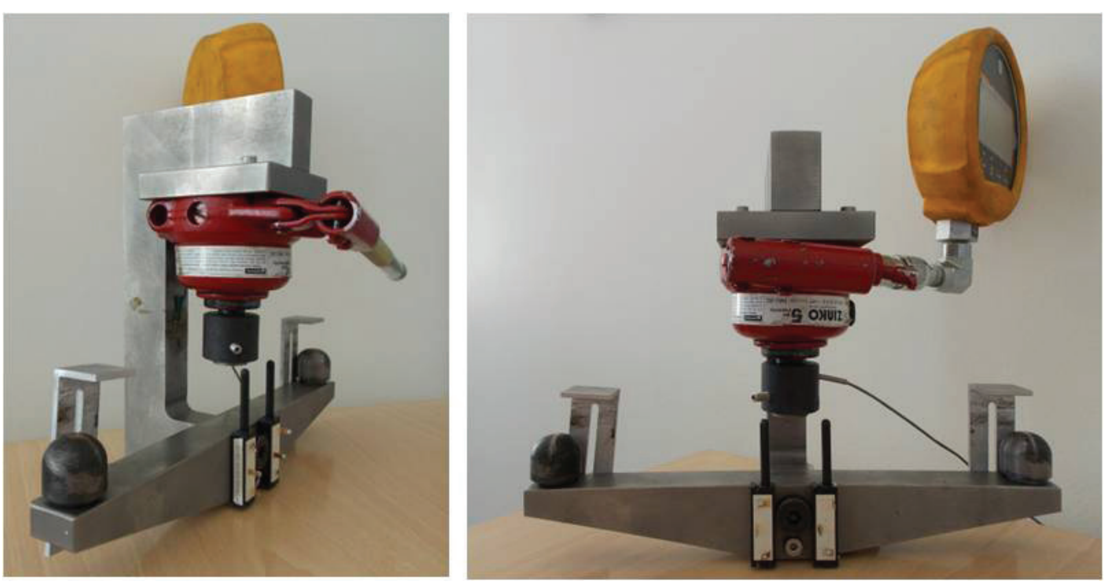

Figure 1

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

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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)

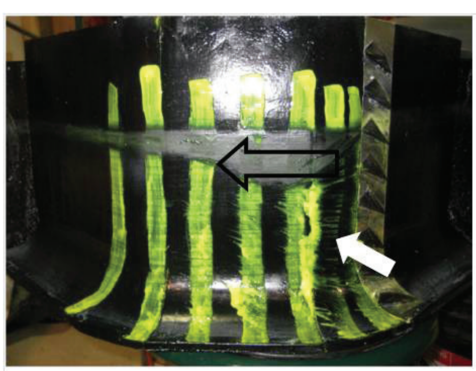

Figure 1

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

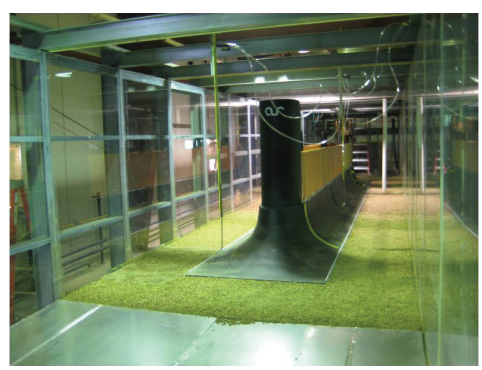

Figure 2

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

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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. (Final Report NTIS # PB2017-101835)

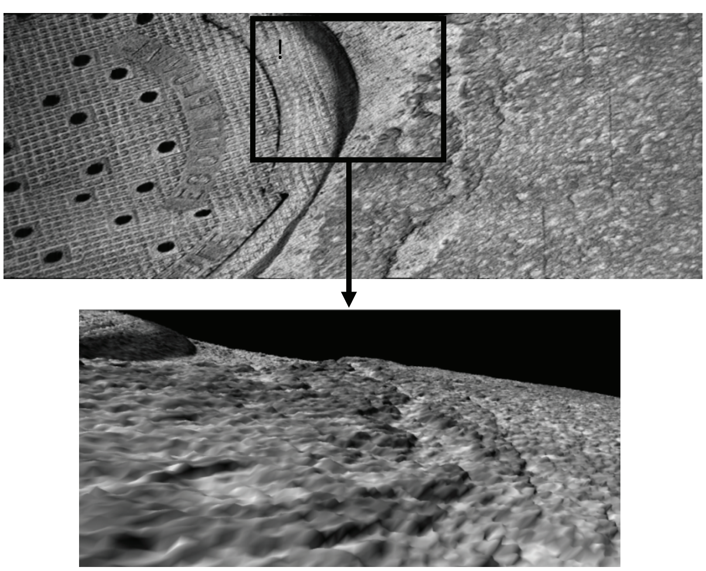

Figure 1

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

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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. (Final Report NTIS # PB2016-100670)

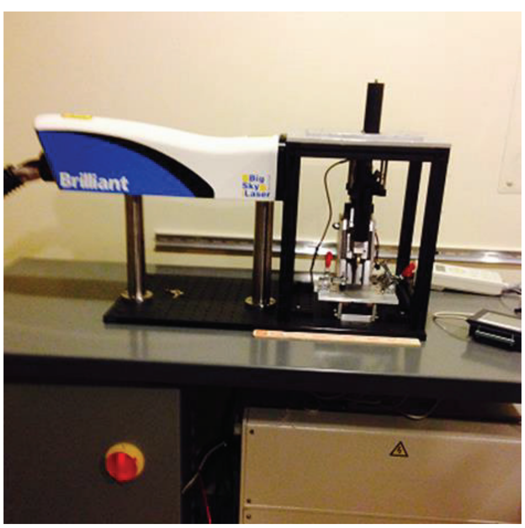

Figure 1

Micro-drill depth profiling laser system.

BATTERY-LESS WIRELESS WEIGH-IN-MOTION SENSOR

NCHRP-IDEA Project 165

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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. (Final Report NTIS # PB2016-100671)

Figure 1a

A box enclosure for installation of sensor inside pavement.

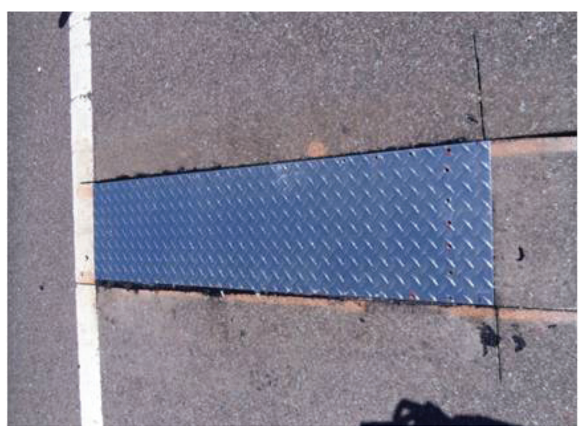

Figure 1b

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

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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. (Final Report NTIS # PB2017-101836)

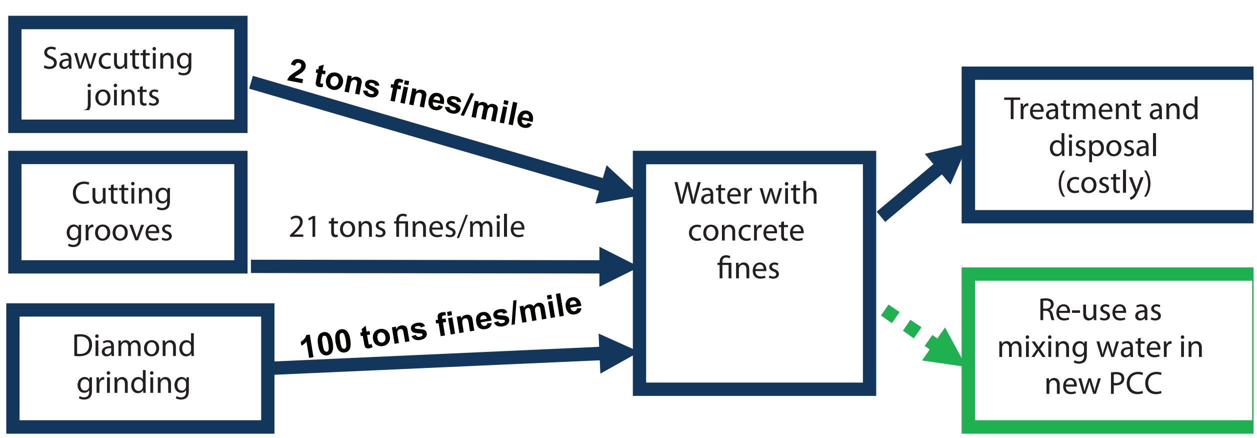

Figure 1

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

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

NCHRP-IDEA Project 167

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This project developed a prototype system for georeferenced augmented reality visualization of buried utility geospatial data and real-time monitoring of an excavator's proximity to buried utilities in its vicinity (Figure 1). A graphics algorithm to place virtual 3D buried utility models in an augmented scene was designed as well as 3D machine control system for monitoring an excavator's pose in real time during excavation operations. The research methodology involved three stages: tracking, representing in 3D, and analysis. The technical feasibility of a fiducial marker-based end effector pose estimation system was experimentally evaluated for excavators, and its performance demonstrated to consistently estimate bucket tooth position within 2.5 cm (1 in.) of absolute error. The accuracy of the pose estimation was primarily dependent on camera calibration, marker corner detection, and marker rig precision. A multi-plane 3D camera calibration method using an affine transformation model was designed. A stereo marker rig was also designed along with a method to compare the camera pose estimation with the ground truth. Finally, algorithmic optimizations were designed to overcome some of the factors that contribute to the uncertainty of corner detection in fiducial markers. It was also found that in the outdoor environment the bright sunlight illuminance complicates the marker detection, but its negative effect can be canceled by automatic exposure. These improvements lead to significant performance improvements in stereo fiducial marker detection at large scales. A working prototype was tested on several active construction sites with positive feedback from excavator operators confirming the solution's effectiveness. (NTIS Report Number: PB2017-101837)

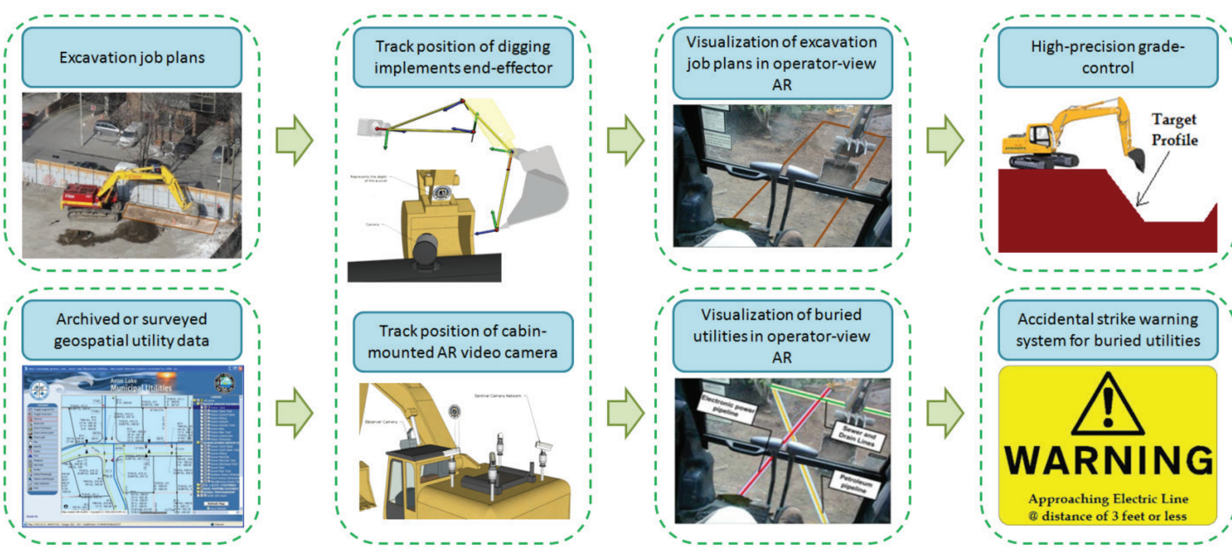

Figure 1

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

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

NCHRP-IDEA Project 168

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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. (Final Report NTIS # PB2017-101838)

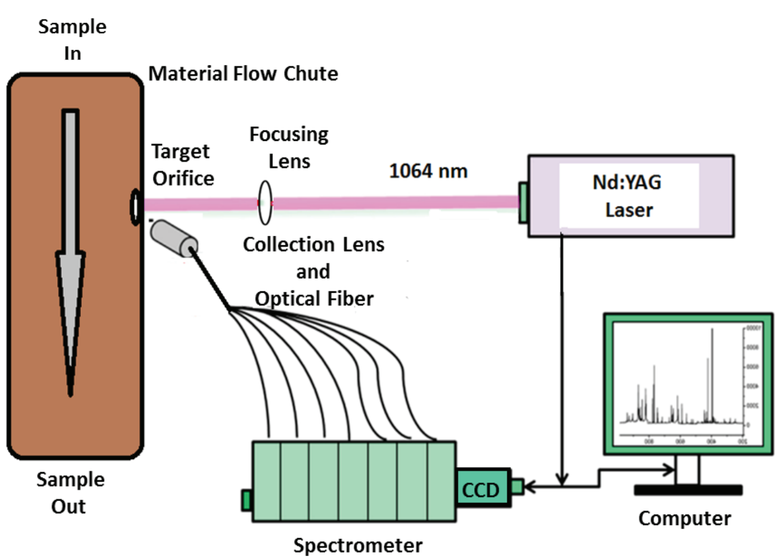

Figure 1

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

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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. (Final Report NTIS # PB2017-101839)

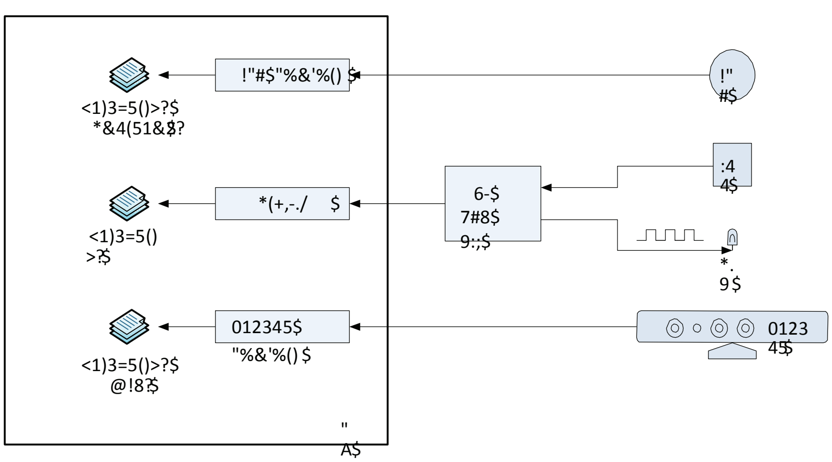

Figure 1

Overview of the 3D scanning system for pavement inspection.

DEVELOPMENT AND IMPLEMENTATION OF THE ASPHALT EMBRITTLEMENT ANALYZER

NCHRP-IDEA Project 170

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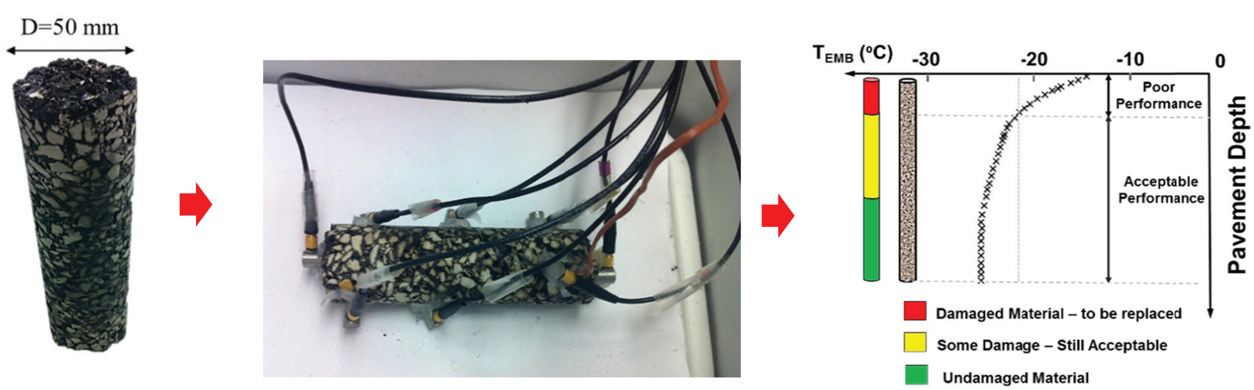
Western New England University, Massachusetts

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. (Final Report NTIS # PB2016-100672)



(a) (b) (c)

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.

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

NCHRP-IDEA Project 171

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The project was aimed at developing and characterizing a bio-asphalt based on swine manure and crumb rubber for highway construction application. The bio-binder reacts with the surface of rubber particles. Bio-asphalts with higher percentages of bio-adhesive overall showed enhanced rheological properties and the level of improvement was highly dependent on the rubber content. Addition of bio-adhesive to rubberized asphalt involved three phases: lubrication, surface treatment, and dilution. To optimize the use of bio-adhesive, its content needed to be designed to maximize rubber surface treatment while avoiding dilution. The most suitable bio-modified rubber (BMR) asphalt studied in this project was when 20% rubber was treated by 20% bio-binder (by weight of asphalt binder). Mechanical tests showed significant improvement in BMR properties as compared to non-modified specimens both at low and intermediate temperatures. Also, the level of compaction energy required for BMR specimens was relatively lower than those of non-modified specimens indicating better mixture workability of BMR specimens. BMR mixtures had lower mixing and compaction temperatures with the same mixture design (aggregate gradations, compaction energy and target air void). BMR and crumb rubber modified without bio-binder (CRM) samples showed better rutting resistance in Hamburg wheel tester compared to neat asphalt mixture samples. BMR samples took more energy to fracture during DC(T) fracture tests compared to both CRM and neat samples (Figure 1). The indirect tensile IDT modulus of BMR samples was also found to be lower than CRM samples. During creep tests at low temperatures (0°C, –12°C, and –24°C), BMR samples were found to have higher creep compliance than both neat and CRM samples. (NTIS Report Number: PB2017-102160)

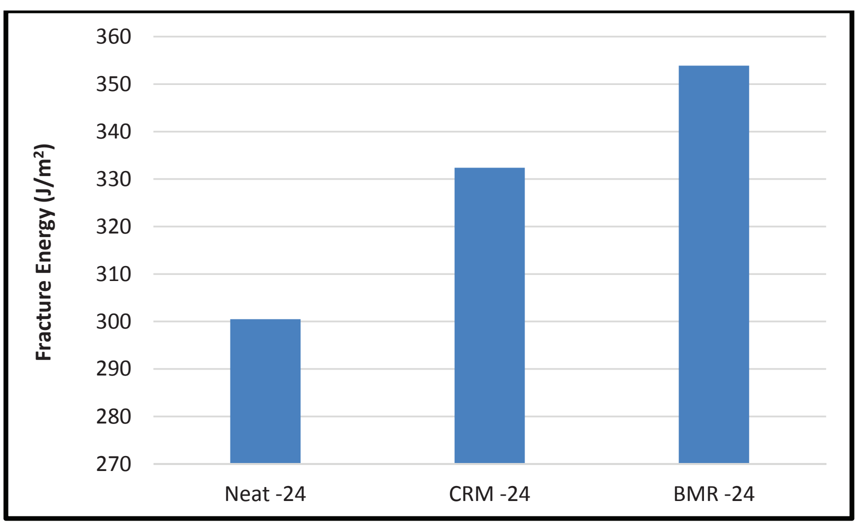

Figure 1

Comparison of DC (T) fracture energy results among neat, CRM, and BMR mixtures at –24°C.

BIDIRECTIONAL-DUCTILE END DIAPHRAGMS FOR SEISMIC PERFORMANCE AND SUBSTRUCTURE PROTECTION

NCHRP-IDEA Project 172

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This project developed bi-directional ductile diaphragms for straight and skewed bridge superstructures to provide resistance to bidirectional earthquake excitations (Figure 1). The proposed ductile end diaphragm systems (EDS) were designed for benchmark skew and nonskew bridges and analyzed using nonlinear time history analysis to examine their seismic performance. A design procedure for the EDS in skew bridges was developed based on the analysis results. The long-term service life of EDS installed across expansion joints and subjected to bridge thermal expansion histories was also investigated and a minimum ratio of the Buckling Restrained Brace (BRB) length over the whole bridge length was recommended. Quasi-static experiments were conducted to subject BRB to a regime of relative end-displacements representative of the results predicted from parametric analytical studies. A test set-up was developed, which consisted of connecting the BRB from the strong floor to a shake table in the SEESL. All BRB specimens tested developed a cumulative inelastic displacement of more than 200 times the BRB's axial yield displacement, which is the threshold of inelastic performance specified by the AISC as part of its acceptance criteria for BRBs. The specimens could also sustain multiple years of severe temperature cycles while meeting the prequalification criterion. No end-plate failure or instability was observed. Following the tests, some BRBs were opened. It was found that fracture typically occurred where the BRB's core plate locally buckled the most. (NTIS Report Number: PB2017-102161)

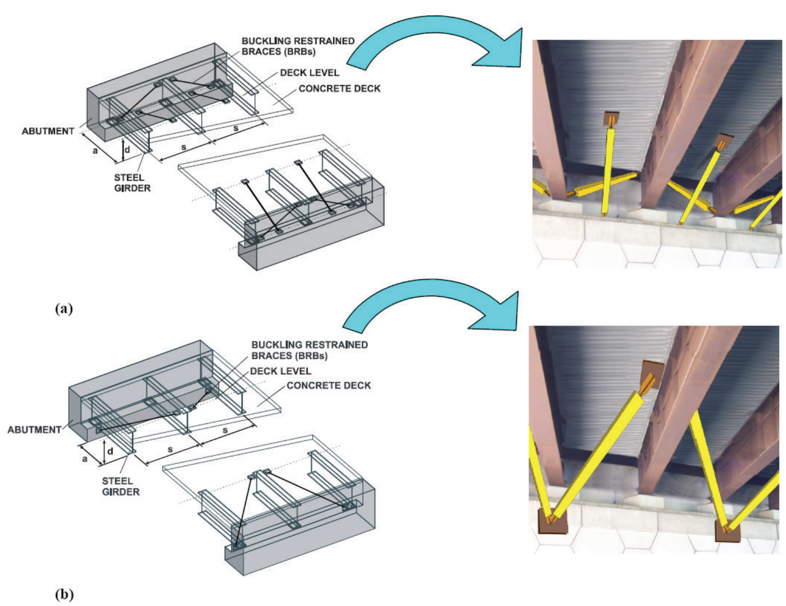

Figure 1

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

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

NCHRP-IDEA Project 173

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This project developed and tested asphalt binders and mixtures reinforced with graphene nano-platelets (GNP) as a multifunctional pavement material. Mechanical properties of GNP-reinforced asphalt binders and mixtures were evaluated. A detailed method for material preparation and a quantitative analysis of the effect of GNP on the mechanical properties of asphalt binders and mixtures was developed. GNP was found to mix with asphalt binders without major dispersion problems. Binder and mixture specimens prepared with different amounts of GNP were subjected to complex modulus test, indirect tension creep and strength tests, and fracture test at low temperature. The tests showed that the addition of GNP greatly enhanced the flexural strength of asphalt binders at low temperatures, moderately improved the creep stiffness, and had no adverse effects on relaxation properties. It was also observed that, compared to conventional asphalt mixtures, GNP-reinforced asphalt mixture specimens exhibited better cracking resistance in terms of strength and fracture energy. However, GNP addition did not improve the electrical conductivity of the asphalt materials. Compaction process of GNP-reinforced asphalt mixtures was also investigated. The addition of GNP significantly reduced the number of gyrations needed to compact the mixtures to a target air void ratio. The reduction ranged from 15% to 40% for different mix designs. Furthermore, the GNP allowed successful compaction at a lower temperature. A series of rut experiments was also performed on GNP-reinforced asphalt mixtures in collaboration with the Minnesota DOT. GNP addition improved the rut performance of the mixtures (Figure 1). A patent for the GNP-based product has been obtained. Work on implementation GNP in actual pavement application is to be done in collaboration with Minnesota DOT. (Final Report NTIS # PB2017-102162)

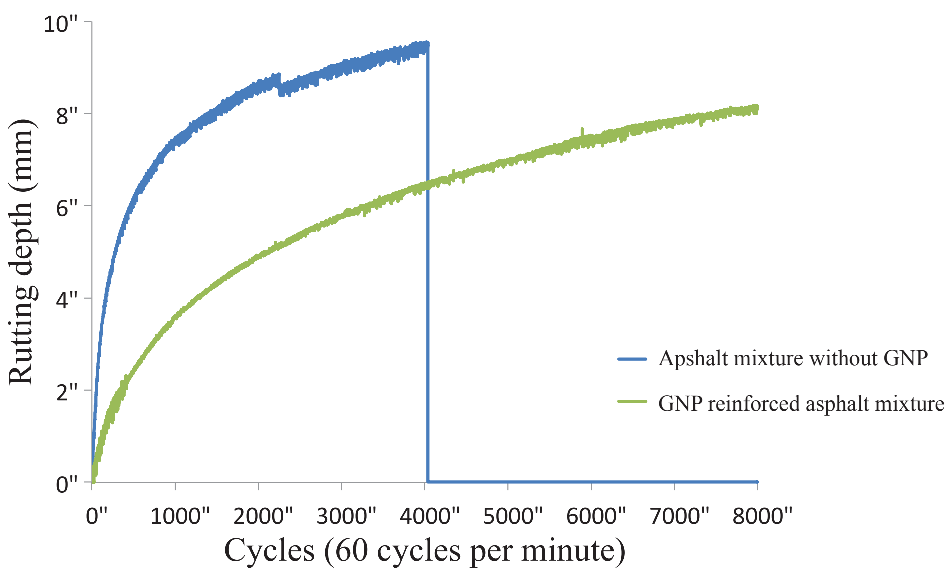

Figure 1

Rutting performance of GNP-reinforced asphalt mixtures.

ENHANCED PERFORMANCE ZINC COATING FOR STEEL IN CONCRETE

NCHRP-IDEA Project 174

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The objective of this project was to evaluate thermal zinc diffusion (TZD) coatings for improved corrosion resistance for concrete reinforcing bar as compared with commercial coatings currently in use. Corrosion performance was determined, using standard ASTM test methods, in good quality concrete [lower water-to-cement ratio (w/c) and higher cover] cracked in flexure with periodic loading to abrade the coatings, in order to capture the two predominant failure mechanisms for coated steels. Both straight and bent bars were evaluated, as well as another set of U-bend specimens for stress corrosion. Steels evaluated were black steel, hot-dipped galvanized (HDG) steel, epoxy-coated steel (ECR), 2304 Stainless Steel (SS), low-chromium ASTM 1035 steel, and the TZD-coated steel. An epoxy coating was manually applied to the TZD bars to evaluate a coated version of the product (TZE). The performance of the corrosion-resistant reinforcing bars was significantly better than the control black bars. The overall relative corrosion resistance ranking in the cracked beam test was:

Black Steel Bar < HDG < A1035 Low-Chromium < TZE ≈ TZD < ECR, 2304 SS

The results indicate that TZD reinforcing steel could improve the corrosion performance of steel in concrete. For the U-bend specimens the HDG performed better than TZD, which may be due to higher w/c of concrete and lower cover that let chloride in too fast, preventing the TZD specimen to adequately form a protective passive coating. The HDG coating was thicker and had a chromate treatment, which helped it to passivate. The TZE bars had lower corrosion currents. The damage on the bars was comparable to the TZD in the beam test but did help in the U bend tests. The coating was not optimized (brushed versus fusion bonded, not formulated for concrete use), which implies that performance could improve with a commercially applied suitable coating. Based on the results of this study, further work with departments of transportation is recommended to initiate trial testing in the field. The cracked beam method (Figure 1) looks promising as a test method to evaluate corrosion-resistant reinforcing bars, high-performance concrete, surface treatments, and a combination of these. It might be useful to develop this flexural cracked beam test into an AASHTO provisional test method specification. (Final Report NTIS # PB2018-100050)

Figure 1

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

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

NCHRP-IDEA Project 175

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This project developed a nondestructive impulse response test procedure for detection of fatigue cracks in steel anchor rods in auxiliary highway structures. This could serve as a rapid screening test able to detect the presence of a fatigue crack with greater reliability than visual inspection. A full-scale structure foundation anchorage assembly was constructed. To perform a test, an accelerometer was coupled to the top surface of an anchor rod, and the surface was struck with an instrumented hammer. Evaluation of the results for the purpose of damage identification involved measuring the variation in the normalized response signal from a known baseline (healthy or uncracked condition). To identify indicators of fatigue cracking, several damage sensitive features extracted from univariate and multivariate regression models were evaluated, including alpha-based regression coefficients, angle coefficients, cosh spectral distances, and regression residuals. Of these, alpha-based regression coefficients were found to be the most reliable indicators of anchor rod cracking. Autoregressive models (AR) that relate the current value of a predicted time series to past values of the same series were used to fit accelerometer recordings normalized by the applied impulse. From the test results, it was found that by establishing a baseline measurement for an uncracked rod and evaluating the change in Mahalanobis distance between the alpha coefficients ($D_m\alpha$) of regression models fitting the test data (Figure 1), the test method could identify artificial cracks at the base of the leveling nut (a region known to be susceptible to fatigue cracking), extending 1/4 and 1/2 of the rod diameter in depth, with at least 95% confidence. Repeatability was influenced by transducer-to-rod coupling conditions and by the consistency of the mechanical impact. (Final Report NTIS # PB2018-100051)

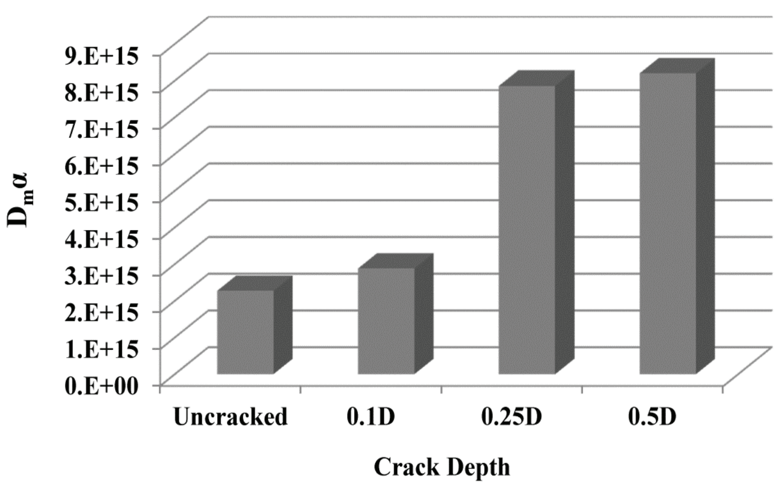

Figure 1

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

CONTACTLESS ELECTRODE FOR FAST SURVEY OF CONCRETE REINFORCEMENT CORROSION

NCHRP-IDEA Project 176

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The project developed and demonstrated a Kelvin Probe (KP) electrode device for rapid and stable electrode potential mapping for early corrosion detection in concrete steel reinforcement in highway structures. An existing stationary miniature proof-of-concept version of a KP electrode device was scaled up to a mobile and practical large size unit suitable for realistic field conditions (Figure 1, left). Operation of the scaled up contactless vibrating probe on a mobile platform was demonstrated on an outdoor reinforced concrete slab. The acquired probe data created a potential map of the slab surface that successfully identified the position of the anodic spot (Figure 1, right). The rapid probe operation was validated against data obtained on the same surface using the traditional and slower contact electrode method. Performance parameters needed to acquire useful data under various vehicle speeds were analyzed, and a conceptual approach using an alternative non-vibrating translating disk to operate at even greater scan speeds was analyzed. A duplicate vibrating unit for testing the coordinated operation was constructed, incorporating an advanced distance transducer and consolidation of the digital processing units into a powerful signal acquisition unit. A post-scanning deconvolution of the KP output was implemented to sharpen the resulting surface potential map to allow for faster travel speeds. Evaluation of the mobile units was conducted in two field tests on a pier deck that had previously served as the Sunshine Skyway Bridge access. The tests demonstrated the practical feasibility of the concept of using a rapidly scanning contactless surface probe to conduct potential mapping of a highway bridge surface for corrosion detection. (Final Report NTIS # PB2018-100052)

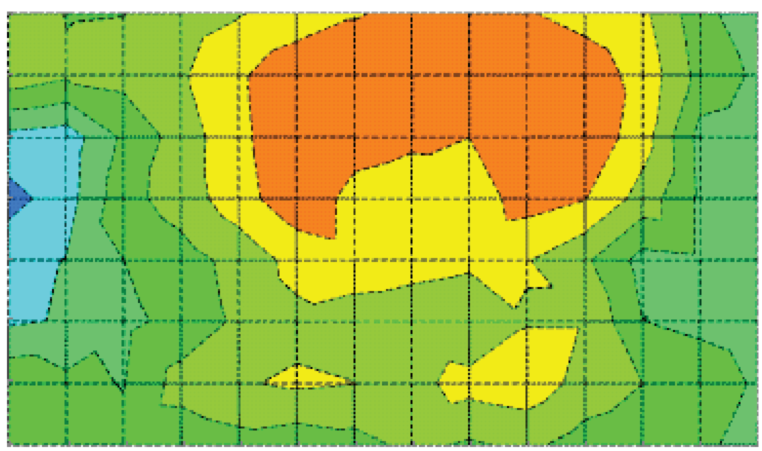

Figure 1

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.

