IDEA

Innovations Deserving Exploratory Analysis Programs

NCHRP HIGHWAY

New IDEAS for Highway Systems

Annual Progress Report

JANUARY 2013

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH BOARD
2012 EXECUTIVE COMMITTEE*

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

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

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

NEW IDEAS FOR HIGHWAY SYSTEMS

An Annual Progress Report of the NCHRP IDEA Program

2013

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP-IDEA PROJECT COMMITTEE

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

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 NCHRP-IDEA program is jointly funded by the state highway agencies through membership in the American Association of State Highway and Transportation Officials.

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

- Transit-IDEA, which focuses on products and results for transit practice in support of the Transit Cooperative Research Program; and
- Safety-IDEA, which focuses on innovative technologies to improve transportation safety, with emphasis on commercial motor vehicles.

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

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

The selection of each IDEA investigation is made by consensus recommendations from panels of national experts in highway and transportation research and practice and is approved by the NCHRP-IDEA Project Committee, 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. In order to begin the product transfer process from the initiation of each IDEA project, a regional panel of experts is nominated to work with the investigator on product development and transfer to highway practice. The products emerging from the NCHRP-IDEA project 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 2012 program year. The products and results from these projects have been applied or are available for further investigation for application to highway practice. The product status is described under each project. Because of limitations on IDEA resources, not all IDEA concepts that prove feasible can be accommodated for follow-up funding by the NCHRP-IDEA program for product transfer. Section 2 presents reports of investigations on projects active or completed during the 2012 program year; several projects in this section are in the initial stages of investigation. Section 3 presents IDEA projects performed under a cost-sharing initiative with the National Science Foundation.

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

The IDEA program welcomes your comments, suggestions, or recommendations on NCHRP-IDEA projects, products, and results presented in this report. Please forward them to The NCHRP-IDEA Program (attention: Dr. Inam Jawed), Transportation Research Board, 500 Fifth St. NW, Washington, DC 20001, fax: 202-334-3471, Email: ijawed@nas.edu.

TABLE OF CONTENTS

SECTION 1: Completed IDEA Projects

SECTION 2: Active IDEA Projects

SECTION 3: NSF/NRC-IDEA Cooperative Projects

Project **Page**

SECTION 1
COMPLETED IDEA PROJECTS

This section presents brief summaries of NCHRP-IDEA projects completed before the 2012 program year. The products 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.

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

NCHRP-IDEA Project 1

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

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

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

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

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

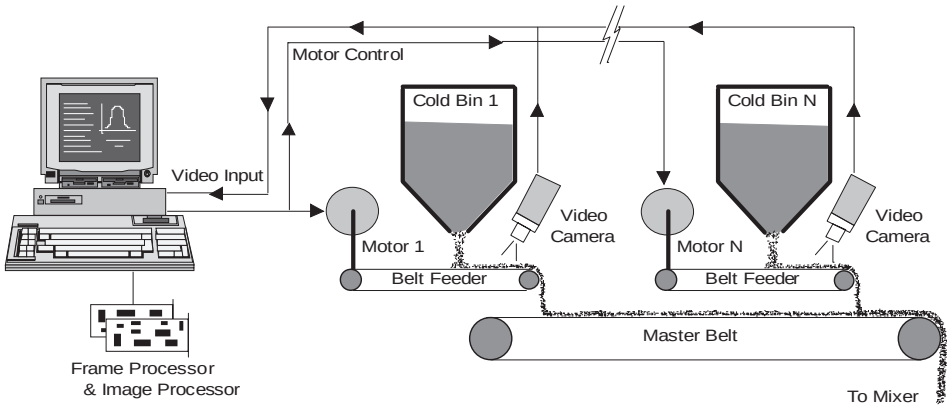


Figure 1

Aggregate gradation control technological concept.

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

NCHRP-IDEA Project 2

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

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

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