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

NCHRP IDEA Project 177

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This project was aimed at demonstrating how vehicle trajectory data can be obtained from an existing radar-based vehicle detection system and used to produce turning movement count reports at signalized intersections with both exclusive and shared lanes. The most noteworthy impact of this work 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. Vehicle trajectory data and video recordings were obtained at a main location in Appleton, WI and at two supplemental locations (Appleton, WI and Madison, WI). The supplemental locations were used to better understand how the data collection and algorithms developed perform under varying geometric conditions. An algorithm that processes vehicle trajectory data collected from a radar device and generates turning movement counts was developed and implemented in the R programming language. The algorithm relies on vehicle trajectories downstream of an automatically detected stop bar to classify vehicle movements into left, thru, and right movements. The actual number of vehicles was obtained by performing manual turning movement counts using intersection video. The stop bar position plays a key role in removing noise in the dataset such as vehicles in nearby parking lots. When the number of vehicles detected by the algorithm is compared with the number of vehicles from a manual count the results indicate an average accuracy of over 99%. A more detailed analysis suggests that the average difference between the number of vehicles classified as making a specific movement during a 15-minute period and the actual number of vehicles in the same period is ± 2 in over 60% of the periods evaluated. The evaluation of the algorithm performance in 15-minute intervals, regardless of traffic volumes, provides a more intellectually-honest evaluation of the results by moving away from the standard practice of reporting vehicle detection system performance using large volumes and ignoring turning movement breakdown. Coincidentally, when the performance of the developed algorithm is evaluated under volume conditions that approach 100 vehicles per movement during a 15-minute period, the results approach accuracy levels greater than 90%. Since the algorithm relies on data from a vehicle detection system, the performance can degrade (as was found in the supplemental data collection sites) when the line of sight between vehicles and the detection system is interrupted (vehicle not visible). 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. (NTIS Report Number: PB2017-102163)

DEVELOPMENT OF RENEWABLE POLYMERS FOR USE IN ASPHALT PAVEMENTS

NCHRP-IDEA Project 178

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This project was aimed at developing and demonstrating the application of biorenewable polymers synthesized from soybean oil for use in asphalt pavements (Figure 1, left). Triglyceride molecules from vegetable oils have been considered as important renewable resources that can be used as biomonomers and be polymerized into biopolymers with properties similar to petroleum-derived monomers and polymers. Biopolymers with various polymer formulations were synthesized to investigate their effects in asphalt modification. Chemical characterization of biopolymers and rheological testing of biopolymer modified asphalt binders were conducted to better understand the materials properties. The results of the evaluations were subsequently used for statistical analysis and modeling to identify the significant polymer formulation parameters that affected the modification results, allowing researchers to optimize the biopolymer formulation for use in asphalt binders. The best-performing biopolymer formulation was produced in the laboratory, and the grading results confirmed its effectiveness in asphalt modification.

A cost comparison between the biopolymer and the styrene-butadiene (SB) based polymer was made to evaluate the economic benefits of biopolymer in the polymer production and the hot mix asphalt (HMA). The comparison indicated that the biopolymer could save about $2,800 per lane mile in the HMA than the SB polymer. A newly constructed biopolymer pilot plant in Iowa was able to produce more than 600 gallons of the biopolymer for paving a National Center for Asphalt Technology (NCAT) Test Track section (Figure 1, right). Production of the biopolymer at the pilot plant demonstrated the biopolymer polymerization reaction could be scaled up from the laboratory to the pilot plant level. The success of the biopolymer asphalt mixture paving construction proved that the biopolymer could be blended at existing asphalt blending and production facilities, and the mixture could be mixed and compacted as easily as other commercial polymer modified binders in mixtures, working at the same dosage level and delivering similar or even better modification effects. These biopolymers are sustainable, cost-effective, and environmentally friendly. The overall research effort demonstrated the feasibility of implementing the biopolymer into construction practices. The final report is available from the National Technical Information Service (NTIS # PB2019-101386).

Figure 1
Biorenewable polymer (left) and construction of biopolymer NCAT Test Track (right).

DEVELOPMENT OF A PORTABLE TOTAL-STRESS MEASUREMENT INSTRUMENT

NCHRP-IDEA Project 179

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This project developed a portable field instrument for in situ measurement of total stress (both dead and live loads) in steel bridge members (Figure 1). Currently, no other tool can perform a total stress measurement on a highway bridge. The developed instrument utilizes the acoustoelastic effect in steel to measure stresses based on ultrasonic wave velocity. The developed technology could be used for safety assessments of bridges by detecting overloaded members, such as gusset plates, at risk of failure. Initial work focused on laboratory testing and development of the ultrasonic technology. This testing included assessment of ultrasonic properties of different types of steel and development of system components. These components were integrated into a self-contained, portable, battery-powered instrument suitable for field operation on a typical highway bridge. Components of commercial instruments were modified to provide unique performance characteristics necessary to support the stress measurement technology, including integrated position encoders necessary to enable automated acoustoelastic measurements. Specific software for processing the ultrasonic signals and providing total stress measurements was developed. Field verification of the new technology (which consisted of making key measurements on a truss bridge to demonstrate the instruments capability to assess shear stresses in gusset plates and testing the system under real-world conditions) was performed. The test successfully demonstrated the system's capability to determine shear stresses in gusset plates nondestructively. Measurements were verified using destructive methods that confirmed the accuracy of the ultrasonic stress measurements. The instrument, now commercially available, 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. (Final Report NTIS Number: PB2018-101352)

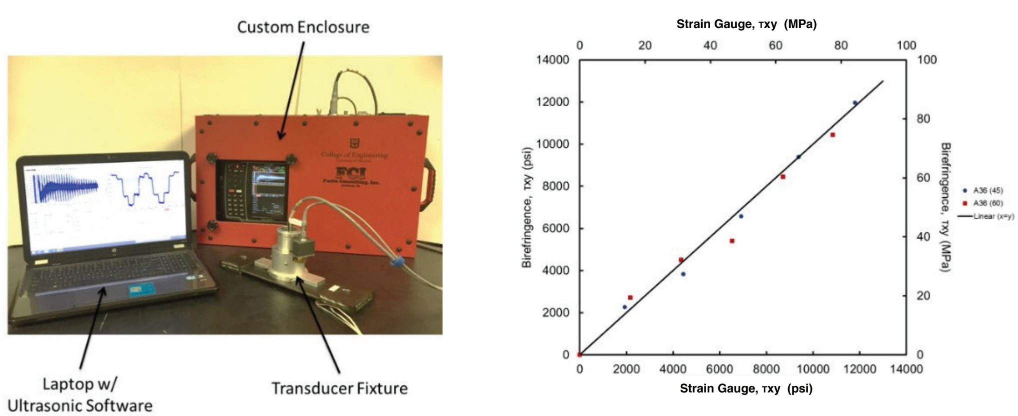

Figure 1

Photograph of the developed technique (A) and results showing the correlation between total stress measured by developed technique and actual stresses measured in a field test (B).

DRAINED TIMBER PILE GROUND IMPROVEMENT FOR LIQUEFACTION MITIGATION

NCHRP-IDEA Project 180

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This project explored the use of drained driven timber piling to provide a cost-effective liquefaction mitigation strategy for transportation infrastructure. A drained timber pile prototype was developed. Following installation, cone penetration tests showed an increase in relative density associated with different pile spacing and with prefabricated vertical drainage elements. Other in situ tests, including standard penetration and shear wave velocity tests, indicated that the drained piles produced better densification than the conventional piles when spaced at three pile diameters, but had no advantage at less dense spacing. A controlled blasting program was conducted to check the effectiveness of various timber pile configurations to reduce excess pore pressures and ground settlements. Following dissipation of excess pore pressures, the control zone settled 200 mm. while soil in between the piles settled approximately 20 to 80 mm, and piles that were tipped within a dense layer settled approximately 20 mm, on average. All excess pore pressures in the improved ground were lower than those in the unimproved ground and showed dilationary responses at the end of the blasting cycle. Simulation of blasting for drained piles indicated that drains with a larger discharge capacity would be required to help reduce excess pore pressures during strong ground motion. The methodology is available to implementation by state DOTs. (NTIS Report Number: PB2017-1021610)

Figure 1

Drained timber piles for soil liquefaction mitigation hazard.

DEVELOPMENT OF SMALL SPECIMEN GEOMETRY FOR ASPHALT MIXTURE PERFORMANCE TESTING

NCHRP-IDEA Project 181

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This project was aimed at developing small specimen geometry for uniaxial dynamic modulus and fatigue testing in the asphalt mixture performance tester (AMPT). A set-up for small specimen testing in the AMPT was developed, and the effect of specimen geometry for mixtures with varying nominal minimal aggregate size (NMAS) was evaluated to determine whether or not the representative volume element (RVE) requirement is satisfied for dynamic modulus and fatigue testing. Plant-produced loose mixes of five different types with varying NMAS values, (ranging from 9.5 mm to 25 mm) were procured. Dynamic modulus results indicate good agreement between the results of small and large specimens for test temperatures at or below 40°C (Figure 1). Cyclic direct tension fatigue test results indicate good agreement between large and small specimens. To develop a uniform procedure for laboratory specimen fabrication, the effect of coring direction was evaluated. Anisotropy did not have an impact on performance test results. Horizontal extraction of specimens appeared problematic for fatigue testing, and so vertical coring was selected as the optimal method for laboratory sample fabrication and used for specimen-to-specimen variability of four plant-produced mixtures with varying NMAS (up to 25 mm). Small specimen performance test results generally demonstrated an increase in specimen-to-specimen variability with increasing NMAS, which also was observed in large specimen testing. Draft AASHTO specifications for specimen preparation, AMPT dynamic modulus testing, and AMPT cyclic fatigue testing of the asphalt concrete were developed for consideration by the AASHTO's materials subcommittee. Development of small specimen ancillary devices and testing platens has commenced with IPC Global. (Final Report NTIS Number: PB2018-101353)

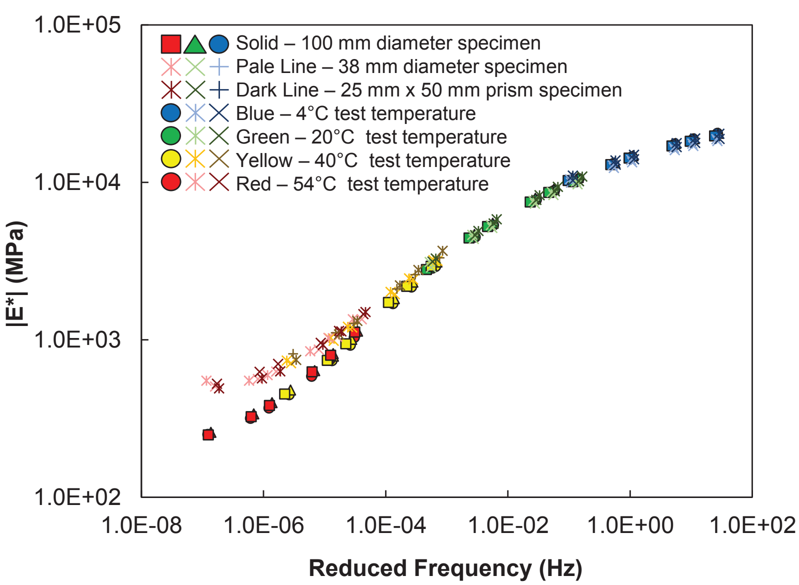

Figure 1

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

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

NCHRP-IDEA Project 182

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The purpose of this study was to reduce nutrient loading and stormwater runoff volume by adding biochar to the soils of highway greenways. The effect of biochar amendment on the hydrologic properties of three natural soils typically found along highway greenways in the mid-Atlantic region was quantified with 2% and 6% biochar. With biochar addition, water holding capacity and unsaturated hydraulic conductivity of the natural soils increased 5-46% and 50-300%, respectively, while saturated hydraulic conductivity decreased 6-61%. Pilot-scale experiments were designed (Figure 1) to evaluate the impact of bicohar-amended greenways on stormwater runoff in which a 24 h storm event with the scaled intensity equal to 10 mm/h was applied to a silt loam with 6% biochar. Biochar amendment reduced runoff by 18%, thus, 18% of the pollutant load to nearby water bodies was eliminated. In addition, saturated water content of the soil increased by 15% in biochar-amended soils, which should enhance denitrification for stormwater that infiltrates the soil. At a field site where biochar was amended to the top 30 cm of a roadway soil, a 4% by mass biochar amendment reduced runoff volume by 83% over 50 storm events, resulting in ~ 83% reduction in loading of nutrients and sediments. The cost of biochar-amended roadway soils for treating stormwater appears comparable to that for urban grass buffers, but requiring much less land: 0.12 acre of biochar versus 3.7 acre of urban grass buffer to treat 1-acre impervious roadway. The researchers are working with Delaware and Maryland DOTs to scale-up and implement the biochar amendment of soils. (Final Report NTIS Number: PB2018-101354)

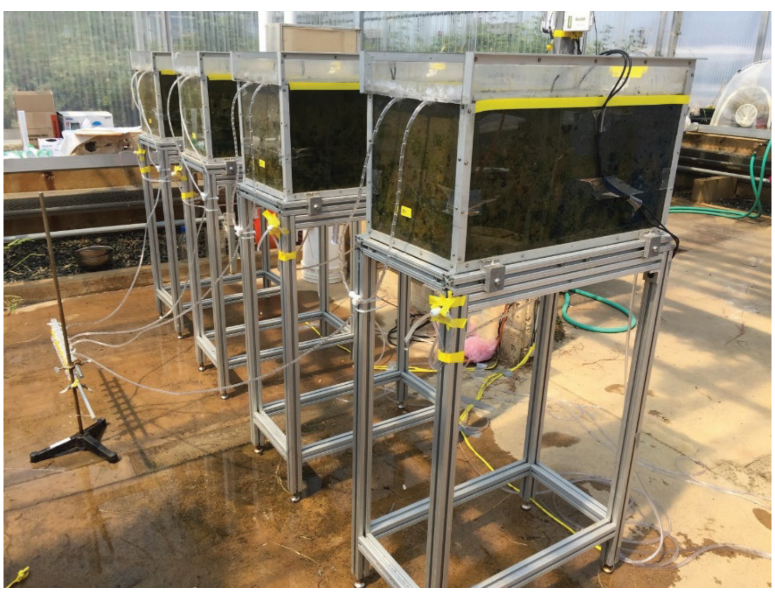

Figure 1

Plot-scale experimental cells.

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

NCHRP-IDEA Project 183

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This project was aimed at developing a novel Radio Frequency Identification (RFID) Scour Detection System, known as the RSDS, for monitoring scour hole evolution autonomously, continuously, and remotely near bridge piers and abutments, providing repeatable and reliable 3-D scour data for both clear-water and live-bed scour conditions. Figure 1 is a conceptual illustration of the process for estimating the scour hole geometry around hydraulic structures using the Return Signal Strength Indication (RSSI) of RFID sensors (transponders) buried in their vicinity. To improve the applicability of the RFID technology for measuring scour, an existing RFID system was enhanced and evaluated in the laboratory and the field. The enhancements included (1) integrated circuits and inclinometers added to improve accuracy and detectability when buried; (2) the implementation of a "wake-up" function to selectively activate a unique transponder; (3) triangulation functionality to identify the x, y, and z coordinates; (4) use of potting compound to prevent moisture build-up; and (5) enabling remote interaction with network capabilities. It was shown that the continuous, real-time measurements of the RSDS can capture the modification to bed shear stress as the scour hole evolves and the resultant effect on the growth rate and extent of the scour hole. This resulting formulation is a decay function, in which the shear force applied by the flow decays as the scour hole develops. The RSDS automates scour data collection and transmission, eliminating the need for onsite surveys and ensuring personnel safety. The RSDS also improves manager insight and decision-making by facilitating a shift to condition-based management that offers a cost reduction through timely recognition. The final report is available from the National Technical Information Service (NTIS # PB2019-101387).

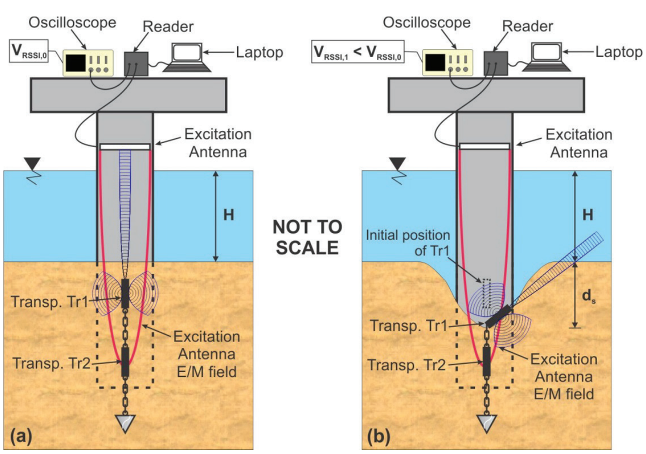

Figure 1

Conceptual illustration of the process for estimating the scour hole geometry around hydraulic structures using the Return Signal Strength Indication of Radio Frequency Identification sensors (transponders) buried in their vicinity: (a) no scour and (b) scour condition. E/M = electromagnetic.

SYNTHETIC HOUSEHOLD TRAVEL DATA USING CONSUMER AND MOBILE PHONE DATA

NCHRP-IDEA Project 184

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The aim of this IDEA project was to apply a prototype in Seattle, Atlanta, and Asheville that fuses passive, big data—including household-level data, firm-level data, and location and speed data from mobile phones—into individual-level synthetic travel diaries. Synthetic travel diaries reveal where, when, why, and how individual people travel, with each person's demographic data appended (e.g. household income, age). The project focused on making the prototype consistent nationally, rapidly deployable for any size city, and systematically updatable over regular time periods. The prototype uses a simulation framework to fuse the passive data with National Household Travel Survey data. The method produces locally sensitive synthetic populations with individual-level travel diaries using the same code in the three metropolitan regions investigated. The validations of time use, tours per day, and geographic distribution of trips were comparable to other validation datasets in each region, and the differences discovered in these measures appear to be reasonable considering the variability in the regional travel estimates. As results for Asheville, North Carolina (Figure 1) show, 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 These results suggest that this passive data approach to analysis will allow 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. (Final Report NTIS # PB2018-100053)

Figure 1

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

CURVEPORTAL FOR AUTOMATED IDENTIFICATION AND EXTRACTION OF HORIZONTAL CURVE INFORMATION

NCHRP-IDEA Project 185

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This project developed a prototype of CurvePortal, a web interface for automatically extracting horizontal curve location and geometric information from GIS roadway maps using an improved curve data extraction algorithm (CurveFinder). The concept of the algorithm is to use the directional offsets of successive line vertices to identify and categorize roadway curves as shown in Figure 1. Model Inventory of Roadway Elements (MIRE) curve types and MIRE horizontal curve elements, including curve length, radius, degree of curvature, direction, etc. (except for superelevation) were incorporated and their compatibility validated. The CurveFinder algorithm was improved, especially its accuracy when applied on low-quality GIS roadway maps. Additional automation features were incorporated to enhance CurveFinder's efficiency and accuracy. A prototype CurvePortal was developed that transportation agencies could access to upload their GIS roadway shapefiles for curve data extraction. The CurvePortal is hosted on WisTransPortal, an online transportation data portal at the University of Wisconsin–Madison. Technology transfer efforts have been initiated with several state DOTs that have expressed interest in using CurveFinder/CurvePortal. (Final Report NTIS Number: PB2018-101355)

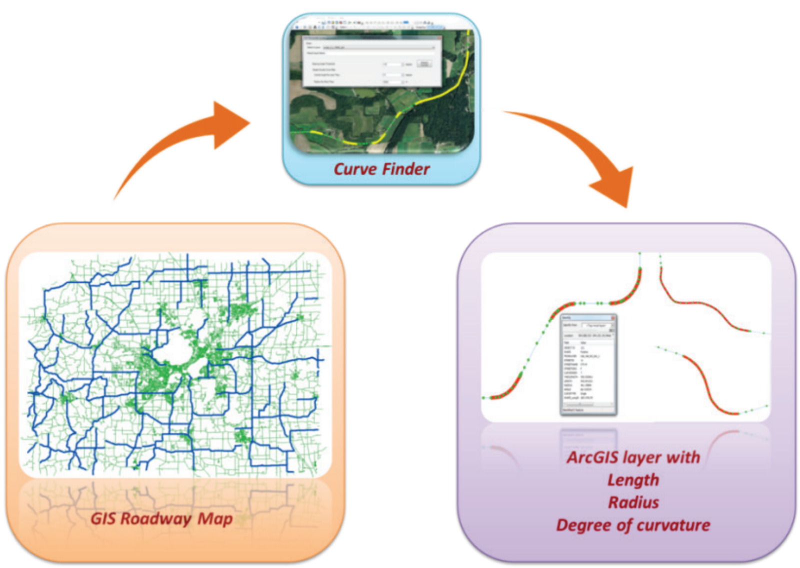

Figure 1

Concept of CurveFinder.

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

NCHRP-IDEA Project 186

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This project developed an electrical push probe and its deployment system (Figure 1) to measure the geometry of ground improvement columns (jet grout, soil mixed, auger cast) during construction or immediately after construction (within 30-60 minutes). 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 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. The probe was engineered to be easily deployable and field-ruggedized and was constructed of ultra-high molecular weight polyethylene, which had a high density to overcome the buoyancy effect in soilcrete columns and is resistant to impact and abrasion. The probe is inserted into a freshly jet grouted column immediately after removing the jet grout monitor. The test requires 20-30 minutes to collect sufficient data to estimate column diameter. The probe was implemented on multiple jet grout construction project sites, primarily granular soil sites (sands, silty sands). In all cases, the estimated diameter was found to be within 5% of the actual constructed diameter. The push probe provides a non-destructive assessment of production columns and results in significant time savings. Instead of waiting 7 days after jet grouting to perform coring and another 7-21 days for unconfined compressive strength test results, a contractor can assess the diameter within 30 minutes of jet grouting. This provides immediate actionable feedback as the contractor can modify jet grouting parameters as needed within the same work shift. Further, the ability to verify diameter immediately and move on to production can save significant time and money.

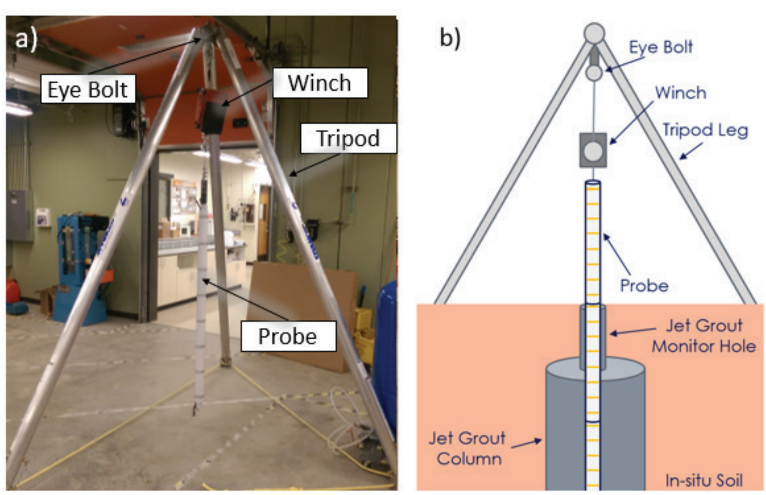

Figure 1

(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.

A LOW-COST MOBILE PROXIMITY WARNING SYSTEM IN HIGHWAY WORK ZONES

NCHRP-IDEA Project 187

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IDEA Concept and Product

This project was aimed at developing and validating a low-cost wireless worker proximity detection and alert sensing system for proactive safety warning in dynamic roadway work zones (Figure 1). A Bluetooth proximity sensing system was developed with customized software. Through Bluetooth-enabled smart devices, such as smartphones and smartwatches, audio and vibratory alerts are sent simultaneously to pedestrian workers and equipment operators when they are in hazardous proximity situations. Extensive lab tests and field trials under controlled environments were conducted to develop and improve the functionalities of the proximity sensing and alert system, and field tests were conducted at an earthmoving construction job site to evaluate the practicality of the system. The primary research findings include: (1) the Bluetooth proximity alert system provides reliable alerts during hazardous proximity situations, based on test results and feedback from workers who participated in the field tests; (2) the experimental results in controlled environments demonstrate that the Bluetooth proximity sensing and alert system provides reliable results with an appropriate alarm, with slight performance differences when equipment approaches a worker at various speeds; (3) the adaptive signal processing algorithm developed in this research was able to significantly reduce the signal processing delay and inconsistency of the Bluetooth system caused by vehicle's approaching speeds; and (4) the field test results show that frequencies of hazardous proximity situations highly depend on the type of equipment and type of work to be performed nearby. The overall study demonstrated that the Bluetooth proximity alert system has a high potential to enhance safety in roadway construction due to its high accuracy, low cost, easy-to-use, scalability, and smart functions. Georgia DOT is evaluating the system for implementation. (Final Report NTIS Number: PB2018-101356)

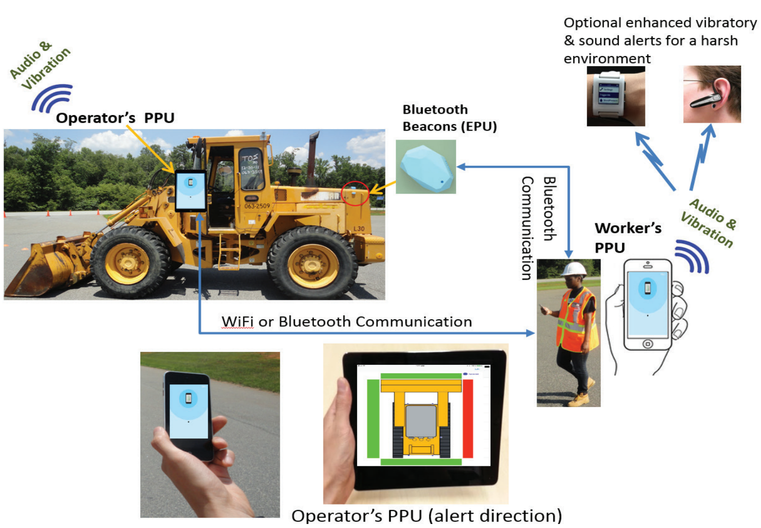

Figure 1

Concept of a mobile proximity safety warning system.

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

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This project developed a class of innovative V-connectors for use as joints between bridge pier and superstructure or between pier and footing, facilitating accelerated bridge construction and providing robustness for needed seismic resistance (Figure 1). Two design subgroups, fixed-end pin (FP) and hinge-end pin (HP), were further developed (Figure 2). In both designs, the top part of the connector was directly mounted onto the bottom surface of a bridge, which is similar to a conventional bearing pod. Two groups of specimens with the HP design were fabricated and tested at the Pacific Earthquake Engineering Research Center at the University of California–Berkeley and a bridge laboratory in China with a 2-degree hybrid-like test. The test involved analytical modeling of the superstructure behavior and experimental testing of the substructure with the V-connectors. The tests demonstrated that the V-connectors do present the hysteresis behavior for seismic isolation, as predicted in Figure 1, providing the expected seismic resistance performance for bridge engineering applications. The final report is available from the National Technical Information Service (NTIS # PB2019-101388).

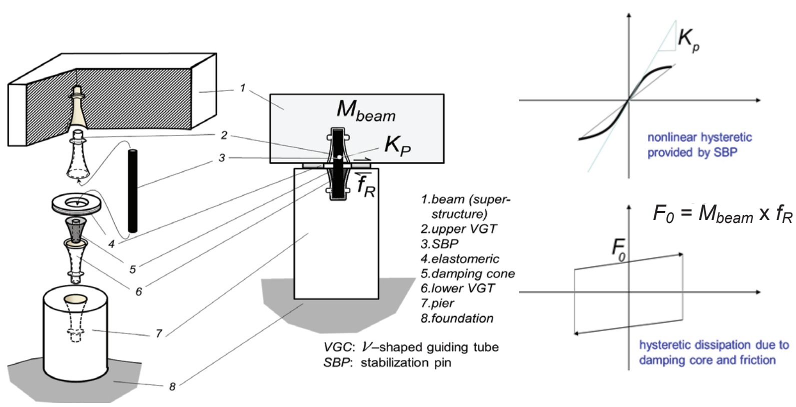

Figure 1

Concept of the V-connectors.

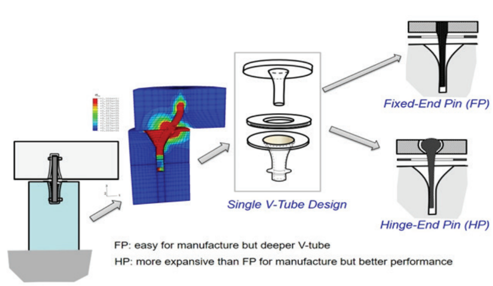

Figure 2

Two subgroup designs of the V-connectors' products family.

A NOVEL VISION SENSOR FOR REMOTE MEASUREMENT OF BRIDGE DISPLACEMENT

NCHRP-IDEA Project 189

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Columbia University, New York City, New York

This project developed a camera-based computer vision sensor system for accurate remote measurement of multi-point bridge displacements in outdoor environments that significantly reduces the cost of the equipment and operation as compared with conventional sensors. Figure 1 depicts the system, consisting of a camera and a tablet PC, for multi-point accurate measurement of bridge displacements, by cancelling camera vibration using a stationary point as a reference. To overcome issues with outdoor conditions such as changes in illumination and background, heat haze-induced image distortions, and camera vibration that can cause significant measurement errors, innovative algorithms for robust tracking of “natural markers,” heat haze filtering techniques, and vibration cancellation methods were developed. In addition, this project proposed a practical calibration method to convert image pixel displacements into physical displacements. The developed algorithms were integrated into a software package, and field performance evaluation tests were carried out in three bridges, including two long-span steel bridges—the Manhattan Bridge and the Williamsburg Bridge—and a short-span concrete bridge, the Jamboree Bridge. The remote, real-time, and multi-point measurement capabilities of the developed vision sensor system were further validated in the presence of various sources of field environmental noise, including heat haze and camera vibration. In the future, the system can be further developed for permanent installation at bridge sites to enable long-term continuous monitoring of structural integrity and safety. The final report is available from the National Technical Information Service (NTIS # PB2019-101389).

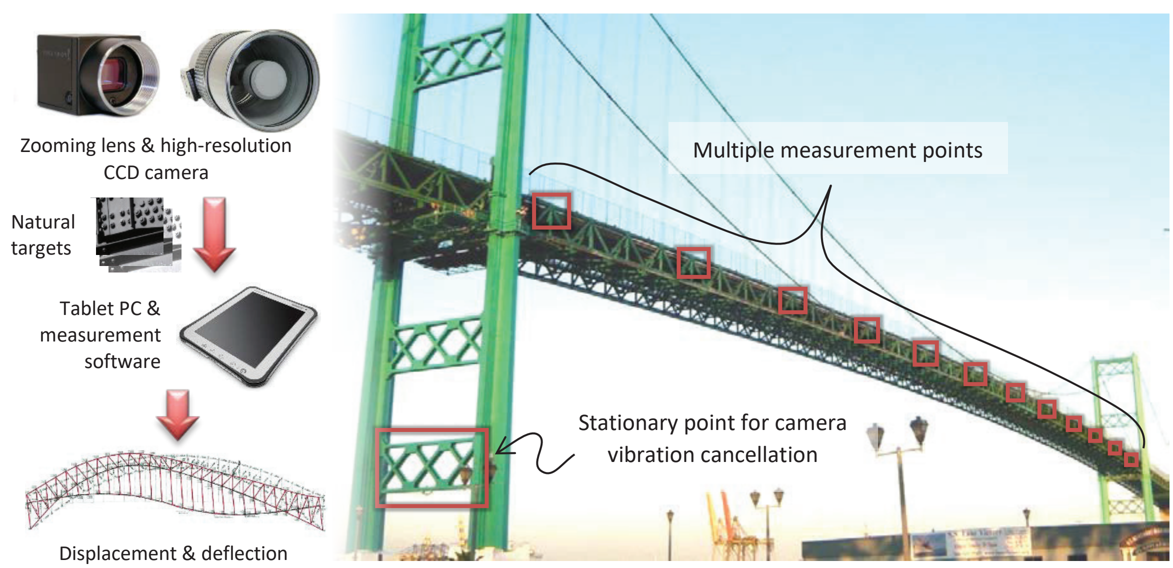

Figure 1

Vision sensors for remote multi-point measurement of bridge displacements.

DART FIELD VALIDATION AND PROTOTYPE REFINEMENT

NCHRP-IDEA Project 193

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This project evaluated the Duomorph Asphalt Rheology Tester (DART) technology, a low-cost, piezoelectric sensor–based portable testing system, to monitor the consistency and uniformity of asphalt binders in real-world production environment beyond controlled research grade settings. Physical improvements were made to the instrument for field portability and software improvements to enhance automation and reduce user controls. Significant improvements also were made to the standard protocols and additional features included in the device (specifically the introduction of a potentiometer in the circuit to enable balancing the bridge for each sensor) to reduce system noise. A large set of asphalt binders was tested in the laboratory. In general, the DART device was capable of matching "like" materials [i.e., of same performance grade (PG)] and distinguishing samples of different grades using materials from three different suppliers and a variety of PGs. Next in tests on binders from two states, DART could identify based on fingerprint comparisons of samples that satisfied the AASHTO M 320 specifications. Further, tests on samples from an asphalt binder production facility showed that the trends in viscosity were evident, and there is potential to use DART in a binder optimization process. Based on this study's results, the DART device could be an effective tool for process control of asphalt binders to enable larger sampling rates and faster testing of asphalt binders in production facilities or district laboratories. Testing can be completed in as few as 2.5 hours with minimal operator time or skills. In its current stage of development, DART can supplement, although not replace, AASHTO M 320 PG specification testing. It provides a means to verify binder consistency or to check deviation of a field sample from a certified sample. (Final Report NTIS Number: PB2018-101357)

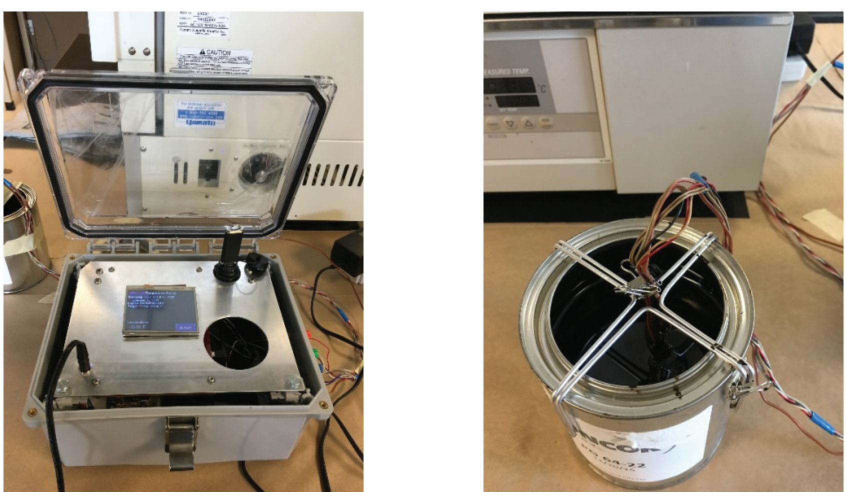

Figure 1

DART prototype for field testing and binder testing setup.

DEVELOPMENT OF AN IDEAL CRACKING TEST FOR ASPHALT MIX DESIGN, QUALITY CONTROL, AND QUALITY ASSURANCE

NCHRP-IDEA Project 195

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This project developed a simple, performance-based indirect tensile asphalt cracking test (IDEAL-CT) (Figure 1) for asphalt mix design, quality control, and quality assurance. The test offers (1) simplicity (no instrumentation, cutting, gluing, drilling, or notching); (2) efficiency (test completion within 1 min.); (3) practicality (minimum training for operator and suitable for both laboratory molded specimens and field cores); (4) low-cost test equipment; (5) repeatability (low variability); (6) sensitivity (sensitive to asphalt mix compositions and aging); and (7) good correlation with field cracking performance. The test is now an ASTM standard test method (ASTM D8225-19: Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature). Two equipment manufacturers, InstroTek and Testquip, have standalone machines to perform the IDEAL-CT. InstroTek also has an IDEAL-CT fixture fitting for existing machines or loading frames. A video describing the test method is available on YouTube (https://www.youtube.com/watch?v=OB4pQDB2Yfs). An article describing the IDEA-CT was published in the trade magazine, *Roads and Bridges* (https://www.roadsbridges.com/ideal-candidate). The test has been evaluated by a number of state DOTs, including Georgia, Kentucky, Minnesota, Maine, Missouri, Ohio, Oklahoma, Virginia, and Texas. Virginia and Texas have already adopted the test. The NCHRP has initiated an implementation project to facilitate implementation of the test by state DOTs. The final report is available from the National Technical Information Service (NTIS # PB2019-101392).

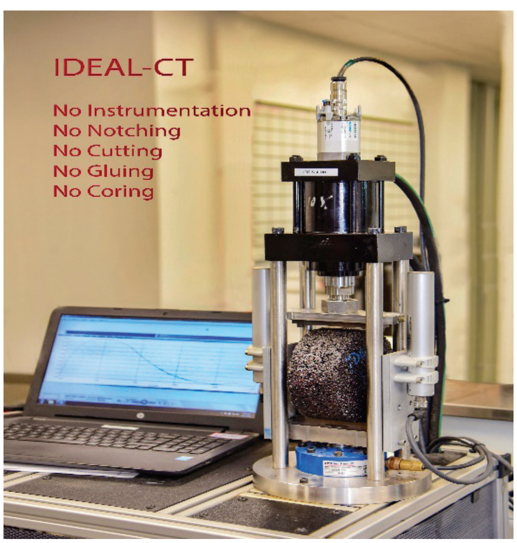

Figure 1

IDEAL-CT test setup.

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all Highway IDEA projects that were completed or active during the 2019 program year.

SELF-DEICING LED SIGNALS FOR RAILROADS AND HIGHWAY INTERSECTIONS

NCHRP-IDEA Project 190

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IDEA Concept and Product

This project has developed a new type of self-deicing LED signal for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light with lens too cool to melt snow and deice 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-deicing LED signal light adopts innovation of "Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture" (Patent No. US 10,215,441 B2) (Figure 1) to harvest both the light and the heat generated by the same LEDs for illumination and heating of the signal lens.

Project Results

The investigative approach is divided into three stages. Stage 1 focuses on laboratory research and development and tests of the prototype self-deicing LED signals. The research team has developed and tested prototypes of the self-deicing LED signals (12 in.) in red, green, and yellow light colors. The research team has tested their thermal and lighting performance to meet all requirements. Stage 2 focuses on testing three fully working prototypes mounted in closed-course settings on the roof of an engineering building and powered by the signal controller cabinet, to avoid interruption on people and ground traffic. The research team has evaluated their thermal and lighting performance of the prototypes to ensure their readiness for follow-up field tests in winter. Stage 3 focuses on the field tests of the fully working 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. Temperature sensors will be mounted on the signal lens to record its real-time surface temperature using a data logger. 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 deicing in wintery conditions. The research team will conduct a real-time performance measurement of those prototype signals under wintery conditions with heavy snow and ice, and hold an on-site demonstration for the project partners for final evaluation for their future implementation in practice.

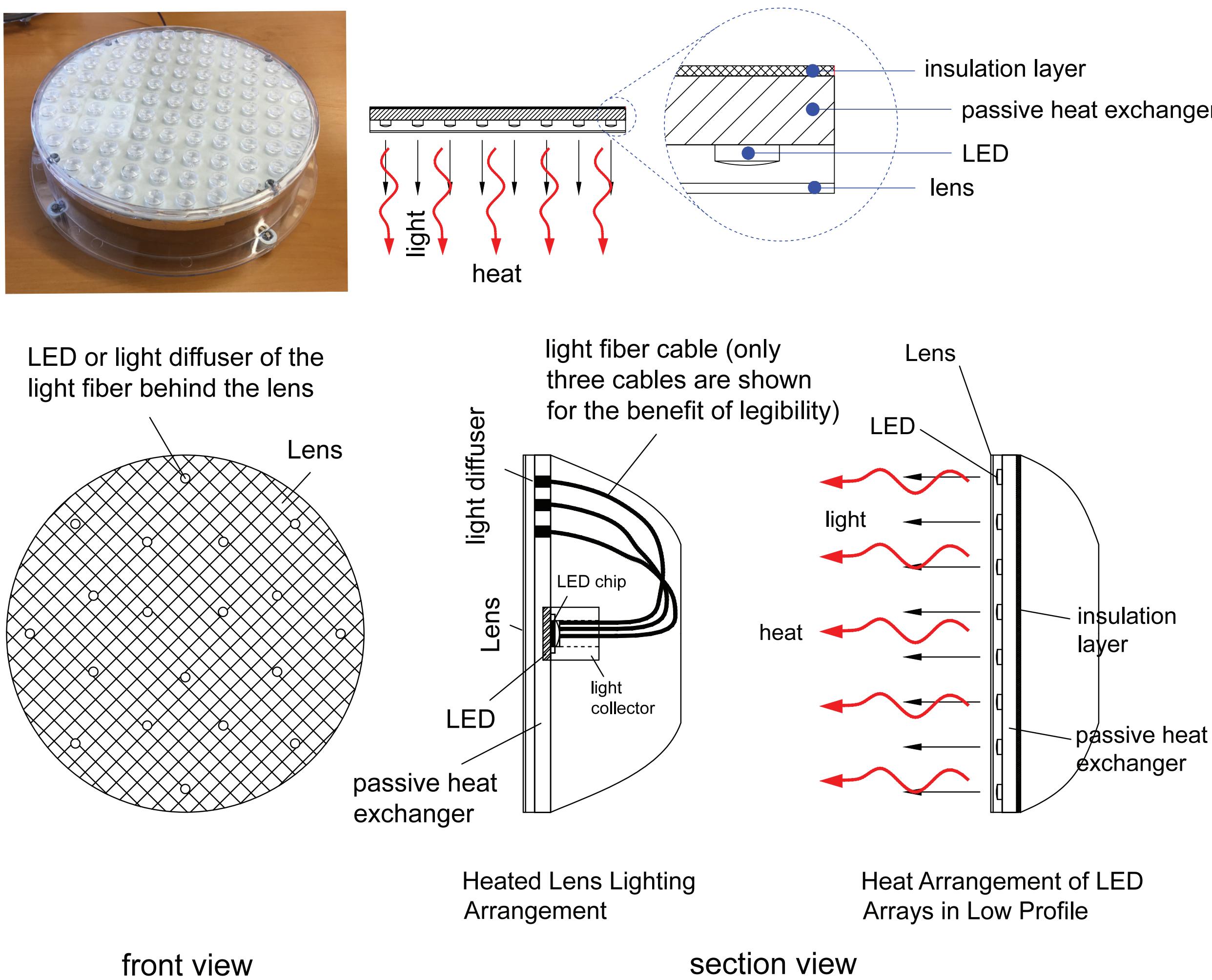

Figure 1

The concept and a prototype of the self-deicing LED signal light, which deploys new architecture of "Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture" (Patent No. US 10,215,441 B2) to harvest both the light and the heat generated by the same LEDs for lighting and heating uses. The heat generated by the LEDs is harvested by the passive heat exchanger and stored to heat the lens for melting snow and deicing in wintery conditions.

Product Pay-Off Potential

Once validated, the self-deicing 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-deicing LED signals are implemented in practice in the snow-belt states, transportation agencies, districts and cities, the railroad companies, and the driving public could expect significant benefits, including safety and efficiency, cost savings, and environmental sustainability. 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-deicing LED signal lights could offer savings on annual maintenance costs.

Product Transfer

A patent was issued for the innovation of “Heated Lens Lighting Arrangement.” (Patent No. US 9,851,086 B2). A second patent was issued for the innovation of “Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture” (Patent No. US 10,215,441 B2). The research team and the University of Kansas Center for Technology Commercialization have been reaching out to the signal industry for patent licensing. Pilot replacement programs are planned to displace the existing signals with the self-deicing LED signals in some collaborative state departments of transportation (e.g., Kansas, California, Maryland, Michigan, New Jersey, Pennsylvania, and Wisconsin), the Union Pacific Railroad, and the Burlington Northern and Santa Fe Railroad. Once validated, the self-deicing LED signals are expected to be installed at highway intersections, Class I railroads, commuter railroads, and short-line railroads in cold weather zones.

TESTING OF IN-SERVICE BRIDGES USING AUTOMATED ULTRASONIC TESTING METHODS

NCHRP-IDEA Project 191

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IDEA Concept and Project

The specific problem is effectively and efficiently detecting and quantifying internal steel discontinuities, including welding discontinuities and fatigue cracks, in order to evaluate the impacts of these discontinuities on performance of bridge members. The innovative approach is to apply automated ultrasonic testing (AUT) methods to bridges that provide superior detection capabilities when compared to conventional testing methods. Advanced methods are capable of significantly more accurately locating, sizing, and characterizing discontinuities such that the new information will better allow more refined and accurate structural analyses of a member's performance. Existing conditions often do not meet current standards, whether due to original as-built condition or due to damage induced in service. Applying current standards to existing conditions can lead to expensive repairs or retrofits or premature replacements. Therefore, existing structures may benefit from additional analysis. One such analysis method is the Fitness-for-Service (FFS) analysis. An FFS employs advanced analytical techniques, such as fracture mechanics, to determine the suitability of an existing member subjected to existing, noncompliant conditions. The results from these analyses will better enable agencies to make informed decisions when managing their assets. More accurate and detailed information is needed when conducting FFS evaluations on bridges including location, size, and characteristics of existing discontinuities, and, therefore, more advanced testing methods are vital.

Project Results

An industry scan of available industry sensor architectures, data acquisition hardware, and analysis software was completed to inform the selection and design of the final inspection system. This system will likely use commercially available data acquisition systems and sensors coupled with a custom assembly for holding and positioning the sensors. In addition, an expert technical panel has been assembled in partnership with the U.S. Army Corps of Engineers (USACE) to identify team members to perform the baseline manual inspections with traditional ultrasonic technologies as well as evaluate the results produced by the selected AUT technologies.

Based on review of the industry scan, the high cost of commercially available scanner systems coupled with the necessity to still customize these systems to accommodate steel bridge members (as opposed to the pipelines for which many of them were designed) has led the project team to construct a prototype system using an *X-Y* plotting printer system (Figure 1). While the cost of such technology has dropped significantly over the last decade, 3-D printing instrumentation meets the need for a device that emphasizes precise and controlled movement of a sensor along a custom-programmed pathway. By replacing the printer head of such a system with the ultrasonic sensor of choice, the same programming interface and modalities are used to automate the motion of that sensor in the course of scanning along its fixed rail system in three dimensions (Figure 2). New programming routines and software were developed to mim-

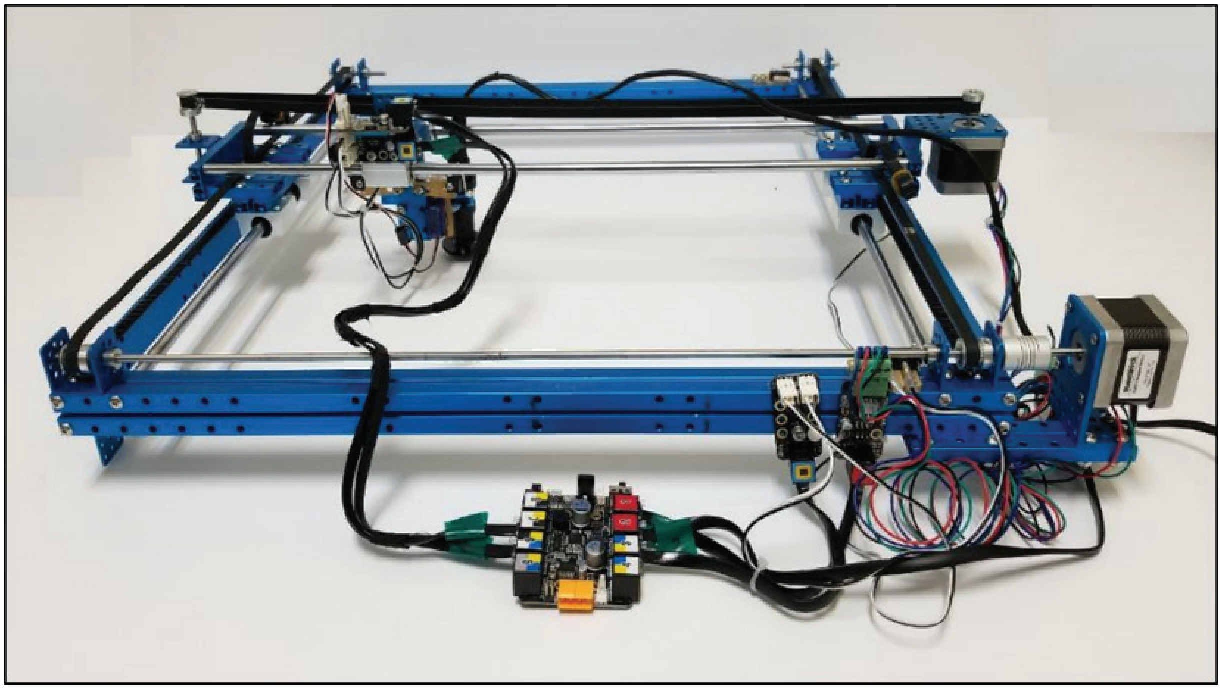


Figure 1

Selected Prototype AUT System (based on Makeblock XY Plotter Robot Kit).

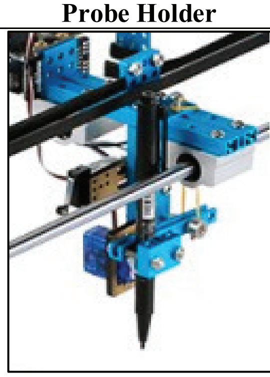
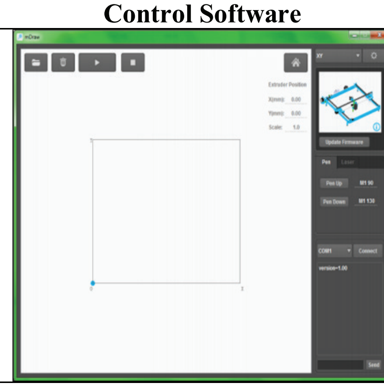
Probe Holder	Control Software
	

Figure 2

Customizable probe holder for use with multiple UT probe types (left) and software for controlling the scan path of the prober (right).

ic the typical motion and travel path of a human inspector through full control of the probe motion speed with movement precision of 0.1 mm in the lateral directions of the test surface.

Preliminary testing with a conventional UT steel thickness gauge has been completed with some success, using the probe to move along a pre-programmed path along a steel plate at a consistent speed. As anticipated, the key challenge lies in maintaining consistent pressure between the probe tip and work surface during transit across the plate, so work has started on designing and constructing a probe holder that can better maintain this contact. An improved Graphical User Interface and programming approach are being created to make scan path input more streamlined and intuitive as the present approach relies on a combination of Python-based scripting and open-source software. In addition, a better probe holder for maintaining consistent contact between the tip and work was constructed for deployment during mock-up testing based on this initial work.

Laboratory mock-ups have been fabricated to conform to the American Welding Society terminology, joint configuration, welding, and ultrasonic testing flaw classification. These mock-ups have been produced with known void locations to help develop the encoder and an accurate scanning procedure to identify, characterize, and quantify deficiencies when evaluating discontinuities in the mock-ups and bridge candidate members. Figure 3 presents photos of the developed laboratory mock-ups.

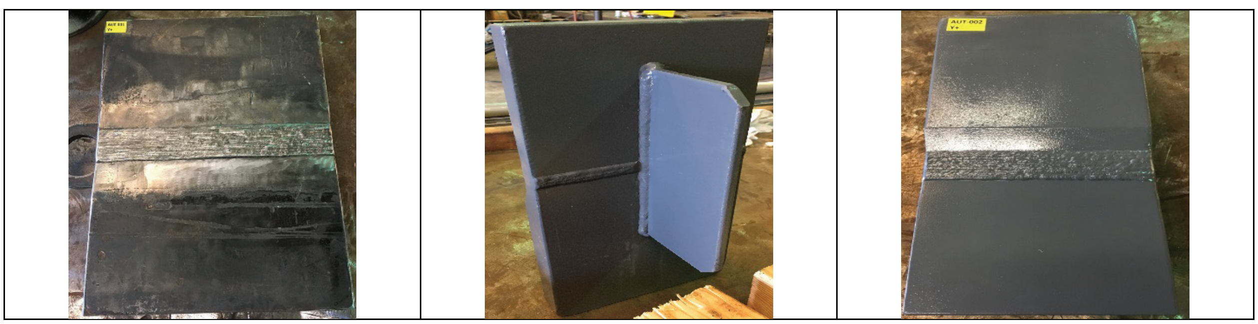
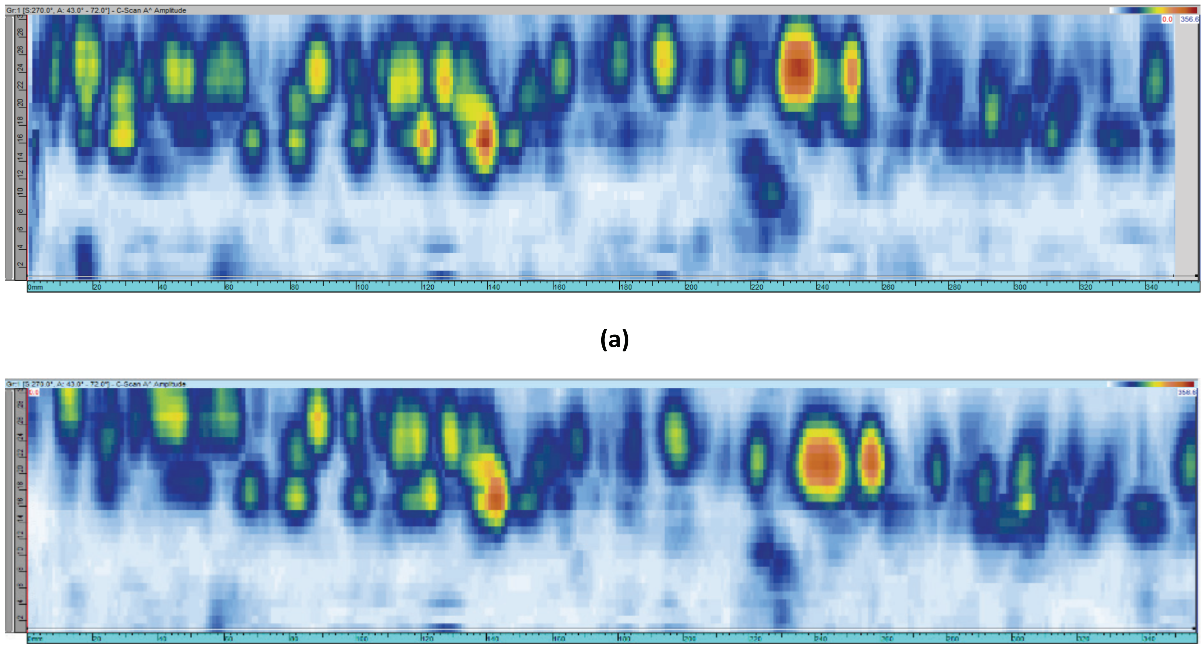


Figure 3

Examples of laboratory mock-up welds fabricated with known voids included.

Manual UT inspections of the fabricated specimens were completed by ASNT III UT inspectors identified by the expert technical to provide a baseline inspection standard against which the AUT system could be compared. Testing of the mock-ups by these qualified technicians took place in October 2018 with video recordings having been taken of the inspector's motion and technique in an effort to replicate these approaches with the AUT system. After setting up the AUT system to follow the same approach of the human inspectors, data was collected and results were generated that show significant similarity of feature measurements between the automated system and human operators, as presented in Figure 4.



(a)

(b)

Figure 4

Raw projection results of UT Weld Inspection by (a) inspector and (b) AUT Prototype System.

Results from these tests and feedback on the prototype system operation were used to prepare for field demonstration of the technology on a suitable in-service bridge identified by the research team. Specific procedures were developed and field tests were conducted on the selected bridge to test and demonstrate the prototype system. The field demonstration of the AUT system was completed under the supervision of an ASNT III inspector, who confirmed the quality of the data being generated by the AUT prototype system was consistent with the results of the qualified inspector. Figure 5 presents images of the AUT System configured for vertical and overhead use on a bridge.

Selected Vertical Weld **Selected Overhead Weld**

Figure 5

AUT system mounted in two configurations to accommodate different weld locations.

Field testing of the prototype AUT system demonstrated the feasibility of deploying this technology for the in-service inspection of steel bridges. Future AUT technologies will need to be more flexible and mobile in their design to accommodate a greater variety of bridge configurations and allow for faster installation. Initial results from application of the AUT system in evaluating the weld specimens show promise for the system's deployment for initial survey scans that allow more informed and time-efficient selection of where expert inspectors should perform more detailed scans. In addition, the present study found that the AUT system is well suited for use with Phased-Array UT probes, as the need for a consistent linear probe path for successful testing is met by the fixed rails used by the instrumentation platform. Finally, the significant amount of noise introduced by weld reinforcement may require that grinding of the weld flush with the steel be part of any protocol for an ideal weld inspection using ultrasonic testing.

Product Pay-Off Potential

The expected benefits gained from this innovation include:

1. Availability of a more accurate and efficient nondestructive testing tool that more accurately characterizes and quantifies embedded discontinuities in steel members.
2. Better quality information allows engineers to improve their evaluation of the suitability of these discontinuities and provide value-added recommendations such as repair or monitoring.
3. Allows managers to make more informed decisions on allocating resources to maintain a bridge inventory.
4. Replaces hazardous and more time-consuming field testing methods such as Radiographic Testing (RT).

A cost or consequence comparison will be made between AUT and conventional testing methods, to include the cost or consequences of decisions made (e.g., monitoring, repairs, replacements) by agencies based on the information provided by the various methods of testing.

Product Transfer

Transfer to practice includes providing AUT test procedures for specific member and joint types, providing procedures for evaluating test results, providing standard operator qualification requirements, and demonstrating how the testing results can be applied to analyses and decision-making. The ability to transfer this knowledge will be enhanced by engaging bridge owners in the demonstration of the technology and inviting other agencies to participate.

APPLICATION OF MICROBIAL FACILITATED STABILIZATION FOR SUSTAINABLE IMPROVEMENT OF EXPANSIVE PAVEMENT SUBGRADES

NCHRP-IDEA Project 192

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IDEA Concept and Product

This project targets the application of microbial induced calcite precipitation (MICP) to mitigate moderate-to-severe cracking in transportation infrastructure built on expansive soils. The goal is to develop a stabilization alternative that could be applied to new and existing construction without major reconstruction activities. Current stabilization options have been inadequate, especially to pavement infrastructure, and result in expensive rehabilitation activities. In MICP, technique bacteria facilitate the precipitation of calcite and alter soil behavior. Researchers have shown it can strengthen sandy and silty soils while also minimizing the liquefaction potential of loose sands. This research is extending its application to expansive soils by conducting both laboratory and field studies. Laboratory studies consisted of examining artificial and natural soils to investigate the effectiveness of MICP in treating expansive soils. The artificial soils, prepared by mixing sand and bentonite, are mixed with bacteria and treated with urea and calcium chloride to precipitate calcite and mitigate swelling. In the case of natural soils, indigenous bacteria are stimulated using treatment solutions to precipitate calcite. Knowledge gained in the laboratory phase was used to treat soils under realistic field conditions and evaluate field performance of this technique.

Project Results

The project consists of two stages: Stage1 includes laboratory studies while Stage 2 focusses on field applications. As part of Stage 1 activities, the research team designed and developed a treatment solution delivery system (TSDS). This device can house a soil sample of 7.6 cm diameter and 15.2 cm height. This soil sample can be injected with treatment solutions under inlet pressures as high as 170 kPa (see Figure 1). There are arrangements to collect effluent and release excess pressures. This device was used to treat both natural and artificial soils. Four artificial soil mixes and four natural soils with varying clay contents and plasticity characteristics were tested in this research. The artificial soils were prepared by mixing fine to medium sand with varying percentages of commercially available bentonite mineral powder. The goal was to study how MICP effectiveness varies with increasing clay content (bentonite). The clay contents ranged from 5, 10, 15, and 20% by dry weight of the soil. Natural soils were also studied to understand the effect of varying plasticity characteristics and microbial communities on MICP effectiveness. The natural soils are denoted as MS (Marsing, ID), GF (Great Falls, MT), DC (Dry Creek, MT) and BR (Bad Route, MT) indicating the location from which they were obtained. Baseline tests, including attergberg limits, gradation, compaction characteristics by standard effort, permeability, unconfined compression strength, 1-D swell strain and swell pressure along with calcium carbonate concertation, were performed on all soils.

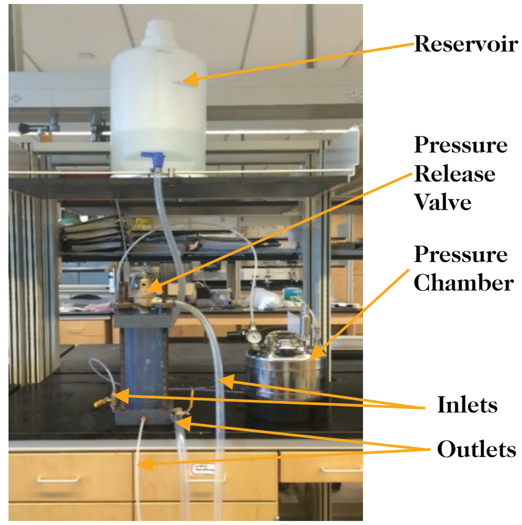

Figure 1

Treatment solution delivery system.

MICP treatment protocols varied between the artificial and natural soils. Artificial mixes were autoclaved prior to testing and laboratory cultured bacteria were added to the autoclaved soil. This augmented soil was then compacted at optimum moisture content (OMC) and maximum dry unit weight (MDUW). The compacted samples were then placed in the TSDS and injected with treatment solutions consisting of 250 mM of calcium chloride and 333 mM of urea in 1:1 ratio. In case of natural soils, the treatment was performed in two stages. In the first stage, soil samples compacted at OMC and MDUW were injected with enrichment solutions containing 0.1 g of glycerol, 0.5 g corn steep liquor, and 20 g of urea in one liter of the solution to stimulate indigenous bacteria. In the second stage, cementation solutions consisting of same ingredients as enrichment solution along with 250 mM of calcium chloride were injected to precipitate calcite. The same TSDS was used to inject these treatment solutions into compacted natural soils.

The results were promising, especially in the case of natural soils (MS, GF, BR and DC). It was observed that after MICP treatment, all soils successfully precipitated calcium carbonate. The precipitated calcite was able to increase the unconfined compression strength (UCS) of both natural and artificial soils. Also, the 1-D swell strains, which ranged from 1.15% to 17.9% before treatments, were reduced to 0.5% to 13.13% after treatment. Figure 2 presents a comparison of 1-D swell strain for natural soils before and after MICP treatments. Artificial mixes also showed similar results of reduced swelling and increased UCS after treatments.

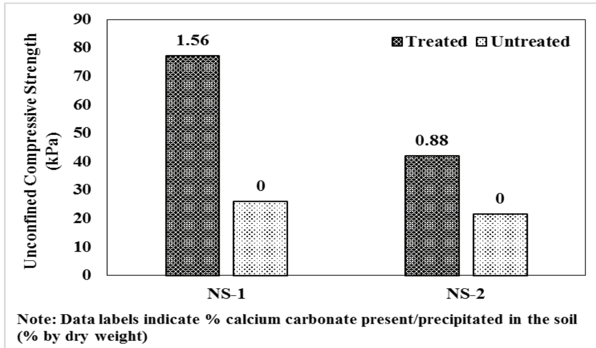

Figure 2

1-D swell strain and swell pressure comparisons for both natural soils.

Preliminary field work was performed with an intent to evaluate the laboratory protocols in the field. For this purpose, a test site was selected with help from the Idaho Department of Transportation (DOT) close to the location from which MS soil was obtained. Two different configurations were tested, the first one with a center-to-center distance of 16 in. (40.64 cm) between the injection points and the second one with a center-to-center distance of 30 in (76.2 cm). The injections were performed using a packer system to ensure the borehole was sealed during injection and the treatment solutions did not escape from the annular space between the injection pipe and the borehole. Five rounds of treatments were performed at 1-week intervals, starting with one round of enrichment solutions followed by four rounds of cementation solutions. Each treatment consisted of pumping approximately 25 gallons (94.6 liters) of the treatment solution. The composition of treatment solutions was identical to that of laboratory experiments. The targeted depth of treatment was between 2 to 3 feet (0.6 to 0.9 m). Samples were collected from the bottom of the borehole after each treatment to be tested for calcite content and free swell index. The results showed that calcite precipitation increased with treatments (up to 8% total), and the free swell index dropped from 114% to 29%. Based on these preliminary tests, a field protocol was developed.

Product Pay-Off Potential

The potential payoffs of this research project are: (1) Extended life and reduced cost—Fewer incidences of cracking would result in lower infrastructure maintenance costs. In addition, the method could be applied without significant reconstruction to existing pavements showing subgrade heaving distress. (2) Improved health and environment—Federal and state agencies would gain a sustainable treatment alternative for expansive soil problems beneath transportation infrastructure. (3) Wide use—Outcomes may recommend the treatment method for other problem soils like soft clays and collapsible soils, thus avoiding sinkhole damage if detected early.

Product Transfer

This project aims to produce a stabilization alternative for use in treating expansive soils. The project will result in a stabilization protocol that will be validated by field implementation. The customer base for this stabilization alternative includes owners of infrastructure (e.g., DOTs), contractors, and civil/construction engineering consultants along with single family home owners. The project team is involving two DOTs specifically during the field testing phase that will help in transfer to practice. In addition, DOT personnel will provide input from the owner/designer/inspector perspective on the stabilization protocol and its application in the field.

SMART INSTALLATION AND MONITORING SYSTEM FOR LARGE ANCHOR BOLTS OF SUPPORT STRUCTURES FOR HIGHWAY SIGNS, LUMINARIES, AND TRAFFIC SIGNALS

NCHRP-IDEA Project 196

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IDEA Concept and Product

This study aims to develop an inexpensive, sensor-based system for monitoring tension in anchor bolts in support structures for highway signs, luminaires, and traffic signals (SLTS) to address the limitations of current practices for bolt installation and inspection. As shown in Figure 1, this washer system consists of two composite copper-glass fiber reinforced polymer (GFRP) rings attached to the top and bottom washers to measure capacitance, which when related to tension, will provide a direct indication of the "tightness" of the nut, enabling easy sensor-based inspections. The proposed system will be battery-free, connected to a low-cost, passive radio frequency readout device (RFRD), which is interrogated wirelessly using a radio frequency (RF) reader. This allows inspections to occur from a distance, such as from any passing agency vehicle, thus expediting the inspection process and reducing maintenance costs.

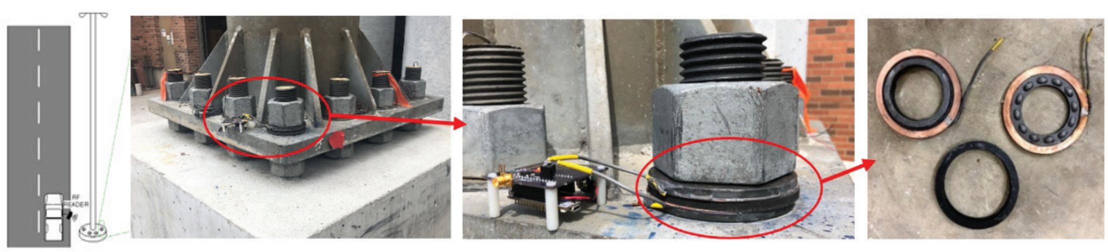


Figure 1

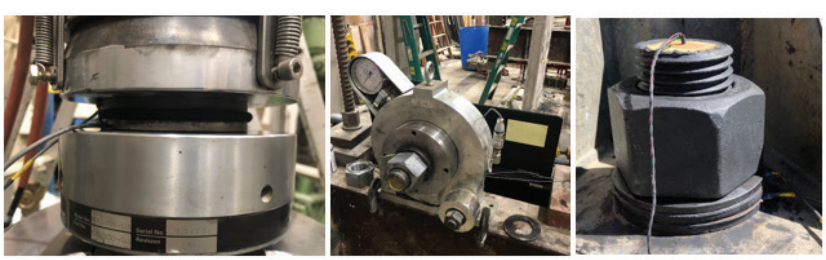
Smart washer system.

Project Results/Planned Investigation

The project consists of two stages of research. Stage 1 focuses on the development of the smart installation and monitoring system, particularly designing the sensor, passive RFRD, and washer. The sensing washer has been assembled and tested. The detailed layers of the system are shown in Figure 1. The middle dielectric layer, represented by neoprene rubber in Figure 1, provides a separation of the top and bottom composite washers. Two copper rings with electrodes welded on are set on top and bottom of the dielectric layer, forming a capacitor. The gap formed by the dielectric layer ensures that the capacitance can be measured via a changing distance; however, the copper is only in contact with non-conductive materials, assuring that the flow of electrons will not be interrupted.

A printed circuit board was created, tested, and utilized to program a microcontroller. The microcontroller, utilized on an RFRD tag, can read and process the signal, indicating the state of the capacitance sensor to the user through an onboard LED. The RFRD circuit is designed to allow results transmission using a small amount of power obtained from the input RF signal. The device and its circuit logic will be optimized for quick reading (from a moving vehicle, for example) and to coordinate readings in the presence of other devices.

Stage 2 focuses on prototype system evaluation and implementation through demonstration projects. The testing and evaluation are done at two levels: component level on single anchor bolt and structural level on the support structure. Three types of tests is planned to be conducted: tightening, static loading, and fatigue loading. To date, the testing on component level is nearly completed. The research group first tested different sizes of the sensors on MTS compression testing system (Figure 2*a*) to simulate tightening and loosening processes and to acquire load-electrode distance-capacitance relationships, which can be used as references for component level testing. Next, the sensors were tested on F1554 Grade 105 anchor bolt with a diameter of 2-1/4” using Skidmore-Wilheim tension testing system (Figure 2*b*), and F1554 Grade 55 anchor bolt with a diameter of 2-1/2” using a sign structure (Figure 2*c*). Initially, the system had a capacitance of 45-50 pF; after tightening, the capacitance was increased to 110-120 pF, depending on the size of the tested anchor bolts. When the nut was released, the final capacitance returned to its initial value, proving the theoretical concept. By comparing the capacitance readings from the RFRD tag and the LCR meter, it was found that they match at the component level but differ at the system level. Work continues to improve the accuracy of the RFRD tag at the system level. Future testing will be static and fatigue loading tests at structure level. The testing will be followed by demonstration projects in collaboration with state DOTs.



(a)! (b) (c)

Figure 2

Component level testing setup: (a) MTS compression testing setup for sensor system, (b) Skidmore-Wilheim tension testing system setup for sensor system of 2 1/4” Grade 105 anchor bolt, and (c) testing setup for sensor system of 2 1/2” Grade 55 anchor bolt.

Product Pay-Off Potential

Anchor bolts are critical structural components of SLTS support structures. The collapse of SLTS structures has frequently been attributed to anchor bolt failures, often due to loose nuts. Therefore, the proposed research addresses an important, nationwide problem. The sensing washer system will provide accurate readings of the tension forces experienced by anchor bolts, which can help tell if the bolt is correctly tightened or has come loose. The proposed system has great potential to substantially reduce inspection costs and significantly improve safety by replacing current anchor bolt installation and inspection methods. The proposed system can be installed mostly with the current installation procedures and equipment, allowing an effective and easy installation. The proposed system could be modified, allowing for use in other types of bolted connections (e.g., bridges, buildings, wind turbines).

Product Transfer

At the final phase of this project, the project team will work with Minnesota DOT and Iowa DOT to implement this concept in demonstration projects. Other than state DOTs, the technology has attracted extensive interest from the industry, including TurnaSure LLC and Valmont Industries, Inc. The project team will work with the industrial partner and a manufacturing plant to achieve low-cost mechanized production, which will facilitate the path to full commercialization.

HEXAGONAL BORON NITRIDE REINFORCED MULTIFUNCTIONAL CONCRETE FOR TRANSPORTATION INFRASTRUCTURE

NCHRP-IDEA Project 197

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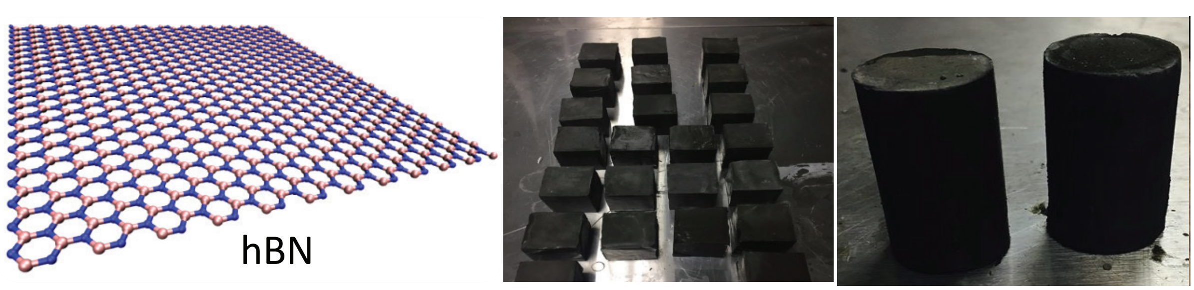
IDEA Concept and Product

Concrete is the most widely used synthetic material on earth. In the United States, more than 75% of bridges and over 60% of Interstate highways are made of concrete. There is no other bulk material on the horizon that could replace concrete as the backbone for increasing demands in infrastructures. Despite several decades of studies, concrete bridges, highways, and infrastructures still significantly suffer from fracture, deterioration, and external chemical attacks (e.g., chlorides/sulfates) with maintenance costs that amount to multi-billion dollars annually. This project developed a new class of ultra-high performance, multifunctional hexagonal Boron Nitride (hBN)-concrete for various transportation and infrastructure applications. The core strategy lied in mixing ultra-thin exfoliated nanosheets of emerging two-dimensional (2D) materials (hBN), as small as a few atoms in thickness (Figure 1*a*) in the bulk cement and concrete. This project opens up up several new exciting opportunities to tailor the properties of these two disparate classes of materials (hBN and cement) at the nanoscale. The overarching goal was to study and identify the optimum experimental conditions and parameters for delivering maximum mechanical properties and durability in hBN/concrete while being economically and commercially viable.



(a) (b) (c)

Figure 1

Multifunctional hBN/concrete: (a) an atomistic image of a monolayer of hBN; (b) representative coupons of hBN/cement mortars; and (c) representative coupons of hBN/concrete.

Current Investigation

Conventional methods of mixing typical additives with cement and concrete are known, but the introduction of the emerging 2-D sheets with ultra-high surface area in cement and concrete is a challenge. Furthermore, creating such composites in a cost-effective way is another difficulty. Our technology includes a set of advanced syntheses followed by characterizations, standard tests, and pilot test studies to realize the proposed new design concepts. Researchers leveraged from the extensive body of knowledge developed over the past decade for two-dimensional materials and synthesizing hBN/cement and concrete composites in which the surface area, size, and thickness and the bonding agents of the hBN were controlled. This enabled significant improvement in mechanical and durability properties with only a very small fraction of hBN in the mix. The core strategy is based on using inexpensive feedstocks and applying simple and green procedures, by for example using sonochemical techniques—an excellent alternative to conventional chemical methods—to exfoliate the surface area of hBN as much as possible, followed by strategic functionalization for mixing with Portland cement chemistry. Following this synthesis protocol, the researchers have created several cement mortar and concrete samples undergoing the following tests.

***Strength, durability and pilot tests*:** Testing mechanical properties include mainly compressive strengths as this is the primary property of concrete. The sample prototypes fabricated have been tested for 3, 7, and 28 days with various weight percentages of nanomaterials obtained from different proprietaries synthesis strategies (Figure 1*b*-*c*). The current mechanical testing results demonstrate >70% improvement in compressive strength and > 100% improvement in tensile strength (Brazilian test) compared with the control sample, with only a very small fraction of treated hBN, which translates into a low-cost product. Similarly, the durability properties (measured via electrical resistivity, AASHTO TP 95-1) of the fabricated concrete cylinders exhibit ~>35% improvement compared with the control sample. Furthermore, the researchers characterized the microstructure, density, and porosity of the cement/concrete samples.

The researchers have held several discussions with the Texas Department of Transportation (DOT) to identify the best efficient ways to apply this technology in practice. To start with, the most appropriate pilot testing was agreed as a patch/repair job on a surface of a road or highway. However, given that Texas DOT typically opens the road to traffic within ~4-8 hours, fast curing was required to prepare the concrete mix. The researchers studied three of their best formula with varying wt% of hBN by addition of various wt% of accelerators (such as $CaCl_2$), and various curing temperatures to evaluate the performance and potential negative cross-effects of accelerators with their formula. The amount of accelerator did not exceed 2% wt% according to the ASTM D98. The mechanical strength of the cement cubes increased by 4 to 6 times within the first 8 hours at room temperature and increased by 2 to 3 times within the first 8 hours cured at 45 °C. Furthermore, more strict requirements by Texas DOT and extensive optimization of concrete mix samples led to a compressive strength of 1,800 psi in ~5 hours, making it readily available for the pilot testing and monitoring long-term durability (the logistics are pending finalization of Texas DOT). Such testing and results, along with further characterizations (ASR, freeze-thaw, abrasion, or scaling) facilitates strategies for product transfer.

Product Pay-Off Potential

This project will develop new types of cement and concrete materials with unique and advantageous mechanical properties such as high durability and high strength, which are extremely desirable for construction materials. For example, a concrete with higher strength and durability allows to "do more with less" for both initial construction as well as maintenance during the lifetime of the material. These innovative approaches have a significant impact on designing concrete highways, bridges, pavements and infrastructures with improved safety and sustainability, which entail economic growth in the United States. To illustrate the potential payoff of this project, consider the U.S. Interstate highways. According to reports, 60% of the 73,000-km of four lanes (3.7 m each lane) interstate highways in United States are paved with concrete that is 28 cm thick; thus ~400 Mt (million tons) of concrete is used in highways. Given the average lifetime of concrete highways is 30 years and assuming that at year 30, 10% of concrete highways are replaced and 90% employ overlay of 6 cm for repair, each year 400/30*0.1=1.3 Mt concrete is used for replacement and 400/30*0.9*(6/28) = 2.6 Mt is used for repair; thus, a total of 3.9 Mt concrete is used annually for maintenance. If the novel results of this research led to a 1.35X increase in concrete durability, only 74% (1/1.35) of the 3.9 Mt concrete will be needed for maintenance, hence a ~1 Mt saving in concrete production per year. This immediately translates into a ~$100 million/year cost savings in just the U.S. Interstate highways (assuming concrete to be $100/t). From an environmental standpoint, each ton of concrete produces about 0.12 ton of CO_2. Assuming the cost of carbon capture and sequestration to be $30/t, the aforesaid savings in concrete production translates into an additional ~$3.6 million/year cost savings. Note that there are also additional advantageous properties associated with hBN/concrete such as high strength and heat diffusion (which improves freeze-thaw behavior). Furthermore, one must also consider broader societal issues associated with concrete failure such as road accidents, environmental blight, public confidence, and reduction in future developments in transportation infrastructure, which could be avoided if our new concrete is used.

Product Transfer

C-Crete is currently in communications with suppliers, manufacturers, ready mix concrete producers and the U.S. Department of Transportation to deliver necessary practical considerations for technology transfer, ease of commercialization, market entry, cost-effectiveness, and commercialization regarding the state's concrete bridges and highways.

PROTOTYPE DEVELOPMENT FOR OBTAINING AUTOMATED TURNING MOVEMENT COUNTS FOR SHARED LANES

NCHRP-IDEA Project 198

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IDEA Concept and Product

The proposed innovation is a data collection and analysis system capable of producing turning movement counts for signalized intersections equipped with a radar-based vehicle detection system regardless of the lane configurations. No commercially available detection system (including radar-based systems) offers this feature as a standard "plug-and-play" solution. As part of an already completed NCHRP-IDEA Type 1 project, the feasibility of obtaining turning movement counts by analyzing the underlying trajectory information of radar-based vehicle detection systems, without any changes to the existing detection system, was demonstrated. As part of this Type 2 project, the research team worked with a commercialization partner to improve the previously developed data collection and analysis procedures and to create a prototype device capable of running an improved version of the algorithm and that serves as a data collection tool for transportation agencies.

Project Results

A review of the performance of the previously developed algorithm (generally over 90% accurate) and a side-by-side comparison of trajectory data and video from signalized intersections revealed that the best approach to improve the performance of the previously developed classification algorithm was to improve the accuracy of the underlying data. To improve the accuracy of the underlying data, a noise removal procedure was developed that achieves similar levels of accuracy by focusing on accurately representing the trajectories of vehicles that use the approach of an intersection.

The noise removal procedure developed keeps track of vehicles that enter the intersection and can take advantage of lane classification data enabled by capabilities added to the data collection system by the commercialization partner. Development of the noise removal procedure required a characterization of the typical noise found in vehicle trajectories data sets. Therefore, key results from the project involved a vehicle trajectory data characterization, a noise removal procedure, a simplified version of the trajectory classification algorithm, and a lane classification process. All procedures developed can be deployed on the prototype device shown in Figure 1, which implements a data analysis framework that relies on the JavaScript programming language and can be accessed by the user via a web browser.

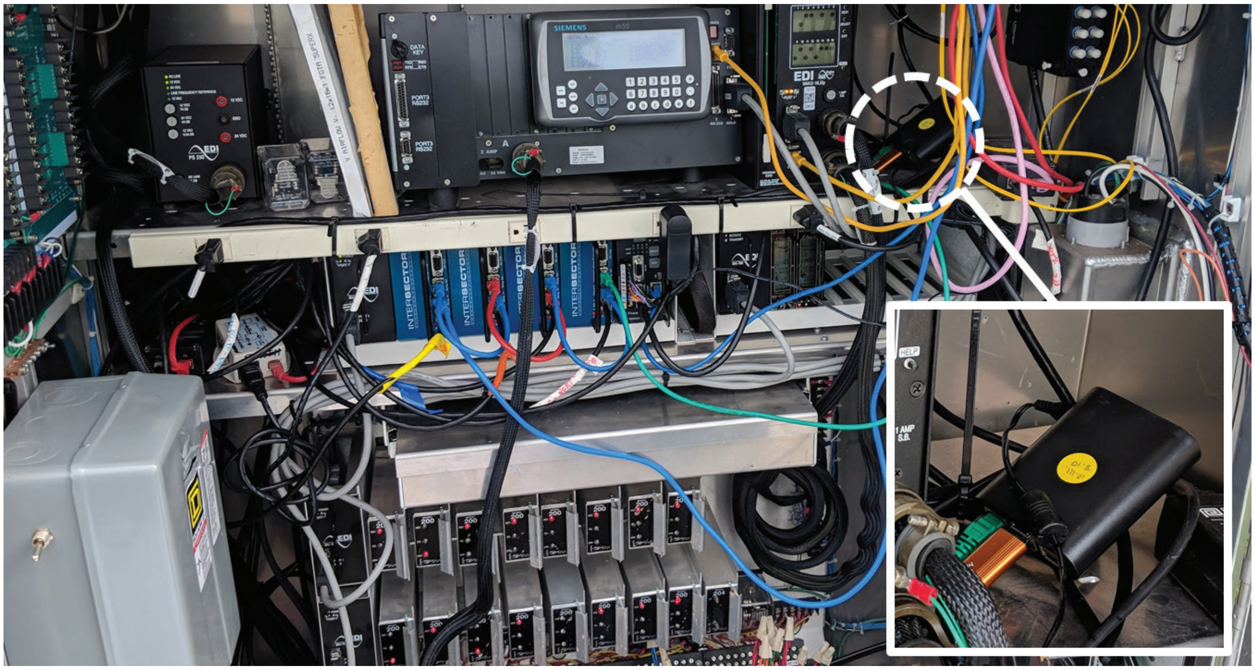

Figure 1

Deployment of a prototype data collection device at signalized intersections.

Product Pay-Off Potential

Even though numerous studies have demonstrated the enormous benefits of signal retiming, many agencies delay or are unable to perform signal retiming due to diminishing budgets and staff that limit the availability of necessary vehicle volume data. The immediate value of having continuously available comprehensive turning movement data is transforming every intersection equipped with a radar-based vehicle detection system into an automated traffic recorder regardless of lane configurations. Data produced will in turn enable transformative changes in the way traffic signal retiming is approached. Furthermore, numerous future applications in the transportation operations, planning, and safety domains are foreseeable thanks to the JavaScript-based data analysis framework embedded in the prototype device shown in Figure 1.

Product Transfer

Just in the United States alone, several thousand radar-based vehicle detection systems capable of producing the necessary trajectory data are currently in use at signalized intersections. The number is expected to grow because research has shown that radar-based vehicle detection systems have superior performance when compared with other nonintrusive detection systems. As a result, a market exists for the proposed data collection and analysis system. The proposed data collection system can be sold as an add-on to existing intersections. An initial version of a data collection system capable of implementing algorithms to obtain performance measures from signalized intersections has been commercialized by the commercialization partner. Having the data collection system commercialized already implements key noise removal techniques developed, can support the new analysis procedures, and serves as a platform for future analysis procedures.

USING MEDICAL X-RAY MACHINES TO DETERMINE THE SERVICE LIFE OF CONCRETE

NCHRP-IDEA Project 199

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IDEA Concept and Product

The CHIP (**ch**ecking **i**on **p**enetration) is a practical, fast, safe, and inexpensive approach to determine the permeability and estimate the service life of concrete, mortar, or cementitious paste. This prototype was developed by adapting existing dental X-ray equipment and the use of tracers to observe fluid penetration. This required calibrating the X-ray equipment, creating an easy to use sample stage, developing standard procedures, and creating a computer algorithm to guide the operator and analyze the data. A photograph of the prototype is shown in Figure 1.

Figure 1

CHIP prototype.

Project Results

By working with a local dentist, the research team modified the settings on a dental X-ray machine and calibrated it to obtain equivalent measurements to the lab X-ray computed tomography (CT). Both the ion concentrations of the dental X-ray and the lab X-ray CT were measured throughout the sample depth and the comparison of these results showed equivalent measurements between the two X-ray measurements. This crucial step shows the dental X-ray machine can produce data equivalent to previously published methods. However, the results showed that there were many challenges in aligning the concrete samples, sample preparation, and data analysis of the images.

The prototype was designed and modified multiple times throughout the fabrication process. The end result produced an enclosed two chamber prototype with one containing an X-ray source mounted on a fixed platform and the other containing a lead-lined area for the sample, sample stage, and sensor. The safety steps behind the prototype include a lead-lined chamber to shield radiation, a door interlock to remove power to the X-ray tube if the door was not closed, and a light to indicate that the X-ray machine was energized. To help ensure a consistent image would be taken, a dynamic stage was produced to rapidly adjust the location of the sample and keep it at a constant position. This makes it simple to align the sample. A computer program was written to handle all data processing steps from the raw data acquisition to the final calculation of diffusion coefficients with minimal user intervention.

An example of the results is shown in Figure 2. The figure shows the location of a tracer in the samples from 1 to 28 days. The gray values from the X-ray images are used to find concentration by comparing with standards. A line profile is used to describe the change of the average ion concentrations at different depths from the surface. The concentration profiles can then be used to measure the rate of ion penetration. Each measurement takes only 2 seconds. The sample was removed between scans, and the machine can then be used for other applications. The data show that the method has great potential to be used on any material to determine the diffusion coefficient and then determine the service life of the concrete.

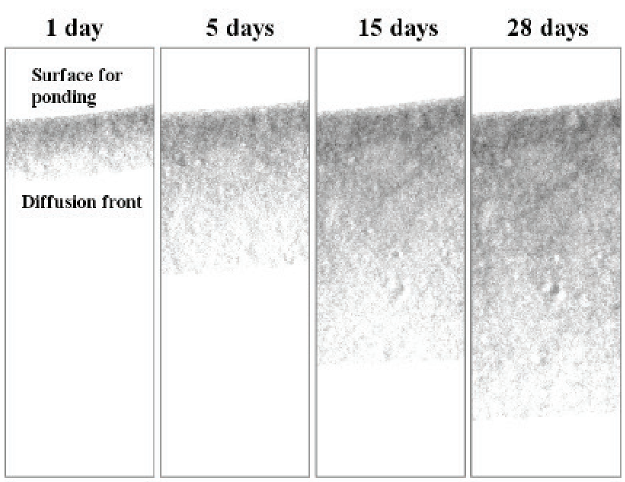

Figure 2

X-ray images of ions penetrating from 1 day to 28 days.

Product Pay-Off Potential

This research product has the potential to give DOTs an inexpensive and powerful tool to help them rapidly investigate the performance of their concrete infrastructure. Furthermore, this could be done while the work is being constructed and also investigate in-place infrastructure. This method could be used on cores taken from the field after the concrete has been placed, consolidated, or cured. This means that the measured values from the test would be representative of the actual in-place properties of the concrete. This would warn the owner if a problem was occurring during the construction process. In addition, the method could be used to compare the effectiveness of different repair materials or the use of surface sealers to prolong the service life of the concrete, allowing DOTs to know how the repair methods are performing and update the predicted service life of the concrete.

Product Transfer

The results from the testing have been shared with the FHWA mobile concrete lab, Oklahoma DOT, Minnesota DOT, and Illinois DOT. All of these partners are interested in providing additional case studies to evaluate the performance of the CHIP; however, it is not clear how these case studies will be performed because there is no more funding available for this work. For these case studies, the team would like to obtain samples from concrete during the mixture design, construction, and then after the placement and curing of the concrete. This would allow important insights into how these different processes change the permeability of the concrete. Also, the CHIP could be used on different repair methods and surface sealers to determine their effectiveness. This will be a great opportunity to show the potential for the CHIP and help the states above justify obtaining this equipment in the future.

RAPID REHABILITATION OF HIGHWAY SLOPES USING SEEDED MICROBIAL BIO-CEMENT

NCHRP-IDEA Project 200

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IDEA Concept and Product

Microbial induced calcite precipitation (MICP, i.e., microbial bio-cement) has been shown to mitigate wind erosion and control fugitive dust via surficial bio-mineralization. This IDEA concept is mitigating wind and water erosion of highway slopes using *Sporosarcina Pasteurii* microbes to induce MICP nio-mineralization. Of particular interest is the mitigation of wind and water erosion for highway side slopes after intense wildfires have denuded the slopes of critical erosion preventing organisms. While there is relatively little innovation in use of MICP bio-cement for mitigating erosion for short-term applications, the specific innovation here is to use a native grass and plant seeded MICP treatment. In cases of new slope construction or intense wildfire, the bare soil slope will require vegetation for long-term erosion control. Thus the innovation is a synthesis between MICP for short-term erosion protection, with vegetation for long-term protection. However, too much MICP application creates a low permeability crust that will slow infiltration and prevent seed sprouting. Thus the innovation is a balanced approach. As a bio-augmentation innovation, it is intended for applications where the soil biome has been badly depopulated. The current practice for mitigating highway slope erosion (including cases of intense wildfire) is to use either (1) a geosynthetic or straw mulch with seeding or (2) hydroseeding. The use of MICP bio-cement has advantage in that it can be used on a wide range of slope angles, around any obstructions, encourages long-term natural vegetation growth, and resists wind and water erosion until the natural vegetation develops.

Project Results

Stage 1 of the project consisted of laboratory testing of soil samples in the laboratory. Soils that have been burned by wildland fires have different chemistry, grain size distributions, and in some cases a hydrophobic layer. Figure 1 shows a scanning electron microscope (SEM) image of a near surface soil burned in a wildfire in the Black Hills of South Dakota. Figure 2 shows the SEM chemistry of the same soil. Compared to soil samples from a few meters away that were unburned, great changes have taken place in the soil structure and chemistry, most notably vitrification of peds and clods with significant clay content. Of particular note is an increase in calcium in the soil matrix. As MICP is a calcite reaction, available calcium is required. In Stage 1, laboratory tests of burned and unburned soils with and without seeding are being performed in controlled laboratory conditions. These specimens are then being testing for both water and wind erosion rates. Part of the testing is measuring the effect of the hydrophobic layer (if present) on the soil surface and how the MICP treatment solution infiltrates. Soil samples are being obtained from wildfires in the western United States after 100% containment and permission from the controlling fire agency. Seeds being used as part of the experimental program are standard department of transportation (DOT) native grass, flower, and shrub mixtures. Notable early findings from Stage 1 are (1) that MICP treatment changes the pH of the soil, which may or may not affect vegetation; (2) that MICP treatments contain large amounts of salts, which may or may not affect vegetation; (3) that MICP treat-

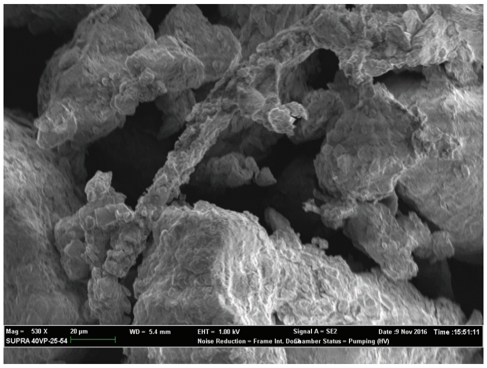

Figure 1

Scanning electron microscope (SEM) image of burned soil.

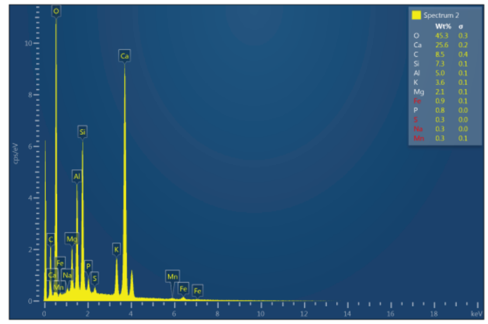

Figure 2

SEM chemistry analysis of burned soil.

ments contain high amounts of nitrogen which greatly affect vegetation; and (4) that seedling germination and seedling growth are encouraged by the introduced microbes. Thus, a seeded MICP approach may or may not be successful depending on the specific plants being applied or nearby.

In Stage 2 of this project, a small scale field study was performed on new construction soils and forest fire burn areas local to Rapid City, South Dakota. Small scale test areas of 20 square meters had the optimal seed and MICP treatments from Stage 1 applied to confirm outdoor growth and field erosion resistance. Locations on department of transportation highway side slopes and right-of-ways within the Black Hills of South Dakota were tested in Stage 2 small-scale field testing. Upscaling the process to large-scale field application is being investigated in Stage 2. As part of Stage 2, a preliminary investigation into the environmental impacts of seeded MICP treatment will be performed.

Product Pay-Off Potential

The use of MICP bio-cement has an advantage in that it can be used by highway departments on a wide range of highway slope angles or geometries over long distances, around any obstructions, encourages long-term natural vegetation growth, and resists wind and water erosion until the natural vegetation develops. This innovation is intended for areas where fire or construction has largely denuded the soil biome. It is economically feasible as the main solution components are urea and soy nutrient broth. Both are readily available. The main costs associated are in the volume of treatment material required for large areas and upscaling the microbial culture process from laboratory to industrial scales. The limitations are highly clayey soils with little to no ash layer where infiltration is very slow and the solution is more likely to run-off and the number of tanks of growth solution needed for treating large areas. The product can be applied via airplane, helicopter, and tanker truck with conventional equipment in a seeding phase and a treating phase. Due to the extreme consequences to highways and waterways from rapid erosion of burned soils or denuded soils, the pay-off of the product is significant.

Product Transfer

The customer base for MICP bio-cement wind and water erosion mitigation of highway slopes features government agencies that own or operate wildlands that may be subject to wildfires or own or operate highways through these wildlands: federal agencies (National Parks Service, Western Federal Lands, Forest Service, Bureau of Land Management, and Bureau of Indian Affairs); state highway departments; state parks agencies; and county highway departments. Customer base extends globally to road agencies and forestry managers who have similar problems with wildland fires along roadways. It is also plausible that the customer base for the technology extends to farmers who have wind and water erosion issues after wild fires in their crop or range lands in which a seeded application would be attractive to rapidly restart crop or grazing activities devastated by wildland fire. In order to transfer to practice, the innovation technology in this proposal must first be demonstrated in the laboratory (this study), on large field scale (IDEA Type 2 proposal follow-up), and then performed on a trial basis along several highways in the western United States.

DEVELOPMENT OF A NOVEL AERODYNAMIC SOLUTION TO MITIGATE LARGE VIBRATIONS IN TRAFFIC SIGNAL STRUCTURES

NCHRP-IDEA Project 201

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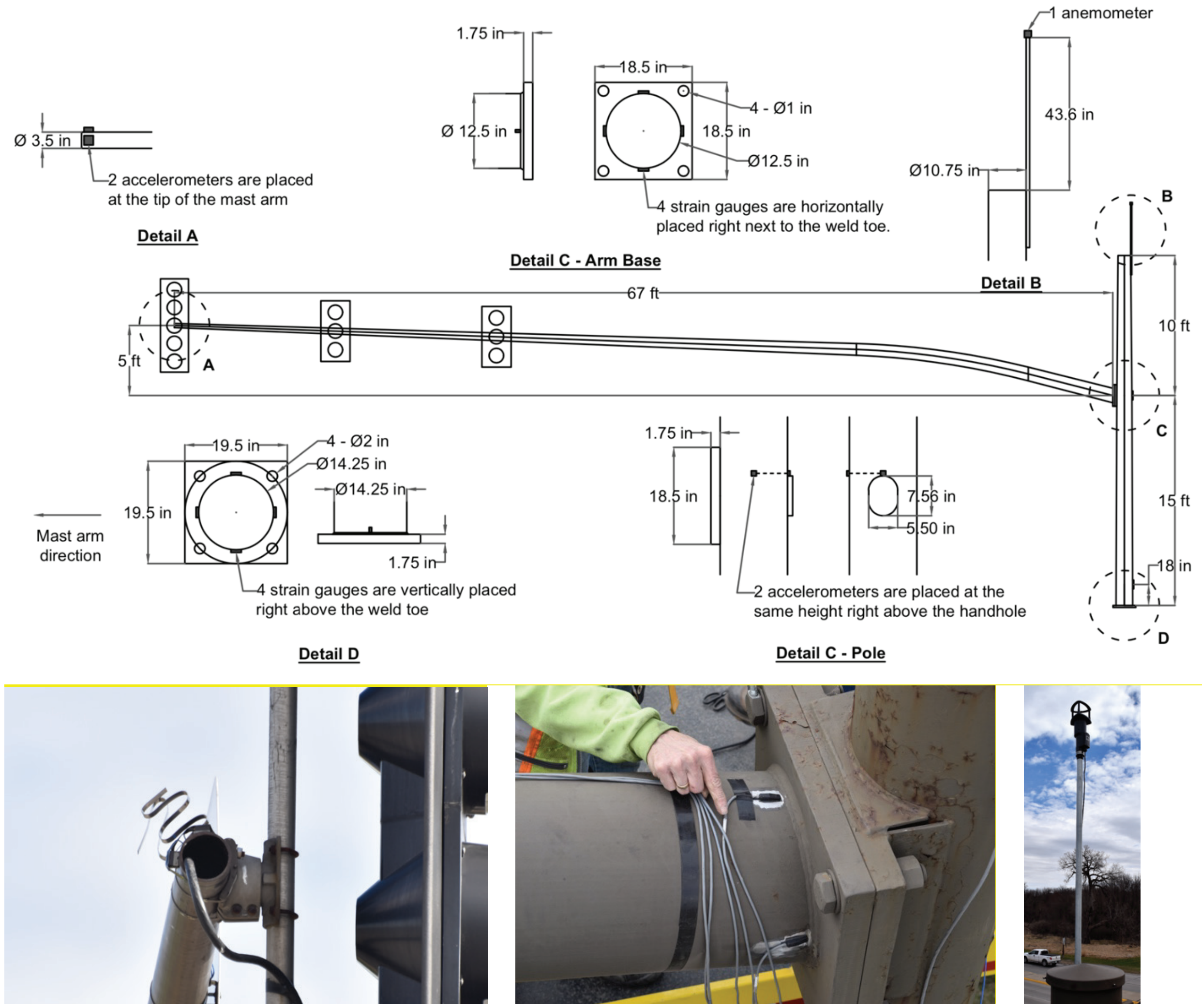
IDEA Concept and Product

The concept of this project is to consider the "aerodynamic damping" as an active means to mitigate the large amplitude vibrations of traffic signal structures. The proposed method is superior to the other common approaches, as it uses the inherent characteristics of the signal light to ensure that the positive aerodynamic damping is maximized during the gust events. It is unique in that it will not require specific tuning (like those required by mechanical damping devices) or implementation of the heavier fatigue-rated connections. The project takes a multi-faceted approach to address this issue. First, a set of wind tunnel tests conducted in the AABL Wind and Gust Tunnel, located in the Wind Simulation and Testing (WiST) Laboratory at Iowa State University, will verify the hypothesis that the current design of the signal light unit is not aerodynamically stable. The tests will identify the component(s) of the signal light unit that causes this instability. The ultimate goal of these tests is to suggest minor modifications to the signal light unit that will help to mitigate the large amplitude vibrations due to the aerodynamic instability (or galloping) and additionally attenuate the vibration from other types of aerodynamic phenomena. Second, a signal light will be instrumented and the vibration data will be used to validate a set of finite element analyses. The validated models will then be used to conduct sensitivity analysis on different structural/shape parameters that influence these vibrations.

Project Results

In order to precisely observe wind-induced vibration of the traffic signal structure, a traffic signal light in Ames, Iowa, has been selected to be instrumented. Figure 1*a*, *b*, and *c* shows the location of the accelerometer, strain gage, and anemometer. Accelerometers were placed at the tip of the mast arm and the pole-to-arm connection which measured the acceleration of the mast arm and pole in both in-plane and out-of-plane directions. Strain gauges were placed at locations with high stress level which are the base of the mast arm and the base of the pole. The vortex-shedding phenomenon has been observed in the monitoring data. Figure 2 shows the vortex-shedding phenomenon in the acceleration data at the tip of the mast arm under 11.25-mph mean wind speed and roughly stable wind direction normal to the mast arm,. The in-plane acceleration due to vortex shedding at this moment is as large as the out-of-plane acceleration.



(a) (b) (c)

Figure 1

Installation plan and sensors: (a) accelerometer, (b) strain gauge, and (c) anemometer.

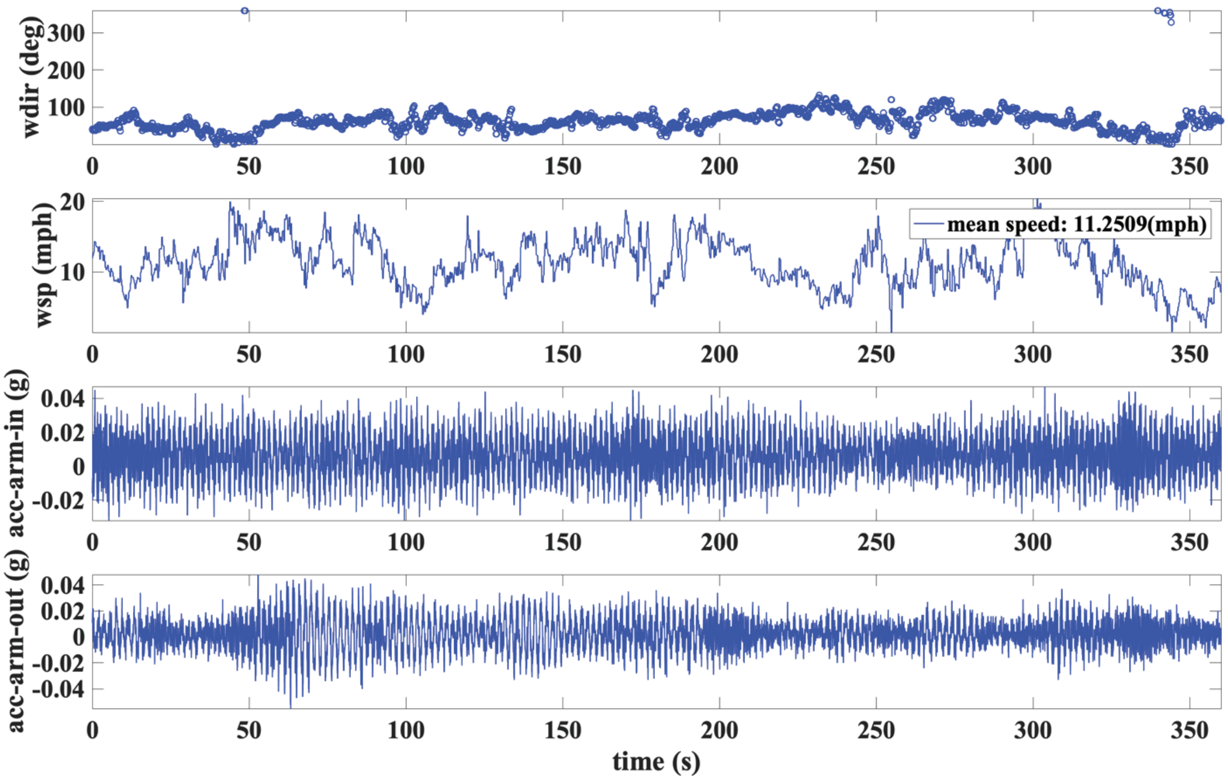


Figure 2

A period of the field data where vortex-shedding phenomenon has been observed.

After installing sensors on the structure, pluck tests have been conducted right away to identify the structure dynamic properties. Eight pluck tests proceeded by either pulling the mast arm tip in in-plane or out-of-plane directions and then releasing. Based on the acceleration data at the tip of the mast arm from pluck tests (Figure 3), a system identification method called Eigensystem Realization Algorithm (ERA) has been used to identify system frequencies and respective damping ratios (Table 1).

The aerodynamic coefficients have been determined through wind tunnel tests and the dynamic properties of a prototype structure have been identified by the pluck test data. Using these information, a precise analytical model for the selected traffic signal light has been built which will be used for the sensitivity analysis in the next stage.

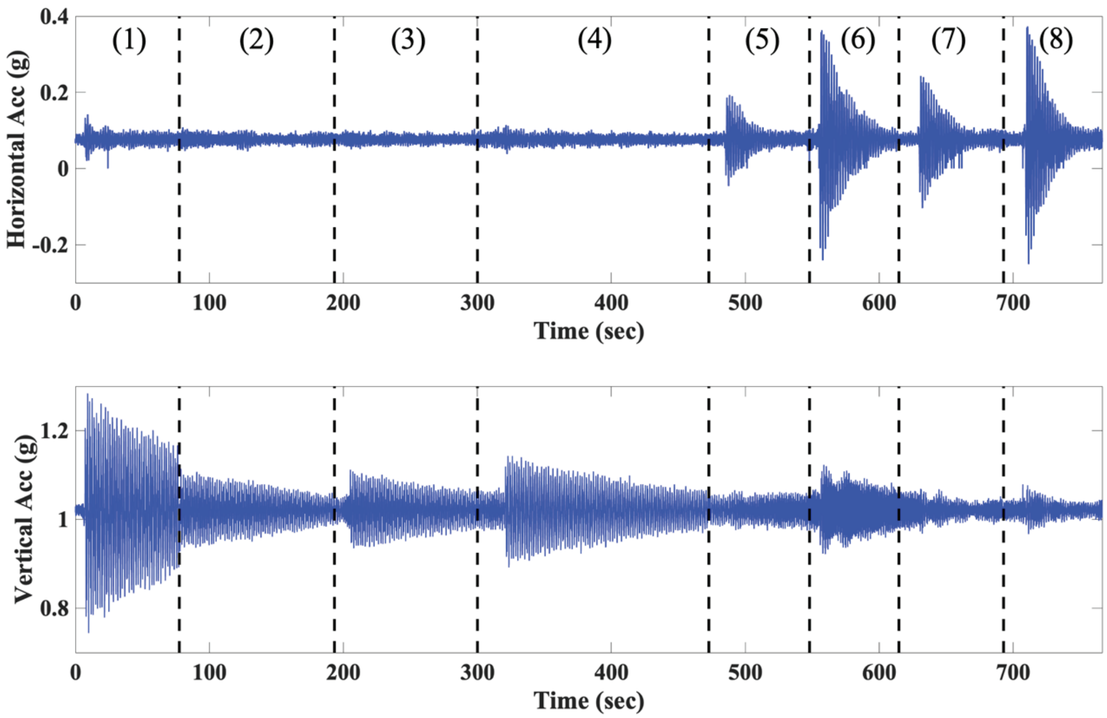


Figure 3

Acceleration data at the tip of the mast arm from 8 pluck tests.

Table 1
Identified system frequencies and respective damping ratios.

Mode	1st	2nd	3rd	4th
Frequency (Hz)	0.531	0.597	2.060	2.118
Damping ratio (%)	1.604	0.315	0.592	0.110

Product Pay-Off Potential

The implementation of the proposed dimensional characteristics in design of signals and signal structures is an excellent opportunity to address the long-standing issue of fatigue-related failures in these structures. The economic implication of this approach is huge, considering millions of these structures are maintained by cities and state DOTs. The implementation of the proposed strategy in design of the signals and signal structures will ensure longer life time for these structures while eliminating the costs associated with possible failures, the user costs imposed due to failures, and costs associated with the replacement. The proposed strategy is expected not to increase the fabrication costs of these structures. The proposed approach is expected to have a larger impact when the concept is extended to other traffic structures such as luminaires and structural support of signs.

Product Transfer

At the conclusion of the project, papers will be presented at the Transportation Research Board's Annual Meeting, the AASHTO SCOBS T-12 on Structural Support Signs and other relevant subcommittees, and in journals affiliated with the American Society of Civil Engineers and the American Association for Wind Engineering.

VERTICAL IMPEDANCE SCANNER FOR CONCRETE BRIDGE DECK ASSESSMENT WITHOUT DIRECT REBAR ATTACHMENT

NCHRP-IDEA Project 202

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IDEA Concept and Product

A high-priority need of state highway agencies is to assess the level of corrosion protection offered to reinforcing steel in concrete bridge decks, especially those bridge decks that have aging protection systems intended to prevent water and/or chloride ingress. Vertical electrical impedance measurements can provide this information but have been limited by slow rates of data collection and the absence of specifications governing data collection and interpretation. The specific objectives of this study were to (1) develop a multi-channel vertical electrical impedance scanner with a large-area electrode that eliminates a direct connection to the reinforcing steel and enables rapid data collection from a continuously moving platform at coverage rates exceeding 1500 ft^2/minute and (2) develop specifications for the use of the scanner, including guidelines for interpretation of collected data. Simultaneous collection of precise distance measurements enabled automated computer mapping of the results.

Project Results

The vertical electrical impedance scanner developed in this project was based on the concept shown in Figure 1. In Stage 1, a new multi-channel scanner with enhanced electronic circuitry was constructed to allow rapid vertical electrical impedance measurements in the field, as is also shown in Figure 1. Extensive numerical simulations of the projected electrode configurations were performed to inform the scanner design, and additional software was created to enable automated mapping of vertical electrical impedance data. This new multi-channel scanner was deployed in the field, with example results shown in Figure 2. Additionally, preliminary specifications for its use were developed. In Stage 2, extensive field testing was performed to develop final specifications for use of the scanner and interpretation of the data.

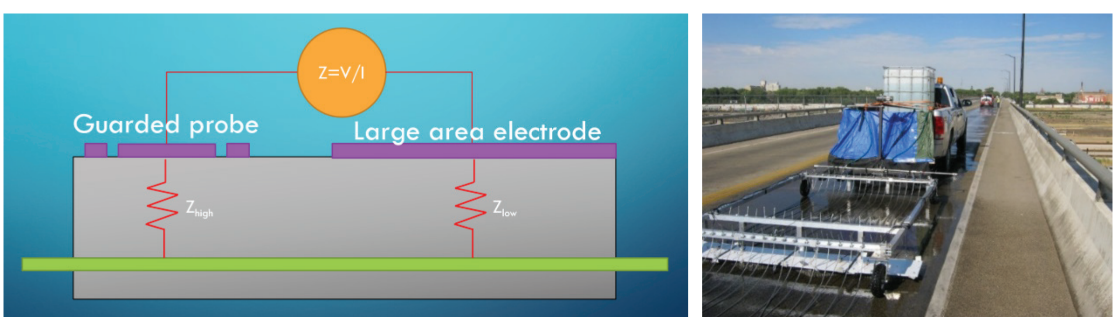

Figure 1

Concept illustration and constructed apparatus as the basis for the investigation: illustration of the concept of a large-area electrode to reduce impedance to the underlying steel reinforcement (left) and photograph of constructed apparatus being deployed in a field experiment (right).

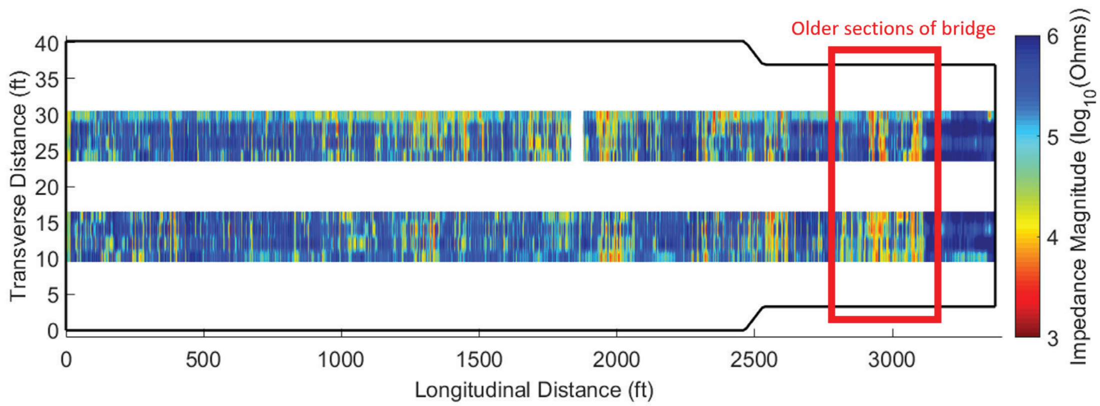

Figure 2

Impedance map generated from scanning across both lanes of a bridge deck in which older sections of the bridge displayed lower impedance, generally indicating that the condition of the deck had deteriorated more significantly in those areas.

Product Pay-Off Potential

Because vertical electrical impedance measurements directly assess the ability of protection systems to prevent the ingress of water and/or chlorides into concrete bridge decks, this research will result in an enhanced ability to quantitatively evaluate the effectiveness of a wide variety of bridge deck protection systems, from rebar coatings to bridge deck overlays. The ability to non-destructively evaluate the condition of concrete bridge deck protection systems will enable monitoring and timely repair or replacement of leaking systems even before visible deterioration is apparent. While vertical electrical impedance measurements may eventually be used at the network level of bridge deck management for selection of decks in need of repair, they have already proven useful at the project level for establishing more accurate scopes of work and verifying deck improvements. For example, measurements obtained before and after an overlay is installed can quantitatively assess the overlay quality. Overall, application of this technology is expected to benefit several aspects of bridge deck management and allow agencies to realize the cost savings associated with preventive maintenance of especially bridge deck protection systems.

Product Transfer

Earlier versions of this technology were deployed on several concrete bridge decks in Utah through cooperative agreements with the Utah Department of Transportation and a major bridge contractor. In particular, the results of the testing performed on several decks were used to inform engineering decisions about the rehabilitation strategy for those decks, and the conditions anticipated from testing were verified during the rehabilitation process. The current version of this technology was used during this project to test concrete bridge decks in both Utah and Nebraska. Because of its many technical merits and economic advantages, aspects of this technology have already been licensed to a company in Utah that will be offering commercial vertical electrical impedance testing services to state highway agencies and contractors in the future.

SAFERCUSHION

NCHRP-IDEA Project 203

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IDEA Concept and Product

This project will develop and test an automated, self-restoring crash cushion to help enhance safety of motoring public and workers on the highways while minimizing or eliminating maintenance and reducing life cycle costs (LLC). Crash cushions protect the motoring public at locations where space is limited. A vehicle must be brought to a safe stop from highway speeds in less than 20 feet. There are numerous devices on the market that already can meet this demand, but those devices vary in function as well as cost. Generally, an inexpensive device is sacrificial and must be replaced after each impact. In contrast, some devices initially are more expensive, but are cost-effective in maintenance and repairs following most impacts. Regardless, in either situation a maintenance crew must be on site to remove the destroyed terminal or repair the existing one. This can be very dangerous to the maintenance crew and can delay traffic due to lane closures. The SaferCushion will be the first automated crash cushion on the market, capable of mechanically resetting itself following a crash. When a vehicle hits the lead diaphragm, the diaphragm slides down a track and is attached to a nylon strap. This strap is wrapped several times around an axle, attached to two drums, and is resisted by a pair of band brakes installed around the drums. The drum will be attached to a motor that will spin the drum in the reverse direction, pulling the compressed device back to its original position. The SaferCushion will be outfitted with sensors that detect the position of the front of the device and send a signal to the motor to adjust as needed. Additional sensors will operate to ensure that the tension in the nylon strap meets a minimum threshold, and adjustments will be made as needed. These sensors will enhance the probability of a properly functioning crash cushion for every impact while reducing the exposure of maintenance crews to dangerous traffic conditions.

Project Results

The project has been under way for a year. It is not a recent one. Prior to the start of the project, the energy absorbing device (Figure 1) was designed and optimized for its diameter, material selection, and bearing design. Extraordinarily stiff Belleville washers were selected to apply the clamping force on the band brakes in a way that was adjustable and that wouldn't create an excess of oscillation in the brakes themselves.

Since the start of the project, a motor and winch has been selected that will provide enough horsepower to pull the compressed terminal back into position. A programmable controller has been designed to operate the winch system as well as incorporate linear actuators that will clamp and release the band breaks. It will also receive feedback from sensors installed on the structure of the SaferCushion to assist in positioning and periodically testing the apparatus.

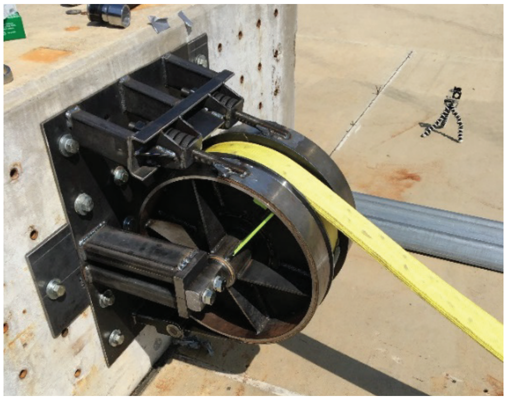

Figure 1

Prototype of energy absorbing device.

Finally, the structure design was altered from the previous description in this publication. The feet, which attach the diaphragms to the track, were gouging the track and causing a sudden cessation of the telescoping action. As such, a rounder design was created that offered more clearance and less direct contact between the feet and the track. A cross-sectional image of the foot is shown in Figure 2, along with the simulation results showing the proper hierarchy of material failure, which is such that the feet yield first, followed by the diaphragms, and concluded with the track. Ideally, the track will never need to be replaced. The model results show that the feet yield first, then the material in the diaphragm (show in varying degrees of green and light blue); however the track is completely dark blue, indicating no plastic deformation.

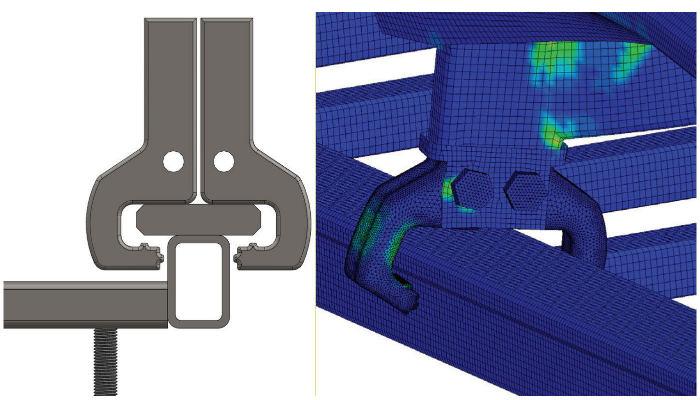

Figure 2

Foot and track design adhering to material failure hierarchy.

Product Pay-Off Potential

This project offers four significant potential benefits. First, maintenance crews would not be required as frequently as for other devices. Since they will not be in harm's way as often, the SaferCushion will reduce accidental maintenance crew deaths and injuries. Second, the self-resetting technology will reduce LLCs of the device by making it a truly reusable, low-maintenance design option. Third, the constant self-evaluation software will maximize the likelihood that when the SaferCushion is impacted, it will perform as intended, avoiding the catastrophe of an impact into an already compressed crash cushion. Finally, as part of the software developed to control the motor, the same software will be able to track the life cycle of the SaferCushion and send that information to the manufacturer and the owner of the device, providing the means to conduct continuous in-service-performance evaluation. In short, the SaferCushion will provide short-term gains in reduced fatalities and injuries as well as long-term gains in cost savings and design modifications.

Product Transfer

The SaferCushion will be tested to national crash test standards outlined in Manual for Assessing Safety Hardware. It will be licensed to a manufacturer, who will seek to have the SaferCushion added to every state's qualified products list. The customer base for the SaferCushion includes owners of private toll roads, owners of infrastructure (e.g., DOTs), and contractors. An advisory board has been selected by the project team and involves three state DOT representatives, one toll road company representative, and one private industry consultant, in addition to the TRB liaison.

BIOMIMETIC ANTIFREEZE POLYMERS: A NOVEL BIODEGRADABLE DEICING SALT ALTERNATIVE

NCHRP-IDEA Project 204

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IDEA Concept and Product

The objective of this work is to design, synthesize, and characterize biodegradable, biomimetic antifreeze polymers (BAPs) that mimic the behavior of antifreeze proteins (AFPs) naturally found in plants, fish, insects, and bacteria. The ultimate goal of this work is to reduce the economic and environmental costs of traditional surface-applied deicing salts in transportation applications. To achieve this objective, our proposed approach (see Figure 1) applies principles of synthetic chemistry to create low-lifecycle cost, non-toxic, biodegradable, water-soluble BAPs based on common biopolymers that exhibit hyperactive ice recrystallization inhibition (IRI) activity.

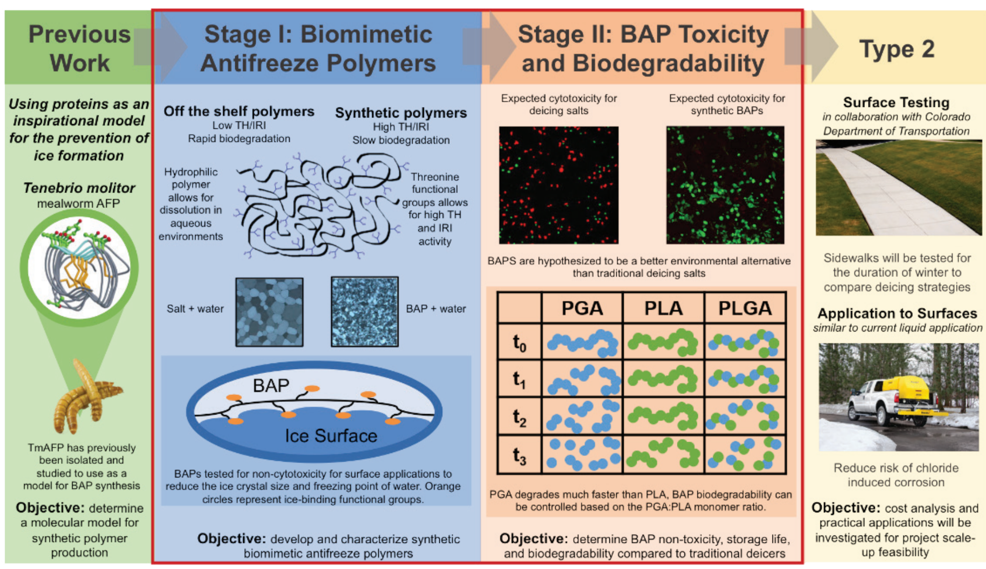

Figure 1

The proposed approach leverages the natural antifreeze behaviors of native AFPs produced by freeze-tolerant organisms, namely mealworms, for the synthesis of BAPs that exhibit hyperactive (>5°C) freezing-point depression of water while maintaining ~0°C melt temperatures (thermal hysteresis activity).

Project Results

The team has synthesized and characterized a polymer poly(2-hydroxy propyl methacrylamide) (pHPMA). Characterization included ice recrystallization inhibition (IRI) analysis, which yielded a synthetic material that exhibits IRI activity, a critical finding, since IRI activity indicates that the material interacts with ice. An off-the-shelf polymer [i.e., poly (vinyl alcohol)-graft-poly (ethylene glycol) copolymer (PEG-g-PVA)] was identified and tested for IRI activity. PEG-g-PVA displayed IRI activity, which has not previously been reported (see Figure 2*a* and *b*). Folic acid was identified as a small molecule with potential for having IRI activity. Analysis has shown that folic acid displays IRI activity.

Toxicity studies (live/dead) were completed for calcium chloride ($CaCl_2$), Bare Ground™Liquid Calcium Chloride Deicing Solution ($CaCl_2$ Deicing Solution), BareGround™Anti-Snow/De-icer (Liquid Deicing Solution), polyethylene glycol (PEG), polyvinyl alcohol (PVA), PVA-graft-PEG, p(HPMA), and folic acid. For these experiments, human derived lung (IMR-90) and human dermal fibroblast (HDFn) cell lines were used. An example of the results for the HDFn cell line can be found in Figure 2*c*.

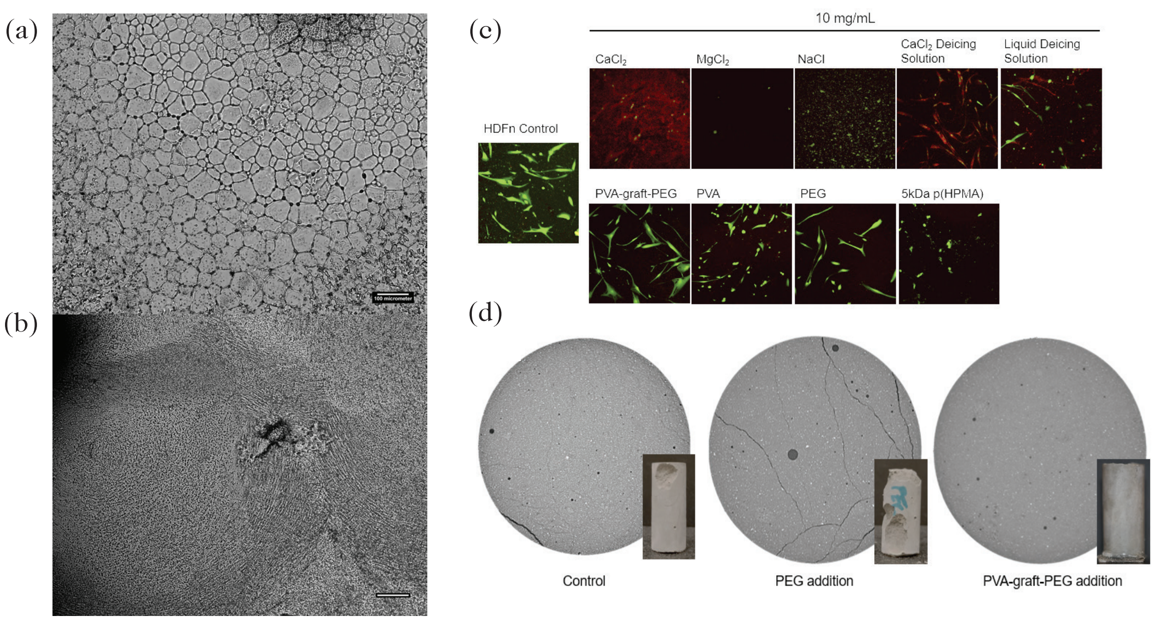

Figure 2

Off-the-shelf polymer: (a) micrograph of phosphate buffered saline (PBS) showing ice crystals with sizes of approximately 50 to 100 µm after 30 minutes of annealing at -4°C; and (b) micrograph of 0.5 mg/mL PVA-graft-PEG in PBS showing ice crystals with sizes of approximately 5 to 15 µm after 30 minutes of annealing at -4°C. Scale bars are 100 µm.(c) Results of live/dead study with human dermal fibroblast after exposure to solutions at 10 mg/mL. Red indicates dead cells and green indicates live cells. (d) Post freeze-thaw MXCT 2D cross-sectional images of control, PEG at 0.021 wt.% of cement addition, and PVA-graft-PEG at 0.021 wt.% of cement addition. Inset images show bulk samples post freeze-thaw. MXCT cross-sections are 9 mm in diameter. Bulk samples are 16 mm in diameter by 32 mm in height.

$CaCl_2$ salt caused the most IMR-90 cell death, evidenced by low cell counts and primarily red cells. The deicing solution and polymeric candidates show primarily live cells with some evidence of dead cells at the 10 mg mL^{-1} solution. At 1 mg mL^{-1}, all solutions appear non-toxic to human derived lung cells. These results indicate that proposed polymeric technologies have toxicity to human derived lung cells as well or better than deicing solutions and better than $CaCl_2$ salt.

PEG, PVA, and PEG-graft-PVA show primarily live HDFn cells at both the 50 mg mL^{-1} and 10 mg mL^{-1} solutions. p(HPMA) shows primarily dead cells at 50 mg mL^{-1} but primarily live cells at 10 mg mL^{-1}. The liquid deicing solution showed some live cells at both concentrations, which is likely due to it containing agriculture by products (in addition to $MgCl_2$). The $CaCl_2$ deicing solution shows primarily dead cells at both 50 mg mL^{-1} and 10 mg mL^{-1}. Of the three salts tested, $MgCl_2$ was the least toxic but all three were toxic at 50 mg mL^{-1}. These results indicate that proposed polymeric technologies have toxicity to human dermal cells as well or better than deicing solutions and better than $CaCl_2$, $MgCl_2$, and NaCl salts.

Degradation of three (3) polymers (PEG, PVA, PEG-graft-PVA) was studied under the presence of local river water (RW), taken from Boulder, CO. Polymers were loaded at a concentration of 20 mg/ml into RW and allowed to stir at ambient temperature over the course of 16 weeks. 200 µl aliquots of polymer-RW samples were removed at predetermined time points (1 day, 2 days, 1 week, 2 weeks, 3 weeks, 6 weeks, 8 weeks, 14 weeks, and 16 weeks) and immediately frozen at –20 °C to halt degradation until analysis could be performed. The molecular weight and polydispersity of the polymers were determined by using size-exclusion chromatography (SEC). PEG and PEG-PVA polymers are exhibiting some level of degradation, albeit slowly, after 16 weeks. This degradation is attributed to the oxide linkage in PEG that is more susceptible to aqueous degradation.

Deicing solutions and deicing salts are known to permeate concrete after their application. With this in my mind, the team investigated the ability of poly(vinyl alcohol)-poly(ethylene glycol) graft copolymer (PVA-graft-PEG) to enhance the freeze-thaw resistance of ordinary portland cement (OPC) paste. Cement paste samples (32 mm in height and 16 mm in diameter) at a water to cement ratio of 0.42 were prepared with an addition of PVA-graft-PEG and PEG at 0.010% and 0.021% wt.% of cement. These additions correspond to 0.25 mg/mL and 0.5 mg/mL PVA-graft-PEG and PEG in water which were previously tested for IRI activity (PEG has no IRI activity and acts as a negative control). After 14 days of curing at 100% relative humidity, the samples (including a 0.42 w/c control sample with no polymer addition) were subjected to cyclic freezing and thawing conditions. All samples containing an addition of PVA-graft-PEG at 0.021 wt.% of cement showed no damage due freeze-thaw cycling. Damage was assessed visually (scaling and spalling) and by identification of internal cracks with micro X-ray computed tomography (MXCT). Figure 2*d* shows both bulk sample and a representative MXCT 2D cross-section image of the control, PEG at 0.021 wt.% of cement, and PVA-graft-PEG at 0.021 wt.% of cement.

Product Pay-Off Potential

For 100 years, the practice of using salt (i.e., NaCl, $MgCl_2$) to depress the freezing point of water to improve the safety of vehicular traffic on roadways has remained virtually unchanged. A major drawback of deicing salt application is chloride-induced corrosion of steel and premature material failure in reinforced concrete. Of notable importance, deicing salts offer an initially cheap solution for transportation-related applications ($900/lane-mile) to reduce collisions on icy roads; however, the annual economic costs associated with chloride-induced corrosion exceeds $3400/lane-mile, a total annual cost for the United States of $29.7 billion. Estimated annual environmental costs of deicing salts are an additional $2,300/lane-mile, bringing the total annual cost of deicing salts to more than $54 billion annually. In summary, although the immediate price of salt is low, the long-term economic and environmental cost is incredibly high. Thus, a novel, economically feasible salt alternative is needed to provide similar performance at lower lifecycle economic and environmental cost.

Product Transfer

The project team aims to leverage this proof-of-concept material technology development project and our relationship with the University of Colorado Boulder's Technology Transfer Office (TTO) to initiate commercialization efforts and to cultivate strong collaborations with local government and industry. The principal investigator, who has previous commercialization experience for novel infrastructure material technologies, will implement a detailed commercialization plan that involves (a) public disclosure of invention(s); (b) submission of provisional and non-provisional patent applications; (c) establishment of collaborative partnerships with the City of Boulder and the Colorado Department of Transportation for future pilot demonstrations; and (d) facilitation of non-disclosure agreements (NDAs) with interested industry partners.

MRI BRIDGE ANALYSIS AND MULTI-MODAL IMAGING USING OPTIMAL MULTI-COIL RESONANT COUPLING

NCHRP-IDEA Project 205

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IDEA Concept and Product

Current non-destructive techniques can accurately and discreetly identify sub-surface defects down to a depth of 2 cm, which severely limits possible deep evaluation of bridge damage, accurate bridge analysis and ratings, and the reliability of the retrofit design / preservation program. To address this limitation of the current technology, this IDEA project will develop and test a multi-modal integrated technology in which LiDAR will be utilized to detect possible surface damage (first pass) followed by magnetic resonance imaging (MRI) using non-destructive optimal Radio Frequency Inductive Testing (RFIT) to detect and discretely locate deep defects/damage in concrete bridge components. The multi-coil facet of this project serves to supplement RFIT using 'metamaterial' coils to control impedance, thus maximizing penetration depth to resolutely and discretely dial-in defects. Metamaterials contain unique electromagnetic properties, such as negative refraction, that are not available naturally, to enhance magnetic inductance (permeability) *and* permittivity (dielectric property), making the latter negative and allowing transmitter signals to re-focus, like the sun's rays through a magnifying glass, to make RFIT into a "perfect lens." This was expected to greatly enhance resolution at large penetration-depth and allow the team to provide apt recommendations on improving Bridge Ratings. After reaching a stand-still with RFIT, finding it unable to discretely detect "materials" beyond a 7 in. depth, efforts adjusted to utilizing helical-shaped round-wire coils, representing the lower frequency inductor coil. However, after increasing coil frequency via larger coil diameter, the multi-coil dummy architecture and exploration of metamaterial slabs resulted in similar incidental benefit with, and minimal increase in, penetration depth. As a result, an alternate approach using an acoustic tomography approach shows preliminary promise as identification of discrete defects at larger depths is already enhanced in 24-in deep concrete sections. This effort is in cooperation with the University of Illinois at Chicago (UIC).

Project Results

The reaction of different materials in electromagnetic fields is different, and therefore power (or voltage) differences of the radio-frequency (RF) electromagnetic (EM) waves propagating in different media will be measured to distinguish geometric shape (outline, width, and depth) of different samples, discretely identifying deep subsurface defects. Similarly, different materials may affect the distribution of electromagnetic wave in space. Upon reaching reinforcing rebar, or even air, in concrete, the EM media can change from pure concrete to concrete with rebar and/or air‡. The materials comprise parts of the new media, validating that detection of those new media can affect EM propagation. Under different frequency of EM fields, the materials engender different values of dielectric constant and permittivity. Consequently, even the same media will have different reflectivity and absorption for different frequency's EM waves. However, in this experiment, different frequency's EM waves should detect different depths of the materials.

The experimental environment consisted of inductive coils, Agilent 33250A waveform generator, Agilent MSO-X 3024A mixed signal oscilloscope, Hp 4396B network analyzer and concrete blocks with XPS foam and steel. Inductive coils consisted of transmitter coil and receiver coil. The coils were scanned over the concrete blocks shown in Figure 1 (measuring into the concrete depth), moving the measuring coil up, down, left and right, with a movement step of 0.5 cm measuring in the vertical direction.

In an effort to improve the penetration depth of samples shown in Figure 1, helical-shaped round-wire coils were used as the lower frequency inductor coil. It was presumed that if the winding pitch of the coil increased, capacitance would decrease and result in higher *Q*-factor, netting larger penetration depth. A prototype steel-core coil (18 AWG magnetic wire) connected with a capacitor to form an RLC circuit (sensor) elicited a combination of resistance, inductance, and capacitance. As a result, the tuned frequency expectedly increased, enabling frequency changes to accommodate different ranges of different materials being tested. In theory, the test results, basically a rendition of what a metamaterial slab would also produce, would provide a stronger micro-magnetic field and consequently discern between concrete, air (voids), and rebar at larger depths. The results are compared with an air-core coil, shown in Figures 2 and 3, and that includes a primary coil, dummy coil, and receiver coil. Although a lower inductance was elicited, a *Q*-factor of 3,000 and operation frequency 9 M Hz made this set-up substantially more stable and with a stronger magnetic field, where its high sensitivity would potentially penetrate significantly deeper than that produced via the steel core inductor coil. If the frequency from signal data was “close enough” to the “natural” frequency produced by the RLC circuit, the voltage could increase, more aptly discerning different subsurface “materials.” Using an input signal of 4 $V_{P\text{-}P}$ (peak-to-peak voltage) and a testing frequency ranging between 350 and 450 MHz, in which 400 MHz is the standard operation frequency, Table 1 summarizes the different materials inside the concrete specimens. In identifying voids (“air”), the voltage ($V_{p\text{-}p}$) output is 25 V; however, in small, medium, and large depth concrete sections, the measured voltage changed due to the presence of different materials; also, the low voltage (25 V) in the deeper concrete specimens indicated that the magnetic field was blocked by the large concrete volume. Therefore, because efforts again stalled in increasing the magnetic field, *Q*-factor, and penetration depth, an alternative approach was investigated in collaboration with UIC.

Figure 1

Typical measured values using three sample blocks (concrete with foam, concrete with steel, and pure concrete), where input signal sent from transmitter coils is 20 V peak-to-peak sine wave, frequency sweep from 9.8 MHz to 15.6 MHz.

Figure 2

Air inductor coil.

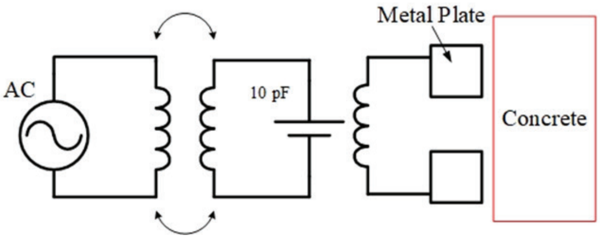

Figure 3

Concept of RLC circuit with concrete, signal generator, and oscilloscope.

Table 1
Examples of Applications of Acoustic/Ultrasonic Tomography in Concrete.

Applications	Application wave/ frequency (kHz)	Materials
Internal cracks	100 kHz	Concrete
Concrete deterioration	50 kHz, 100 kHz, 130 kHz	Concrete
Artifical void	60 kHz, 45 kHz	Concrete
Artificial inclusion: foamed -styrene disc	Rayleigh wave/45 kHz	Concrete
Artificial inclusion: honeycomb of 300 mm diameter	10 kHz, 25 kHz	Concrete
Surface crack	60 kHz	Concrete

The dummy coil architecture and series capacitor connected to the transmitter coil failed to create the necessary resonance to strengthen the magnetic field, resulting in minimal improvement in penetration depth, only increasing by 2 to 3 mm. Similarly, the use of novel metamaterial slabs was abandoned because minimal improvement was elicited via multi-coil setup, believed to again provide little distinction between foam (air) and concrete and little increase in penetration depth (as validated by the multi-coil/dummy coil design). The unimproved results were further validated even after tuning the operating frequency to the exact defect depth information through the use of new and larger coil size designs and implementation of a coil driver system. As a result of exhausting efforts of using a metamaterial/RFIT multi-coil approach, with very limited success, effort was shifted to using an acoustic tomography method, which is based on mapping internal structures by reconstructing the propagating high frequency waves in solid mediums. Preliminary results show that a formulated ray-tracing algorithm, based on reconstructing rays of ultrasonic wave velocity, may be a feasible solution in concrete acoustic tomography. Table 1 shows some application examples of the ray-trace method.

In this light and in collaboration with the University of Illinois at Chicago (UIC), the same two concrete blocks, each 24-in. deep and previously used in the multi-coil/dummy coil architecture approach, eight sensors were placed on each side of the blocks, where ray paths connected one side of transmitters to the opposite side of receivers. Although low frequency was used, the effective property of the ray-traveled medium was obtained, providing good indications of the location of the internal damage or inclusions ("foam"). The results were far more superior, in terms of clarity and consistency, to those obtained by the RFIT approach with dummy coils or metamaterial slabs. See Figure 4.

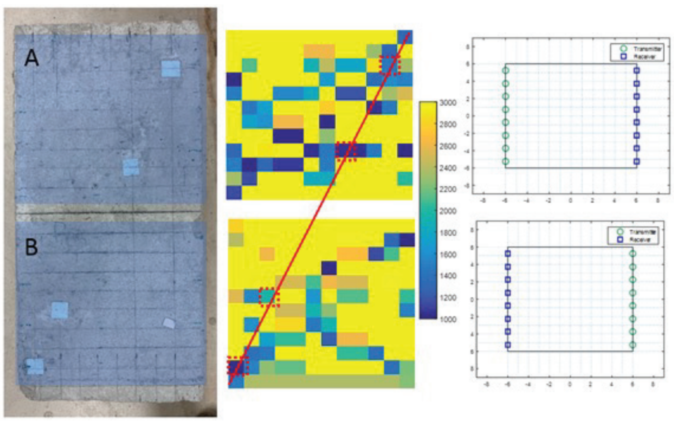

Figure 4

Preliminary ultrasonic tomography results.

After the preliminary success as noted above, the next step, as part of an acoustic tomography approach to discretely detect subsurface defects at large penetration depths, is to develop numerical models to select correct frequency and sensor array, increase the excitation frequency until the ultrasonic wave penetrates through the entire concrete depth, and study waveform-based imaging method. Additionally, the results have been discussed with the project's industry partner, Thornton Tomasetti (TT), who believes that the acoustic tomography approach should help to dramatically increase penetration depth and improve detection of deep subsurface defects, as well as provide conducive data for TT's proprietary electronic magnetic software (EMFlex) and structural finite element software (NLFlex).

The plan moving forward is outlined in the five tasks that follow.

1. The co-PI at UIC (Dr. Didem Ozevin) will receive one damaged retrofitted specimen from the PI, retrofitted per a cost-value function using the unique x-HMC composite, and one undamaged specimen. Each concrete specimen will be 2.5 feet to 3 feet deep.

    a. UIC will calibrate ultrasonic tomography for detecting inclusions inside concrete with 25 mm size at depth of 0.25 in. up to 24 in. The research has an experimental component using the samples provided by UAB, numerical validation, image improvement, and possibly field testing if Illinois DOT agrees to provide access to a concrete bridge near Chicago.
    b. Experimental Component: Selection of ultrasonic frequency and number of sensors plays a significant role in image resolution. We will test two sets of sensors, near frequencies 60 kHz and 150 kHz to be placed in an array for mapping internal microstructures. The number of sensors in the array will be gradually increased until the target resolution is achieved.

2. The undamaged specimen will be used to establish a baseline for sub-surface damage using an acoustic tomography approach.

    a. Modeling Component: Samples utilized in Task 1 will be modeled to validate the experimental results. COMSOL multi-physics software will be used. The model will mimic details of the experiment (e.g., geometry, inclusions, sensor positions, or frequency), and design parameters (e.g., frequencies) of the set-up shall be optimized. Once the model is validated, realistic concrete samples will be modeled to demonstrate the minimum detectable inclusion in thicker concrete and to validate the optimal design model. The influence of reinforcement to image resolution will be studied numerically.

3. Damage in the retrofitted specimen, that is, in the thin hardened skin and into the concrete, will be detected, and the parameters of the acoustic tomography approach will be optimized.

    a. Image Improvement Component: The ray-path and frequency selection are usually determined with the experimental scheme. Once the testing setup is finalized, the selection of effective ray-path and image post-processing are the only options to improve tomography. We currently use the ray-tracing algorithm, which assumes a straight path between the transmitter and receiver. The ray-tracing algorithm is common in solid systems because it can dramatically reduce the computational cost and increase the efficiency without compromising much accuracy in honing the target resolution in a given application. However, if the target resolution is not achieved by the ray-tracing algorithm, we will introduce and utilize a waveform-based imaging method, adapted from biomedical imaging. The waveform-based algorithm starts with solving the fundamental wave equation, which is widely adapted in the medical field because of its high resolution and accuracy.

    b Field Testing Component: We will contact Illinois DOT regarding the possibility of applying and validating our concept in the field using state concrete bridges.

4. We will also attempt to build and test a new undamaged specimen (3.5 feet deep), followed by a retrofit and subsequent re-test in order to substantiate the cost value in performing the retrofit procedure. This may validate the long-term sustainable properties of the retrofit plan.

5. We will report our findings back to the DOT and set up a workshop to discuss the results and implementation strategies of the detection approach and the retrofit strategy

A finite element model of the large-scale concrete girders has been developed that will be tested (4-point bending test), incurring incremental damage (due to internal defects, including pitting corrosion) and using an optimal ultrasound system to scan and detect the progression of the mechanical damage.

A COMSOL simulation package will be developed to design the coil and a comparison made to the experimental results. The scanning results (defects) will be transferred via TT's FLEX software to a damage-based finite element model, previously created and in conjunction with Light Ranging and Detection (LIDAR) results.

Product Pay-Off Potential

This project will provide recommendations on possible implementation to local state and federal officials on the long-term prognosis effects of the evaluated/analyzed sub-surface damages detected in bridges. A cost-effective preservation or retrofit plan will be developed in conjunction with initial bridge ratings, predicated on HMC composite design and Cost-Value function.

Product Transfer

This project will include two hands-on workshops (coordinated by AGC/Alabama DOT/ Illinois DOT and TT/ AECOM) for teaching potential end users about the recommended guidelines for evaluating deep subsurface defects. In addition, it will be suggested to DOT officials that a "live-bridge" demonstration be provided to potential end users of the ultrasound technology if the research is successful.

RULE-BASED AUTOMATED SAFETY MONITORING SYSTEM FOR WORK ZONE SAFETY

NCHRP-IDEA Project 206

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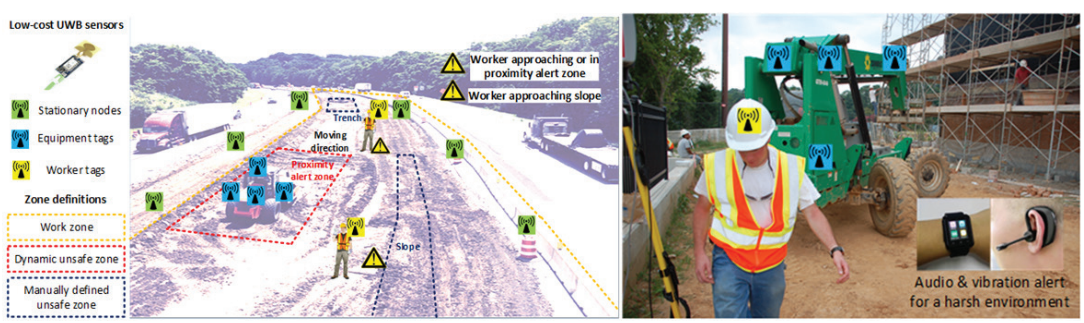
IDEA Concept and Product

Due to the complex and changing work zone environment, it is difficult to recognize unsafe conditions that can potentially lead to fatalities or injuries. Utilizing various location tracking sensors, automated safety monitoring is considered one of the most promising solutions that allow continuous and accurate monitoring of work zones. However, commercially available sensing tools and recent research studies focus mainly on acquiring real-time locations without deriving meaningful information from it. This project develops a rule-based work zone safety monitoring system that enables a systematic and immediate interpretation of the location data. Two concepts are introduced to allow timely detection and prevention of safety hazards: (1) rule-based approach for real-time data interpretation; and (2) customization of new generation ultra-wide band (UWB) sensing. Completion of this project will lead to the development of tools supporting a new approach of monitoring highway work zone safety. Figure 1*a* shows an overview of the system when UWB sensors are deployed. Locations of all the objects with UWB tags (worker tags and equipment tags) will be calculated based on known locations of stationary UWB tags. Static unsafe zones (e.g., trench, slope, or outside the work zone) are registered by an onsite safety manager, and dynamic zones are created around moving equipment. Predefined rules automatically adjust parameters for hazard detection depending on the characteristics of related activities, status of equipment, and workers. The research team will integrate audio and vibration alerting tools into the prototype system. These devices will be worn by workers and operators to give alerts as shown in Figure 1*b*.



(a) (b)

Figure 1

Automated safety monitoring system: (a) overview of the safety monitoring system and (b) wearable devices for real-time warning.

Planned Investigation

The project is being conducted in two research stages. Current Stage 1 focused on developing core functions of the proposed automated safety monitoring system. A real-time location viewer was developed and integrated with UWB sensors implementing two-way ranging (TWR) and time difference of arrival (TDOA) protocols. The maximum error of the two types of UWB sensing was 20 cm when it was tested in a controlled environment of 50 m x 50 m. For the development of a rule-based software program, past studies, safety regulations, and the result of in-depth interviews were organized as a list of safety hazards that can be effectively monitored by a location-based system. The literature review and interviews with construction safety experts selected "entrance to no-go zone," "runover/backover by a moving equipment," and "crane-related hazards" as the safety hazards that will be monitored by location sensors. During Stage 1 research, additional capabilities were developed in both TWR and TDOA UWB tracking systems to increase robustness in congested and dynamic work zones. The capabilities include algorithms for automated processing of signal blocking by heavy equipment as well as for differentiating between direct and reflected signals. However, field tests in dynamic construction environment with vehicles (Figure 2) identified critical limitations (such as insufficient location data points and inaccurate tracking of vehicles) of commercially available UWB tools that led to a new design of the Radino UWB TDOA system overcoming the limitations to be developed in Stage 2. The real-time location viewer is under further development into a rule-based software program that applies the predefined rules to analyze location data.

Stage 2 develops the Radino UWB TDOA designed system based on lessons learned from Stage 1 and tests an integrated safety monitoring system comprising all the core functions. The system will be deployed in a cloud-based platform and tested in two controlled environments and two real construction projects. We will evaluate the system in terms of accuracy and reliability, and we will use other indirect measures (such as time, cost, required system infrastructure, and flexibility) to thoroughly assess the system's real-world feasibility. We will conduct interviews with state DOT and industry partners to assess the system's usefulness and effectiveness in real world situations.

Figure 2

Truck and bulldozer tracking experiment at Pulice Construction work zone.

Product Pay-Off Potential

Immediate benefits of this project is twofold. First, the process of monitoring the work zone can be automatically conducted by mobile sensors deployed to workers, equipment, and around the work zones. Instead of visiting individual activities, a safety manager can monitor the entire work zone. Second, meaningful interpretation of the location information is automatically derived based on predefined rules. This information will be valuable for on-site managers to make prompt decisions to protect workers, and also it will allow effective post-activity analyses. In the long run, the outcomes of this project will provide an important basis for future research studies and development of commercial applications. This project establishes a knowledge base comprising "if-then" statements. Also, optimal parameters, such as sizes of workspaces of workers and operators, will be identified throughout this project. The knowledge base can be extended for new types of safety hazards or adjusted based on project-specific conditions.

Product Transfer

The research team plans to transfer the outcomes of this project for implementation and potential commercialization. For that, we closely collaborate with state departments of transportation (DOTs), construction companies, a safety training provider, and a construction software vendor during and after the development of the safety monitoring system. More specifically, the research team will involve potential users from state DOTs and construction companies during the entire development stage. Then, trial implementations will be conducted after the development with the potential users. After the validation, the team will give a presentation and provide a small-sized demonstration session to state DOTs. All the information relevant to this project will be posted on a project webpage with a marketing video in order to introduce the outcomes of the project to a wider range of potential users. Finally, the results will be presented in industry conferences in Houston, Texas, and potential users to measure the interests and potential market size.

MILDGLASS: GFRP STRANDS FOR RESILIENT MILD PRESTRESSED CONCRETE

NCHRP-IDEA Project 207

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IDEA Concept and Product

Corrosion of steel reinforcement is the primary cause of durability problems in aged reinforced concrete (RC) and pre-stressed concrete (PC) structures. In the case of the transportation infrastructure in coastal areas, corrosion problems are mainly experienced by bridge substructures, sheet pile bulkheads and seawalls. In Florida, about 3,600 coastal miles are armored with aging sheet piles with an estimated $21 billion maintenance, repair and replacement (MRR) liability. The construction industry has only partially answered the rising demand for corrosion-resistant pre-stressing technologies, offering expensive, complex, and sometimes ineffective solutions.

This study focuses on developing a glass fiber reinforced polymer (GFRP) strand prototype (Figure 1*a*) to be applied in mild-pre-stressed concrete (MPC) elements. GFRP bars are effective corrosion-resistant reinforcing solutions, but a GFRP pre-stressing strand is not available in the marketplace. Glass fibers are an efficient alternative to carbon fibers in applications that do not require high levels of concrete pre-stressing such as sheet piles for seawalls, bearing piles, and retaining walls.

The technology implements electrical/chemical resistant (E-CR) glass fibers and thermoplastic (TP) resin to ease manufacturing of a twisted 7-wire geometry specifically optimized for pre-stress to reduce shear lag, guarantee adequate creep-rupture strength, and allow coilability and steel-like constructability. Coilable GFRP-TP round solid bars (Figure 1*b*) are being developed as well.

Limiting the initial level of pre-stress in the reinforcement addresses the main constructability issues observed with carbon FRP and guarantees compatibility with standard steel chucks and conventional tensioning techniques. At the same time, the reduced cost of glass fiber makes GFRP reinforcement a competitive and durable alternative to standard low-relaxation high-strength carbon steel.

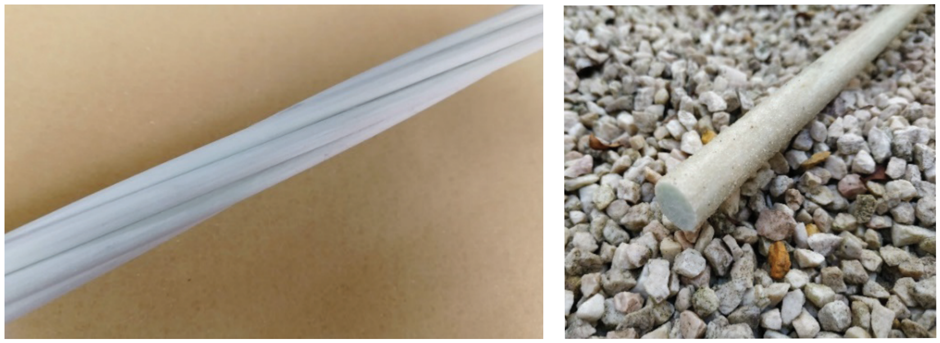

Figure 1

Geometrical configuration: (a) 7-wire GFRP-TP pre-stressing strand and (b) GFRP-TP round solid bar).

Undergoing Investigation

The project has a duration of 2 years, subdivided into two stages. Stage 1 focused on the development, testing, characterization, and validation of GFRP reinforcement as a material system for concrete pre-stressing. Stage 2 focuses on the design, construction, and testing of demonstrative structures using GFRP reinforcement. Results collected on real-scale structures and through material testing will allow calibrating long-term models in order to extrapolate the performance of MPC structures over their service life (100 years). A relevant component of the study aims at quantifying the economic and environmental implications of the technology. To this purpose, detailed life cycle cost and life cycle assessment analyses will be performed.

Product Pay-Off Potential

The GFRP strand under development does *not* alter the conventional fabrication process at the precast plant. The strand is coilable, shippable, and compatible with traditional techniques applied to steel-PC tensioning and construction. Due to the low-level tensioning as compared with ultimate strength capacity, no additional efforts or safety precautions will be required, thus removing any barrier to industrial-scale implementation. Additionally, mild pre-stressing can be attained with conventional steel chucks.

The innovation associated to the use of TP resin in GFRP reinforcement was recognized by the *2019 JEC Innovation Award in Construction and Infrastructures* presented to a partnership of Arkema, the National Cooperative Highway Research Program, SIREG, and the University of Miami for the work developed within the MILDGLASS project. The JEC Group is the world's leading company dedicated to the development and promotion of the composite industry. Figure 2 shows the award ceremony.

Figure 2

Sonja Blanc, SIREG CEO, receiving the JEC 2019 Innovation Award in Construction and Infrastructures on behalf of the team.

Product Transfer

Several industrial partners are actively involved in this project aiming to leverage the diffusion of the technology. This includes the SIREG Group, Owens Corning, and Buzzi Unicem. If successful, the Florida Department of Transportation (DOT), a key stakeholder, will be the first utilizer of the technology, leading a nation-wide pre-standardization effort among other DOTs.

DETERMINING BRIDGE DECK CHLORIDE QUANTITIES WITH GROUND PENETRATING RADAR

NCHRP-IDEA Project 208

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IDEA Concept and Product

A major problem facing transportation agencies is corrosion-induced delamination of concrete. Delamination is the result of corrosion of the embedded reinforcement caused by intrusion of chlorides and moisture into the top layers of the deck concrete. This defect affects the rideability of the pavement and compromises the structural integrity of the bridge. Traditional remediation methods have included removal and repair of delaminated portions of bridge decks. While this method of repair can be effective, defects are often found soon thereafter in areas surrounding the repairs, i.e., the halo effect. Thus, the strategy of repairing only the delaminated area generally does not alleviate the underlying problem of chloride intrusion into the concrete and can, in fact, result in accelerated deterioration in surrounding areas. To remedy this remediation problem, many transportation agencies have begun to focus on a long-term solution. The primary method of identifying chloride-contaminated concrete has been through extraction of several concrete samples and laboratory testing for chlorides. While effective when performed in sufficient quantity, this is destructive, time-consuming, and expensive when considering the extent of the sampling that is necessary and that lane closures are required. However, once identified, bridge owners can remove and replace all chloride-contaminated concrete, thereby improving the effectiveness and longevity of repairs.

Ground-penetrating radar (GPR) technology responds to the presence of chlorides in concrete, which are also the prerequisites for reinforcement corrosion and delamination. This research will define a better method for quantifying chloride concentration in Portland cement concrete. This will investigate the relationship between GPR measurement of conductivity by way of signal attenuation, and chloride concentration in materials. The anticipated results of this investigation will provide a deck-wide mapping of chloride concentrations at the rebar level and develop a technique that can be used by bridge owners to identify and quantify chloride contaminated concrete for subsequent removal during bridge deck rehabilitation.

Project Results/Planned Investigation

This project is proceeding in two stages. Stage 1 research has produced promising results. To investigate the concept, GPR field tests were conducted on an asphalt covered bridge deck. GPR signal attenuation measurements were compared with ground truth information derived from laboratory measurements of chloride to determine the correlation between GPR attenuation and chloride levels in the concrete. This comparison, which included six chloride measurements produced an R-squared of 0.875, indicating a strong correlation between GPR attenuation measurement and chloride quantity and suggests that GPR is a good predictor of chloride quantity in PC concrete. It was also found that the attenuation-chloride relationship could be reasonably defined with only three chloride sample measurements, such that only three core samples were needed, one corresponding to low, intermediate and high attenuation. Using three chloride samples resulted in an *R*-squared of 0.835.

From the GPR attenuation data and core samples used for calibration, it was possible to create a mapping of bridge deck chloride quantities, showing detailed levels of chloride throughout the deck. Those results are shown in Figure 1. Based on the chloride mapping, it was possible to extrapolate the maximum and minimum chloride levels as well as the average chloride level for the entire bridge deck. These radar estimates compared favorably with statistical laboratory chloride measurements. From the GPR based chloride mapping it was possible to identify areas of high chloride levels. i.e. those in excess of a predefined level.

In Stage 2, an analytical model will be developed that defines the GPR attenuation and chloride relationship. The model will provide an understanding of the effects of chloride and moisture on the dielectric and conductive properties of concrete and their effect on GPR signal propagation in PCC material. The analytical model may also provide the basis for future GPR prediction of chloride levels without the need for ground truth input. In stage 2, experimental laboratory tests will also be performed on test samples that simulate chloride contaminated concrete to validate both the analytical model and the GPR attenuation/chloride relationship.

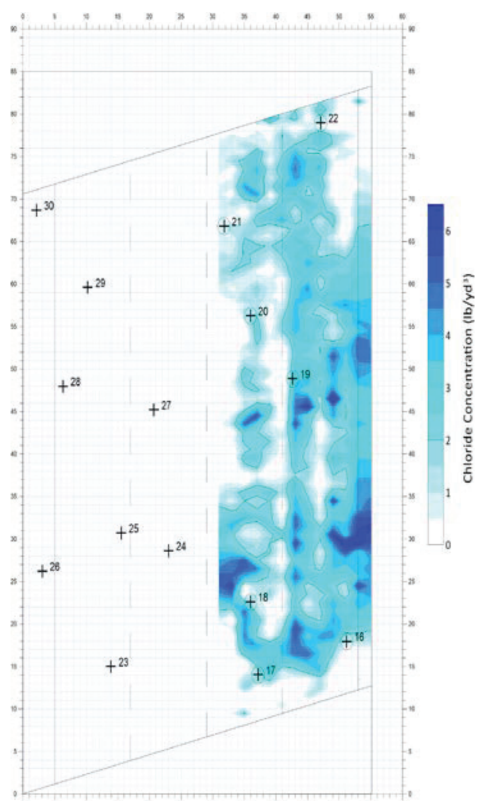

Figure 1

Bridge deck chloride content derived from GPR measurements, shown in a topographical format.

Product Pay-Off Potential

Given the large number of bridge decks and the high cost of maintenance and rehabilitation, the results of the proposed research could have a significant impact on extending the useful life of the decks that are ubiquitous in the nation's transportation network. Additionally, the information gained from this improved test method will significantly increase in-depth knowledge of bridge deck condition, which will lead to better prioritization of bridges for repair.

Because our method focuses on nondestructive GPR, we anticipate that thousands of hours of lane closures can be avoided, which will minimize the effect on the traveling public. A successful and reliable demonstration of this project would not only serve bridge owners, but may be applied to other concrete structures exposed to deicing salts and chlorides.

Product Transfer

This project aims to produce a methodology for use by highway agencies and bridge owners to improve rehabilitation methods. The customer base for this analysis method includes owners of infrastructure, i.e., DOTs, contractors, and civil engineering consultants.

AN AUTOMATED SYSTEM FOR PEDESTRIAN FACILITY DATA COLLECTION FROM AERIAL IMAGES

NCHRP-IDEA Project 209

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IDEA Concept and Product

The concept of this project is to build a prototype system to automatically collect data about major pedestrian facilities, including marked crosswalks and sidewalks, from aerial images. Collecting these data has been recognized as a high-priority action item in the states' strategic highway safety plans to meet the urgent need for improving pedestrian safety. To address this need, a novel data collection system is under development to automatically detect, classify, and measure major pedestrian facilities. Aerial images will be input into the system where pedestrian facilities will be detected and measured using deep learning combined with traditional image- processing techniques. The final output will be information about paved sidewalk presence, marked crosswalk presence, and marked crosswalk length. This information will be stored for future integration into the existing roadway inventories owned by state DOTs. Figure 1 illustrates the concept of this system.

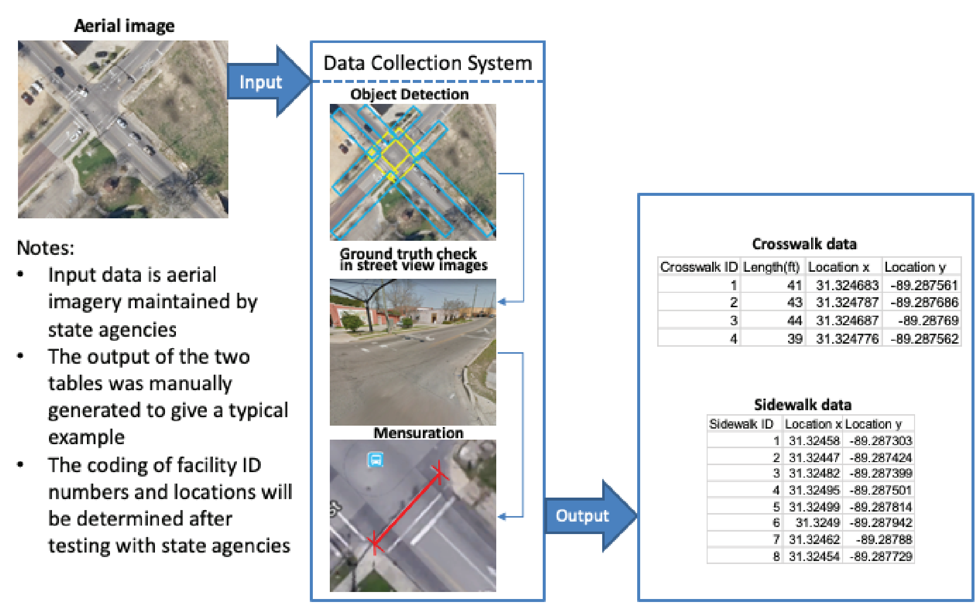

Figure 1

Illustration of the data collection system.

Project Results

The data collection system consists of four function models, including (1) a “sample data acquisition model” for automatically acquiring labeled aerial images as training and testing samples; (2) a “facility detection model” based on deep learning methods for detecting and classifying non-occluded facilities; (3) an “occluded-facility-checking model” that smartly combines satellite view and street view information to check the ground truth for occluded facilities; and (4) a “mensuration model” to automatically measure the length or width of the target facility. Prototypes for the sample data acquisition model, the facility detection model, and the occluded-facility-checking model have been completed.

Table 1 lists the results of the current evaluation of the detection model testing non-occluded targets. Next, the occluded-facility-checking model needs to be tested for its ability to detect occluded targets. In order to prepare a testing data set for this task, a computer-based user interface was built to let human volunteers to manually verify the presence of occluded facilities in our images. Afterward, the mensuration model will be designed to measure the size of the crosswalk.

Table 1
Non-occluded facility detection evaluation accuracy organized by imagery type and target facility.

Imagery Type (Target Facility)	Accuracy (%)
Aerial (crosswalk)	98.43
Aerial (sidewalk)	90.16
Street view (sidewalk)	89.02
Street view (crosswalk)	84.81

Product Pay-Off Potential

The system has the potential to greatly reduce the costs for collecting pedestrian facility data by reducing the need for labor training, travel, observation, and record digitization, which are all inevitable requirements of manual data collection methods. The cost associated with the system is very limited since our data sources are free, and the training process only needs to be conducted once. Furthermore, using the proposed system only requires one staff member to input existing aerial images and monitor the results. The proposed system will transform the way state agencies collect information about not only major pedestrian facilities but also other safety-related items, such as curb ramps, median refuges, and pedestrian signals, with future system enhancements.

Product Transfer

In order to make sure this prototype system will be developed as a foundation of a future tool used by state DOTs, participation of these agencies will take place in every stage of the project. During the development process, Caltrans and Mississippi DOT have been providing sample aerial images for testing and analysis, and they are assisting the research team to modify the system to interface with state DOT software and data management environments. They also provide guidance from the end users' perspective regarding data format, database structure, and geocoding. Once the development process is finished, these two state agencies will assist in testing the system on their work sites. A user guide, oriented to a state DOT audience, will also be produced as part of the project report to make it easy for a first-time user to adopt this system.

MATERIAL CHARACTERISTICS OF CU-BASED SUPERELASTIC ALLOYS FOR APPLICATIONS IN BRIDGE COLUMNS TO IMPROVE SEISMIC PERFORMANCE

NCHRP-IDEA Project 210

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IDEA Concept and Product

In this project the necessary underlying research is undertaken to characterize Cu-Al-Mn (CAM) superelastic alloys (SEAs) under all the relevant mechanical and environmental loading conditions to enable their application in bridges with the objective of improving bridge seismic performance. CAM SEAs have undergone major development over the last decade. Currently, they provide stable superelastic behavior at low and high temperatures, with recovery and rupture strains reaching 12% and 25%, respectively. CAM SEAs are available in sizes up to 1.2 in. in diameter, they are cost-effective, and they are easily machinable. In this research, the low-cycle fatigue characteristics, corrosion resistance, machinability, and coupling of CAM SEA bars to traditional steel rebar are being studied. If successfully demonstrated for their suitable characteristics, the CAM SEA bars could replace their NiTi counterparts at a significantly lower (up to 10 times) cost and accelerate their applications in bridges.

Project Results

This project is ongoing, and tests to determine the effects of corrosion on the mechanical properties of CAM SEAs are being performed. In these tests, an additional 20 mm diameter single- and poly-crystal CAM SEA bars that are three different diameters (No. 3 [9.53 mm]), (No. 5 [15.88 mm]), and (No. 10 [32.3 mm]) of mild steel (MS), epoxy coated steel (EP), stainless steel (SS), and high chromium steel (MX) rebar are kept in a corrosion chamber as shown in Figure 1. NiTi bars will be added to this batch as the research progresses. Salt solution is constantly sprayed on the test specimens at 5% NaCl concentration by weight as per ASTM B117-16 [1] at 40°C, which is slightly higher than the recommended temperature of 35°C in the standard, to accelerate the corrosion process. CAM SEA bars were taken out of the salt chamber at 9 days, 20 days, 30 days, and 75 days of exposure, while steel bars were taken out of the salt chamber at 30 days and 75 days for mechanical testing. Further testing will be performed

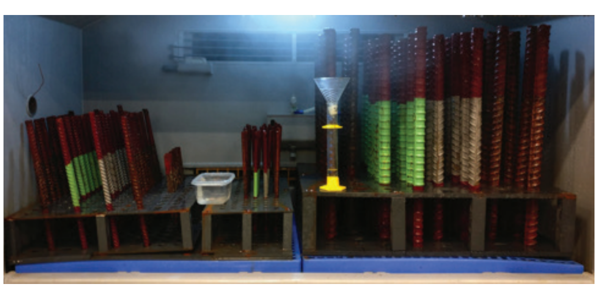

Figure 1

CAM SEAs and different types of reinforcing steel are subjected to accelerated corrosion testing in a salt spray chamber.

at later ages to allow for more severe degradation of the bars. After mechanical testing of CAM SEAs, the specimens were put back in the chamber.

The material properties of the steel bars and CAM SEAs are estimated as shown in Figure 2*a* and *b*. At 75 days, approximately 4.5% and 2% of corrosion (in terms of weight loss) was observed in No. 3 MS and MX bars, respectively, while the same numbers were 2.5% and 1.5%, respectively for No. 5 MS and MX bars. Essentially no corrosion was observed in EP and SS bars. At the same level of exposure, poly-crystal CAM SEAs showed about 1% of corrosion, while the single crystal CAM SEAs showed about 0.3% corrosion, which was significantly superior to MS and MX rebars. To confirm the results of long-term salt spray tests, electrochemical tests were performed on the same materials using a potentiostat and cyclic polarization testing. The same trends in terms of corrosion resistance as in the long-term tests were obtained from the cyclic polarization testing and ensuing analysis. Over the 75-day period, the yield strength of No. 3 MS and MX bars reduced by 13% and 6%, respectively. The same numbers for No. 5 MS and MX bars were 6% and 7%, respectively. As research progresses, corroded No. 10 steel rebars will be tested for their mechanical properties, the low-cycle fatigue characteristics of CAM SEAs will be characterized under various temperatures relevant for bridges, the coupling of CAM SEAs with steel rebar using mechanical couplers will be investigated, the machinability of the CAM SEAs will be quantified and the cost of a potential implementation of CAM SEAs in bridge columns will be estimated.

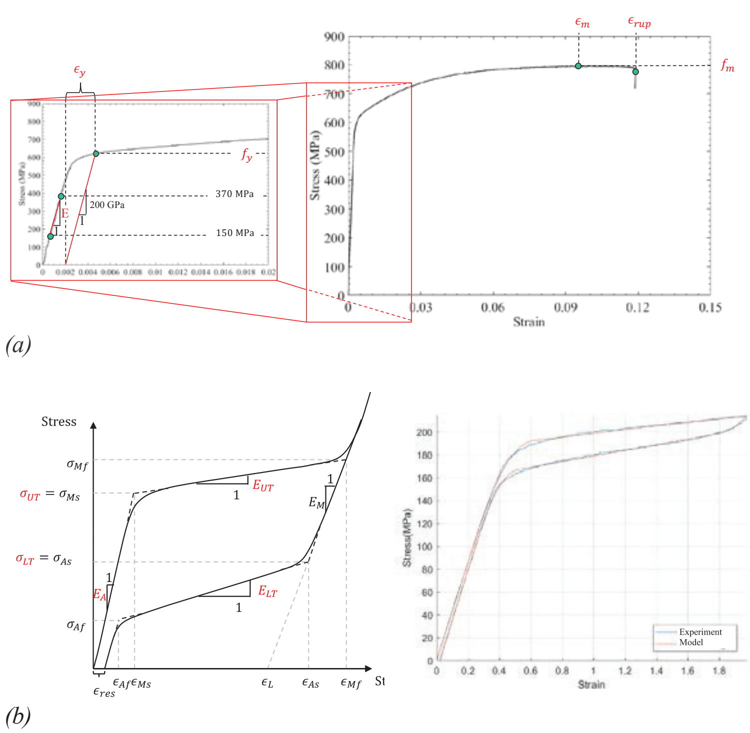

Figure 2

Estimation of material properties for (a) steel bars and (b) CAM SEAs.

Product Pay-Off Potential

This project will test the sufficiency of material performance of CAM SEAs for use in bridge columns. The project addresses a high priority need of state highway agencies as the functionality of transportation infrastructure is essential following an earthquake. This project can save state highway agencies millions of dollars in direct and indirect costs should a major earthquake happen. With more cost-effective and easier-to-implement SEAs, the number of bridges with SEA reinforcement could increase quickly resulting in a safer and more resilient national transportation network.

Product Transfer

The project advisor board comprises several DOT engineering firms from states with high seismicity risk. The research team is investigating the potential of a follow-up implementation project once the CAM SEAs have proved to perform satisfactorily under all relevant loading and environmental conditions.

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

NCHRP-IDEA Project 211

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IDEA Concept and Product

In this study, the reduction of stormwater runoff by biochar amendment to the soils of highway greenways is examined. Biochar is a charcoal formed by combusting waste organic matter in an oxygen-limited environment. Amending biochar to highway soils may increase total porosity and water retention, increase soil aggregation and infiltration rate, and enhance sorption and transformation of pollutants. However, biochar's effect on stormwater runoff and pollutant loading reduction varies with soil type, biochar type, and time. In this project, the dynamic effect of biochar amendment to roadway soils across a wide range of geographic locations on increasing soil aggregation, stormwater infiltration, and runoff reduction will be monitored and tested. Results will guide DOTs to determine for which soils biochar amendment is a cost-effective stormwater management option.

Project Results/Planned Investigation

To evaluate biochar's effect on soil aggregation and stormwater infiltration, 15 roadway soils were selected and collected with assistance from California, Delaware, and North Carolina DOTs and the Maryland Transportation Authority (Figure 1A). Physicochemical analyses of the soils and preparation of the soils for laboratory testing were initiated. The experimental setups for these laboratory experiments were designed, and fabrication was completed for most items (Figure 1B). Columns will be packed with soils with and without biochar, and laboratory tests will be conducted over 6 to 10 months to assess if biochar amendment increases soil aggregation and infiltration and, if so, by how much. In addition, a pilot-scale highway greenway constructed at the University of Delaware Greenhouse in the previous Type 1 IDEA project (NCHRP 182) has been operating for approximately 2 years (Figure 2). During the past year, changes in stormwater runoff were monitored weekly using artificial storm events. Modeling of hydrologic behavior of these pilot-scale experiments was initiated. Core samples will be collected at the end of the experiments and physical, chemical, and biological analyses will be conducted to understand biochar-induced soil aggregation.

In addition, field-scale measurements will be performed to evaluate the longevity of biochar performance on reducing stormwater runoff at an ongoing roadway test site in Delaware. Engineering and cost analysis of biochar-amended roadway soils will be performed.

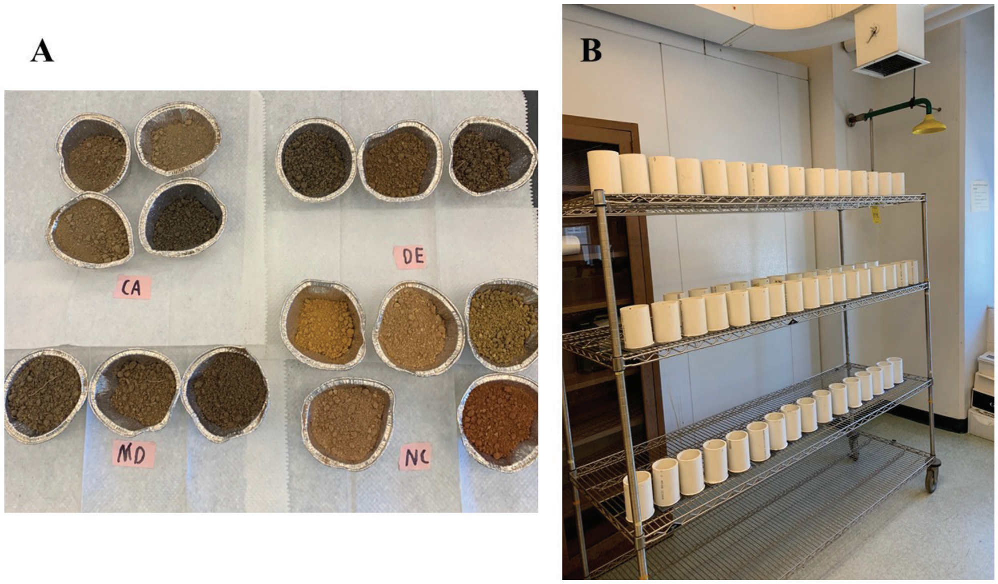

Figure 1

Evaluating biochar's effect: (A) Soil samples collected from California (CA), Delaware (DE), Maryland (MD), and North Carolina (NC) and (B) laboratory columns to measure dynamic effect of biochar on soil infiltration and aggregation.

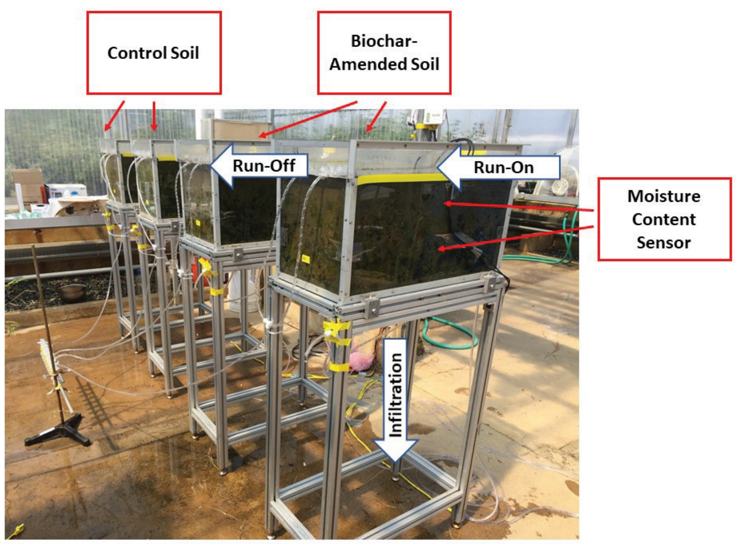

Figure 2

Pilot-scale highway greenway constructed at the University of Delaware Greenhouse in the previous Type 1 IDEA project (NCHRP 182) and studied for long-term performance in this project.

Product Pay-Off Potential

The data from this project can be used to develop an engineering and construction cost analysis and preliminary specifications for DOTs to incorporate biochar in roadway soils. The laboratory/pilot-scale experiments will provide a fundamental understanding of the influence of biochar amendment on time-dependent soil aggregate formation and hydraulic properties for a range of representative roadway soils. Field-scale measurements will document the long-term (> 2 years) effects of biochar on hydraulic properties. These data are necessary to estimate the frequency of biochar replacement.

Product Transfer

The results from this study will be shared through IDEA quarterly, stage, and final reports. In addition, findings of this research will be shared with the scientific community and decision makers via publications in peer-reviewed journals and presentation to the private and public consulting firms, non-profit organizations, state departments of transportation, and the U.S. Environmental Protection Agency.

DEVELOPMENT OF NON-GATING TERMINALS

NCHRP-IDEA Project 212

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IDEA Concept and Product

Roadside guardrail terminals can be classified as either gating or non-gating. Gating designs allow vehicles that strike the end of a barrier at an oblique angle to "gate through the barrier" and travel behind the barrier at a high rate of speed. Since the barrier is in place to shield motorists from a hazard behind the barrier, a gating event normally produces more severe outcomes than non-gating events. It is therefore generally accepted that the risks of injury or death can be significantly reduced if a non-gating guardrail terminal can be developed. As of yet, technology in the field of guardrail terminals has not progressed to the level of fully non-gating performance.

The key component of a non-gating guardrail terminal is the lateral restraint system that must be created and tuned to provide sufficient redirective capability. At present, guardrail barriers are intentionally soft in the lateral direction to provide a low-force redirection of the vehicle. However, this relative softness, on the end, leads directly to gating. One mechanism for providing this new redirective capacity is to connect the impact head to a very tightly stretched wire rope. In this configuration, as the impact head is carried out of line with the guardrail, the wire rope will pull the front of the vehicle back toward the travel way. Lateral resistance provided by the wire rope is a combination of the tension in the cable and the spacing and stiffness of the posts to which the wire rope is attached.

The focus of this research project will focus on obtaining the knowledge and tools necessary to develop a non-gating terminal. The overriding goal of this study is to determine the combinations of energy dissipation rate, lateral stiffness of the cable guidance system, and the degree of mechanical interlock between the impacting vehicle and the energy absorption system that can produce non-gating behavior.

Project Results

The project began with an investigation in previous crash testing done on barriers, in particular W-beam longitudinal barriers. Online research hubs were searched for *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Ross et al. 1993; available at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_350-a.pdf), and MASH crash tests focused mainly on redirection test such as the *NCHRP Report 350* Test Nos. 10 and 11. However, additional tests were included if available, such as Test Nos. 32, 32, 35, and 37. This search revealed 47 crashes on the Midwest Research Safety Facility (MwRSF) website (mwrsf.unl.edu).

Each of these tests included acceleration-time plots, but precisely reading the data required software development. A MATLAB code was written to receive in the image of one of these plots and then establish the scale along the ordinate and abscissa. Then, by clicking on each relevant peak, the point of that peak was recorded. This provided a precise way of gathering peak loads and displacements. It was found that the minimum redirecting force was 21.5 kips, with an average force of 36.2 kips. Similarly, the maximum lateral compliance was between 2 and 5 feet.

Next, a spring model in LS-Dyna was set up like the one shown in Figure 1. The boundary conditions of the cap with the two springs was such that it could translate in any direction on the horizontal plane but could not translate vertically or rotate about any axis, thus generating a theoretical lateral stiffness and longitudinal rate of energy absorption inherent in guardrail terminal designs. After spending some time debugging the model and verifying adherence to physical laws, the lateral and longitudinal springs in this model were adjusted to provide a lateral displacement between 2 and 5 feet while remaining consistent with the redirecting forces from the literature search. This task is ongoing and will isolate the lateral and longitudinal components of the redirecting force, allowing engineers to create designs based on these results and innovate the market with redirecting, non-gating terminals.

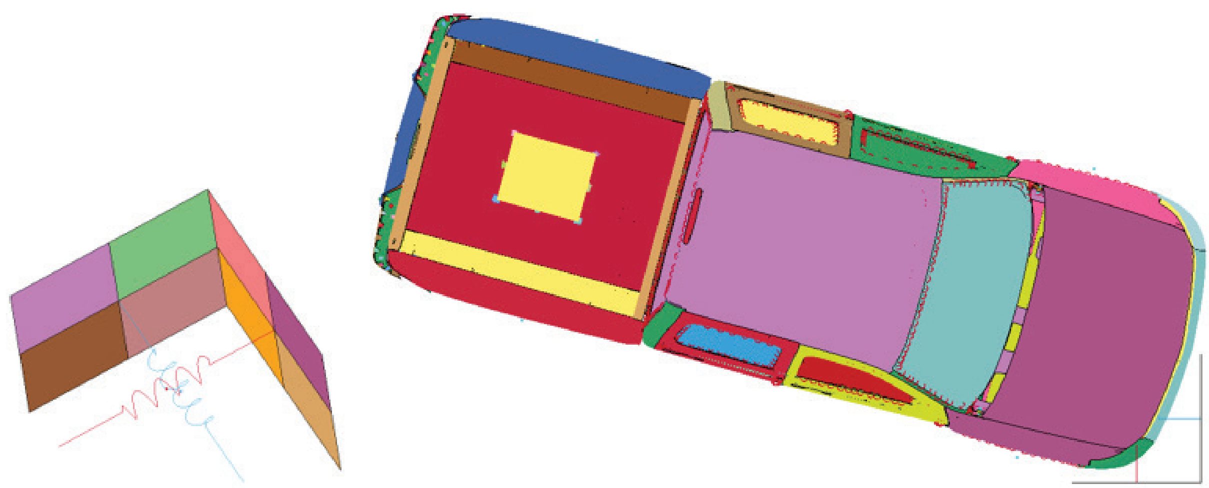

Figure 1

LS-Dyna spring model setup.

Product Pay-Off Potential

The primary benefit of a non-gating guardrail terminal is the reduction in the number of serious injury and fatal accidents associated with vehicles gating through that terminal. The Fatal Accident Reporting System between 2014 and 2016 showed that the first harmful event was classified as striking a guardrail terminal in an average 178 fatal crashes per year, and striking the terminal was classified as the most harmful event in 91 of these crashes. The remaining 87 crashes that involved a vehicle first striking a guardrail terminal and another event classified as the most harmful event were fatal accidents that can be eliminated by non-gating terminals.

Also, gating terminals require a longer length of need to put the area behind the terminal sufficiently far from the danger that is being shielded. However, if gating is not possible, then the overall length of the guardrail installation would be reduced. This shortening can be at least 12 feet 6 in. (one standard length of W-beam), saving approximately $180 per installation. This cost savings would offset most, if not all, of the additional costs associated with non-gating designs.

Product Transfer

Upon successful completion of this research project, at least one manufacturer will explore the potential for adapting its energy-absorbing terminal to be non-gating. In addition, the findings from this work will be published and presented at conferences, such as TRB's annual meetings. Such findings will include minimum redirective force and maximum lateral displacement that result in a successful non-gating crash. This information will become the design constraints that need to be met in order to produce a non-gating terminal.

SEAHIVE—SUSTAINABLE ESTUARINE AND MARINE REVETMENT

NCHRP-IDEA Project 213

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IDEA Concept and Product

The project centers on the structural morphogenesis of a novel modular seawall system called SEAHIVE. The system is composed of a series of perforated tube elements that can be installed horizontally or vertically, stacked in a tight configuration or with an offset, allowing the system to adapt for various applications and topography, while perforations along the length of the elements allow wave energy to dissipate within them, thus increasing material efficiency and performance (Figure 1). SEAHIVE elements will be fabricated using low alkalinity cement with seawater and non-corrosive reinforcement rebars to avoid corrosion to ensure a good integration with the natural environment. Moreover, elements at higher elevations can be filled with sand and soil to promote coastal vegetation, creating a protective environment for marine life to thrive. It is thus expected that the SEAHIVE system will be an efficient and ecofriendly seawall design.

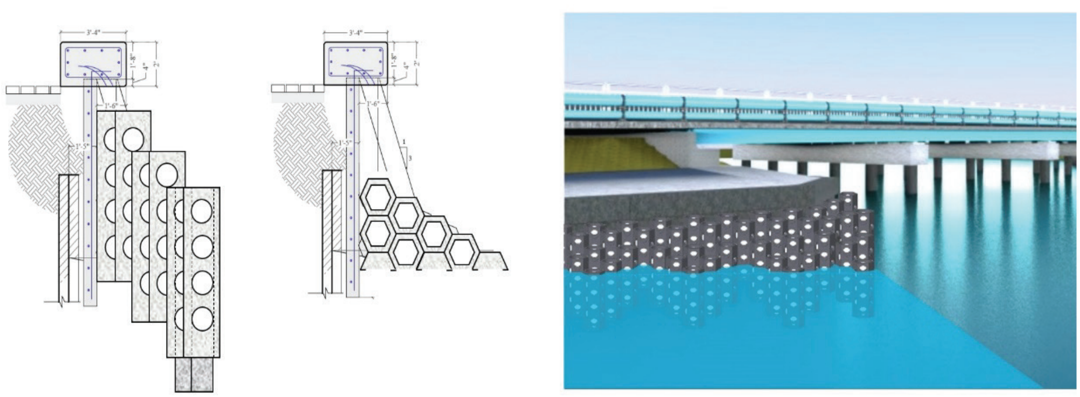

Figure 1

Illustration of SEAHIVE system configurations (left) and application of the system (right).

Project Results/Planned Investigation

SEAHIVE is currently under development through physical testing at the University of Miami, Surge STructure Atmospheric Interaction (SUSTAIN) Facility (Figure 2). SUSTAIN is a wind–wave tank that can generate directionally varying waves using a 12-paddle system combined with direct wind forces, simulating hurricane conditions up to Category 5 on the Saffir-Simpson scale. SUSTAIN allows physical testing of SEAHIVE elements at near-full-scale conditions, as well as scaled system configurations, providing a unique opportunity for experimental validation of the system's performance under varying wave conditions and water levels as well as extreme tidal conditions.

SEAHIVE elements with circular, hexagonal, and square cross-sectional profiles and circular perforation configurations that vary in diameter and/or void wall surface over solid surface ratios are currently being tested under a series of wave conditions for load definition, optimization of the outer profile, void configuration for wave energy dissipation, and performance characterization through pressure, water velocity, and wave height measurements (Figure 3). Testing conditions were defined based on a dimensional analysis of the Froude number between wave history data from four locations/zones within the United States and the experimental models designed for the SUSTAIN tank. Preliminary results showed that element perforations decrease wave dynamic forces on the elements as well as reflection. Future tests include multi-element SEAHIVE testing for system design considerations as well as quantification of the system's performance.

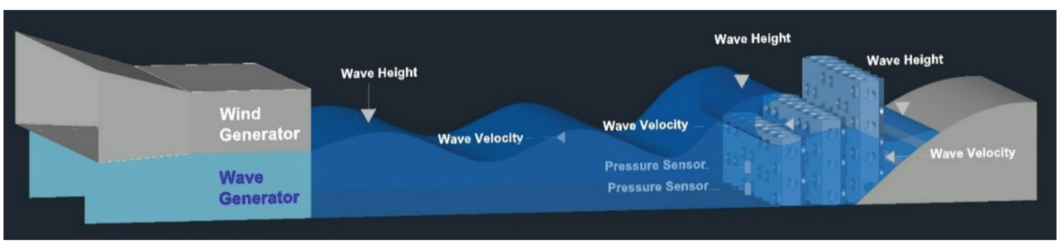

Figure 2

Illustration of the physical testing of SEAHIVE at the University of Miami, SUSTAIN Facility.

Figure 3

SEAHIVE elements under testing in the SUSTAIN tank.

Product Pay-Off Potential

This project aims toward the development of an efficient and cost-effective shoreline protection system for areas with high energy tidal flow, with adaptive features for various applications and topography that creates an ecofriendly environment for marine life. Efficiency is obtained by employing a profile shape and perforation configuration that ensures good stability while increasing wave-energy dissipation capabilities with physical testing at SUSTAIN used to ensure effectiveness at various conditions, including high tidal flow. Element shape tuning and modularity are expected to allow the system to be used for a wide variety of applications, while material selection and structural complexity can ensure a good compatibility with the natural environment. Finally, cost-effectiveness can potentially be obtained by adopting traditional concrete pipe fabrication technology for element fabrication.

Product Transfer

Although the SEAHIVE system is still under development with expected project completion in 2020, the developing team has already made significant efforts toward product transfer and implementation by promoting SEAHIVE and its development process at a number of professional meetings, such as the 2019 Florida Shore & Beach Preservation Association's annual conference and Coastal Structures Conference 2019, an international conference organized by the American Society of Civil Engineering's Coasts, Oceans, Ports, and Rivers Institute. The developer has already received inquiries from cement manufacturers and ready-mix producers, as well as from local stakeholders and the private sector. Product transfer and implementation efforts will continue and intensify as the product design reaches its final development stage.

AN ENHANCED NETWORK-LEVEL CURVE SAFETY ASSESSMENT AND MONITORING USING MOBILE DEVICES

NCHRP-IDEA Project 214

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IDEA Concept and Product

This project addresses an urgent need for network-level curve safety assessment (Figure 1). The current methods are labor-intensive, time-consuming, and often dangerous for the engineers collecting the data. This significantly hinders transportation agencies' capabilities for applying proactive safety improvements at the right time to reduce the number of crashes on curves. This project develops an enhanced method that enables transportation agencies to assess network-level curve safety conditions safely and cost effectively by collecting and analyzing vehicles' GPS trajectories and kinematic data using intra-agency, crowdsourced, low-cost mobile devices. Thus, multiple runs of data from different drivers at a single curve can be used and analyzed to eliminate biases that could occur in data collected by only a single driver. To ensure data quality and ease the concerns on privacy, crowdsourcing data collected from the fleet and employees in a single transportation agency, that is, an intra-agency, is recommended.

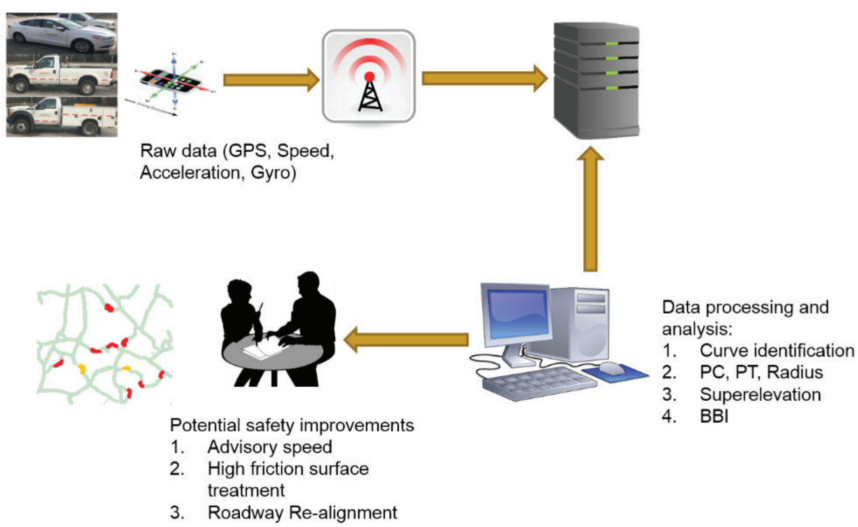

Figure 1

Operation flow of network-level curve safety assessment (PC = point of curve, PT = point of tangent, and BBI = ball bank indicator).

Project Results

This project will be performed in two stages. Stage 1 will focus on developing a framework for a network-level curve safety assessment and calibrate and validate the developed algorithms using a single run of mobile device data. In Stage 2, the method to improve data quality by integrating multiple-run data will be developed and comprehensively validated.

The framework for a network-level curve safety assessment is under development. A project panel has been formed by the experts from Florida DOT, Georgia DOT, Nevada DOT, Texas DOT, and a consulting company. A literature review on computing ball-bank indicator, super-elevation, and curvature using a vehicle's kinematic data has been performed.

Using single-run data, the ball-bank indicator and super-elevation data have been validated by comparing them with the ground reference data. A good correlation has been observed. Next, more data will be collected and validated from the test roads that are selected with Georgia DOT. The cost-sharing project with Georgia DOT has been set up, in which Georgia DOT will assist in the system validation.

A mobile device application was explored for the Android and iOS mobile operating systems for low-cost, frequent, and crowdsourced road infrastructure condition data collection. The application integrates and stores data from multiple smartphone sensors already included in modern mobile devices.

Figure 2

Mobile data collection.

Product Pay-Off Potential

If successful, the proposed method will provide a means to improve the accuracy, productivity, and safety of current curve safety assessment methods. The proposed method can be used by state DOTs and other transportation agencies to assess curve conditions while they are working on other tasks. The proposed method is expected to significantly reduce the cost and time spent by state DOTs in assessing their network-level curve safety conditions, including BBI computation, super-elevation computation, advisory speed determination, and pavement surface treatment determination, by using crowdsourced, low-cost mobile devices, such as smartphones and tablet PCs. In addition, this cost-effective method will be specifically useful for counties and cities with limited resources.

Product Transfer

Several state DOTs have committed to participating in this research and will support this study by collecting and providing the necessary data. Their personnel will work with the research team to validate the results obtained in this study. In addition, Georgia DOT provided a cost share on this study with a focus on collecting the data using Georgia DOT's vehicles to support the development of calibration and validation procedures. Once the algorithms are refined and the prototype applications are tested through this research study, software products will be further developed in the future to promote the developed technology and offer them to other state DOTs and transportation agencies.

ACHIEVING RESILIENT MULTI-SPAN BRIDGES BY USING BUCKLING-RESTRAINED BRACES

NCHRP-IDEA Project 215

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IDEA Concept and Product

The objective of this NCHRP-IDEA Type 2 project is to make the bidirectional ductile diaphragm concept applicable to common multi-span bridges as a way to prevent damage in the substructure and superstructure due to earthquake excitation. The concept uses energy-dissipating buckling restrained braces (BRB) as “fuses” or sacrificial elements located at the end of the superstructure’s floating spans. The viability of the concept was initially demonstrated in a NCHRP-IDEA Type 1 project for single-span bridges. Figure 1 shows different configurations of the energy dissipation system. The current project aims to expand the concept to multi-span bridges through analytical and experimental research. Therefore, this project is a final step to expanding the use of ductile diaphragms [already implemented in the AASHTO Seismic Specification (*AASHTO Guide Specifications for LRFD Seismic Bridge Design* 2007; available at http://www.ce.memphis.edu/7119/PDFs/AASHTO/2007-03-09GuideSpec.pdf) but limited only to transverse excitation application]), to provide resistance to bidirectional excitation, in multi-span bridge configurations. This innovative system using BRBs can provide seismic resilient and damage-free bridges applicable to different levels of seismic forces at low cost as a result of the availability of BRBs in different capacities ranging from 20 to 1,400 kips and already tested for building use purposes.

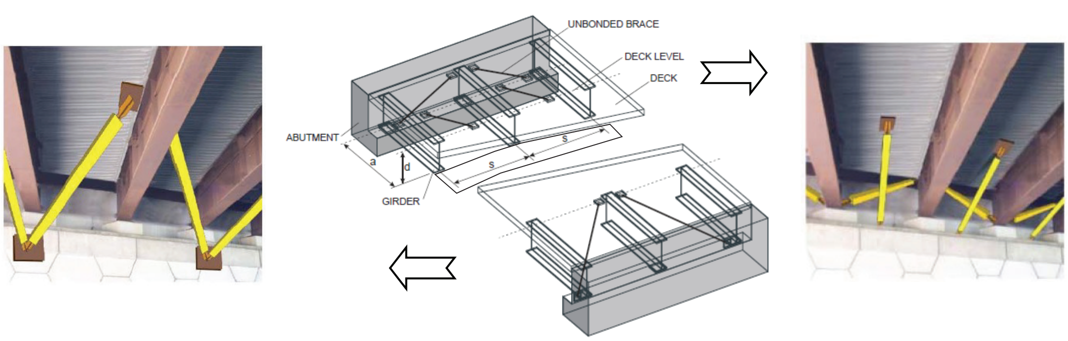

Figure 1

Conceptual illustration of the bidirectional diaphragm with two possible configurations.

Two main problems, however, prevent the implementation and broad use of this concept, which will be addressed in this project: (1) the need to understand analytically the behavior of the system in a multi-span configuration, to be able to propose a simple design procedure, and (2) the need to validate experimentally BRB connections to demonstrate their ability to work under 3-D displacements imposed due to the inclination of BRBs.

Planned Investigation

The project will be performed in two stages. In Stage 1, multi-span bridges with the proposed ductile diaphragms will be investigated to understand their seismic behavior, considering various layouts and implementation strategies. Moreover, a parametric analysis will consider the influence of different elements of the structure, such as the geometry of piers, the span mass, and other factors. Two kinds of analyses will be conducted in order to determine the level of complexity required to define the design rules. They are modal analysis and nonlinear time history analysis. This will be done for two different layouts of BRBs: one with BRBs connecting the end of the span to the adjacent bent cap or abutment, as shown in Figure 2 (shown schematically, as, in reality, BRBs will be hidden between girders), and a second with BRBs connecting adjacent spans to each other. After understanding which is the optimal configuration and under what circumstances, a design procedure simple enough to achieve adequate seismic performance will be proposed. The design procedure results will be assessed by subjecting example bridges to suites of ground motions using nonlinear time history analysis. The analysis will allow the research team to investigate the impact of the simple design on global behavior, as well as to understand the magnitude of the local demands and the magnitude of hysteretic displacements that the BRBs will have to accommodate. A significant part of the project will be invested in this Stage 1 research because it is of extreme importance to understand adequately how different configurations of BRBs along the bridge can help to dissipate the seismic energy proportionally across all BRBs and in such way that the substructure and the superstructure remain elastic. Finally, results from nonlinear time history analysis will be used to design the full-scale specimens to be tested in the second stage.

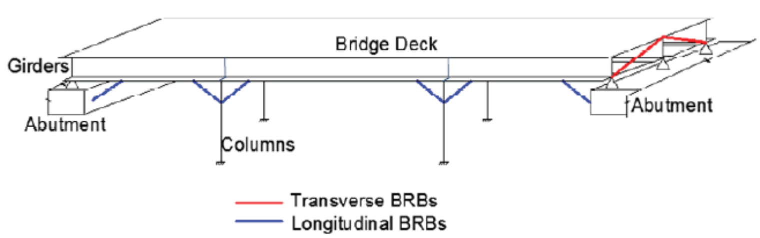

Figure 2

Illustration of a tentative study configuration.

During the second stage of this project (Stage 2), specimens designed in Stage 1 will be subjected to shake table testing. Shake table testing is equivalent to field testing, with the advantage that specimens can be excited by ground motions immediately instead of waiting for severe ground motions to validate the design in the field. The main purpose of these tests will be to experimentally validate proposed connection details when subjected to the 3-D displacement histories (compared with the axis of the BRBs) that will result from bidirectional ground motions and the fact that the connections must accommodate inclined BRB layouts. Tests will include a qualification hysteretic test protocol (adapted to 3-D), as well as earthquake displacement histories (obtained from Stage 1), and combinations of earthquake and thermal excitations. The test protocols will be repeated on each specimen until failure, to establish their ultimate hysteretic capacity. The validation from experiments will provide the final piece needed to implement the proposed design procedure.

Product Pay-Off Potential

The pay-off potential is to achieve resilience in ordinary multi-span bridges, using inexpensive BRBs. In contrast with the large seismic displacements that must be accommodated by special expansion joints when using base isolation solutions, the proposed concept results in small displacements that can be accommodated by regular expansion joints. Another advantage of the concept is its simplicity, which makes it an attractive solution for seismic design for all seismic regions and applicable to routine designs, avoiding expensive peer reviews. The way that BRBs are to be located along a bridge also makes them easy to repair, avoiding closure of the bridge in case of needed substitution after an earthquake. Finally, considering the simplicity of the concept, it also makes for an economical and rapid scheme for bridge retrofit.

Product Transfer

The main objective of the project is to validate the seismic behavior of the bidirectional ductile diaphragm by testing connections subjected to 3-D excitations and to develop a simple design procedure with examples that could be used as a guideline to apply in different bridge projects. The objective is to develop this proposed design procedure in language ready to be implemented in bridge design specifications.

THE PORTABLE SINGLE LANE TRAFFIC COUNTING DEVICE

NCHRP-IDEA Project 216

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IDEA Concept and Product

Considering the amazing technology all around, one must wonder why state DOTs still use road tubes to monitor traffic. Why are workers still being put in harm's way, kneeling in the middle of the road using a hammer and nails to install road tubes (Figure 1)? The short answer is that transportation agencies have not yet devised a system that can replace road tubes without sacrificing quality, cost, or both. It is the objective of this innovation to be that replacement.

For years, transportation agencies have been looking for new, non-intrusive ways to perform this work. Various industries and technologies have answered the call for non-intrusive traffic counters by developing products that utilize Doppler microwave detection, acoustic detection, passive infrared, video-based offline processing, and video-based online processing. While there have been steady increases in the utilization of the new products in the higher speed and traffic areas where road tubes are less practical, the vast majority of the traffic counts (over 80% in the United States, as estimated by industry experts) still rely on road tubes. The data quality and cost remain the two main factors preventing more extensive use of the newer technologies.

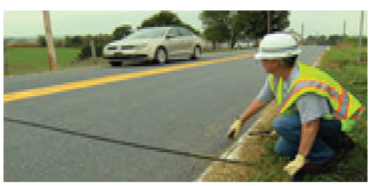

Figure 1

Road tube installation.

Among the new products, Leetron in 2018 successfully developed a portable real-time video-based traffic counting unit (Figure 2) called AI (artificial intelligence) Count 100. The success of AI Count 100 provides the confidence and experience for Leetron to take the technology to the next level. In the process of searching for alternatives to road tubes, Leetron discovered that by combining the best features from sensor technology with the best features of video-based technology, and by concentrating on measuring a single lane only, the goal of accurate data collection at a low cost can be achieved. While this single lane system will not work on roads with more than two lanes in one direction, internal study indicated that it will be suitable to replace most tubes counts currently in use.

This project is complex in many ways, yet simple in other ways. The basic idea is to use simple LIDAR sensors to perform the majority of the counting and classification tasks and to use a video-based system for special conditions. When deploying the device, it is mounted on the side of the road as shown in Figure 3. When a vehicle passes by a LIDAR distance sensor, the sensor detects the presence of the vehicle at the same time and the video-based system takes a sequence of images. In most cases in which the confidence level on counting and classification results from the LIDAR sensor are high, no further processing is needed. Otherwise, the system will trigger the video-based processing system to analyze the images to determine the count and classification.

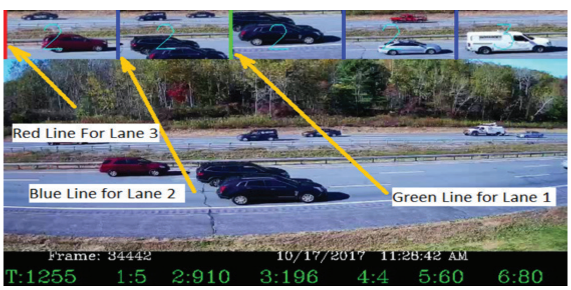

Figure 2

Leetron AI Count 100 video display.

Figure 3

Indication of device-mounting location. The device in the photograph does not represent the actual counting device.

Project Results

This project is divided into three phases of development. They are:

Phase 1: Prototype. The prototype phase consists of building a test unit that is capable of counting and classifying vehicles on the road. As of July 2019, work is underway on this phase.

Phase 2: Test and Refinement. The research team learned from developing AI Count 100 that a counting system needs to deal with many weather and traffic conditions.-Therefore, the research team will invest heavily in this phase and subject the proposed innovation to a rigorous testing and refinement process.

Phase 3: Production Unit. The production unit phase will concentrate on building a production version.

Product Pay-Off Potential

Safety. While the research team is not able to find comprehensive statistics on incidents of injuries related to traffic data collecting, there are some examples worth mentioning. The Connecticut DOT had a close call when one of its staff felt a car brush his jacket while installing a road tube. In Texas, a road worker was killed during data collection. After that, the use of road tubes was banned in that county. All states take safety very seriously and want an alternative solution to the road tube to remove their workers from the risks of intrusive data collection. This innovation will help these states to accomplish this high-priority goal.

Labor-intensive work can introduce repetitive motion injury. Because of the constant kneeling in the road and the force at which a worker is required to hammer, workers can develop joint issues and repetitive motion injuries. Because of this risk, it is becoming more and more difficult for states to find workers willing to perform the task. With this innovation, there is no labor-intensive work involved. There is no heavy lifting, nailing, or kneeling required.

Productivity gain. Installation time will be shortened and have a positive impact on workers' productivity. In addition to labor savings, there will be savings from not having to purchase and inventory nails, tape, and tubes.

Count accuracy. Traditional traffic technologies accuracy will suffer when a trailer is attached to a vehicle and when a vehicle slows down due to traffic conditions such as heavy congestion. This innovation utilizes the same technologies used in AI Count to handle these conditions, resulting in higher count accuracy.

Classification accuracy. Road tube counts use the measurement between wheels to determine vehicle classes. As a result, road tubes do not always provide accurate classifications. This device utilizes AI to classify vehicles and is expected to achieve higher than 95% on classification accuracy.

Product Transfer

Once the production unit is ready, an industry leader in traffic count monitoring device vendor will promote and sale the product through exiting sale channels.

A REAL-TIME, PROACTIVE INTERSECTION SAFETY MONITORING AND VISUALIZATION SYSTEM BASED ON RADAR SENSOR DATA

NCHRP-IDEA Project 217

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IDEA Concept and Product

Enabled by placing temporary or permanent radar sensors near the intersection, which can track the trajectories of all vehicles and pedestrians that use the intersection, the concept of this project is to develop an Intersection Proactive Safety Visualization (IPSV) system to monitor intersection safety in real time and visualize the spatial distribution, frequency, severity, and types of all near misses that have happened at the intersection. Traffic engineers can use this visualization approach to identify the potential intersection safety problems. This innovation addresses the U.S. DOT's high priority need by targeting the areas of highway safety and vulnerable users such as pedestrians. Using this approach, the traffic conflicts and their magnitudes that will be visualized in the proposed system are actually true representations of the intersection safety issues, because the traffic conflicts do not miss any safety problems or near misses that have happened at or near the intersection, even including all crashes. Figure 1 illustrates six different types of traffic conflicts that will be identified by IPSV.

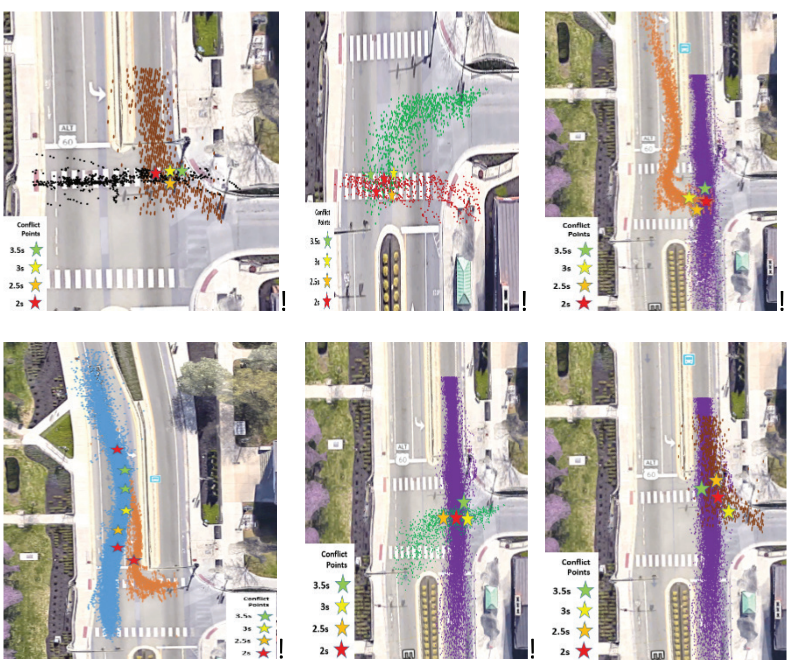

Figure 1

Conceptual illustration of the proposed process: identification and visualization of traffic conflicts by types.

Project Results

The investigative approach for the project is divided into the two stages: IPSV Development and IPSV Field Testing and Validation. The project has proceeded in two stages of research. Work in Stage 1 of the project will focus on developing the IPSV algorithm from automated data collection of radar sensor data. An algorithm of automated data preprocessing will be developed and implemented in IPSV. The algorithm will integrate trajectory data from the four radar sensors used at the intersection.

The coordinate transformation algorithm will be implemented and noise reduction algorithm will be developed to remove the trajectory noise from the analysis. After data processing, an algorithm that automatically classifies different traffic and pedestrian movements will be developed. Based on the algorithm, the time to collision (TTC) of different types will be automatically computed. Using the predefined threshold of TTC, traffic conflicts of different types will be automatically identified and their severity measured. Figure 2 illustrates a pilot study in Louisville, in which rear-end and vehicle-pedestrian conflicts were tentatively identified.

Work in Stage 2 will involve developing an interface for the user to configure IPSV parameters, as well as testing and validating the IPSV at an intersection in Louisville, Kentucky. The research team will develop a configuration tool that provides interface for users to configure the TTC thresholds and traffic conflict types through a user-friendly interface. Trajectory data will be collected, along with data for TTC and traffic conflicts and their severity. All functions of IPSV will be tested to ensure they work as they are supposed to do. All functions of IPSV will be validated based on field-collected data. The accuracy of TTC, traffic conflicts, and traffic conflicts severity will be evaluated using trajectory data collected from a video camera. The safety performance accuracy will also be compared with the historical crash data to see whether there is a consistent trend.

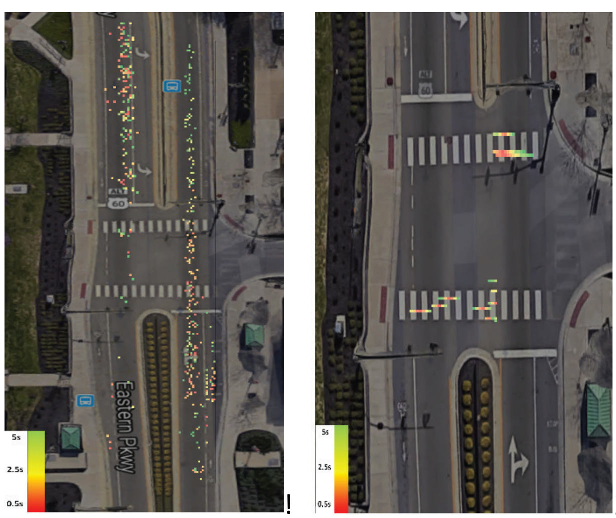

Figure 2

Pilot study: identification and visualization of rear-end conflicts and vehicle-pedestrian conflicts.

Product Pay-Off Potential

The most profound impact of this innovation is the ability to obtain proactive intersection safety measures that (1) accurately represent the intersection safety performance, which does not miss any safety issues, including both conflicts/near misses and crashes; (2) are not necessarily obtained at the cost of losing lives and injuring road users, which allows fast adjustment of safety treatment to save lives and economic costs incurred; and (3) enables fast highway safety improvement evaluation using data 1 week before and 1 week after safety treatment is implemented rather than years of crash data.

Product Transfer

This project aims to produce an IPSV system provided as both hardware and software. Potential customers of this system are state DOTs, FHWA, and local transportation agencies, including existing customers of the radar provider. Consequently, the market for the proposed system is large and expected to increase with time. The project team is involving the radar manufacturer and a state DOT and a city traffic engineering department specifically on implementation issues. In addition, the state DOT personnel will provide input from the user's perspective. The University of Louisville Office of Technology Transfer will assist in patent filing and licensing as well as supporing commercialization of the technology.

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

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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.

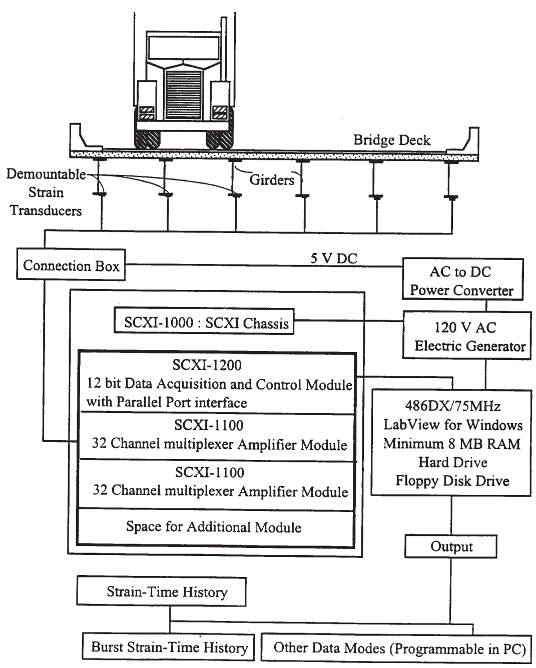

Figure 1

Data acquisition and control system.

PULSE-ECHO TOMOGRAPHIC MICROWAVE IMAGING SYSTEMS FOR QUANTITATIVE NDE OF CIVIL STRUCTURES AND MATERIALS

NSF/NCHRP-IDEA Project 2

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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.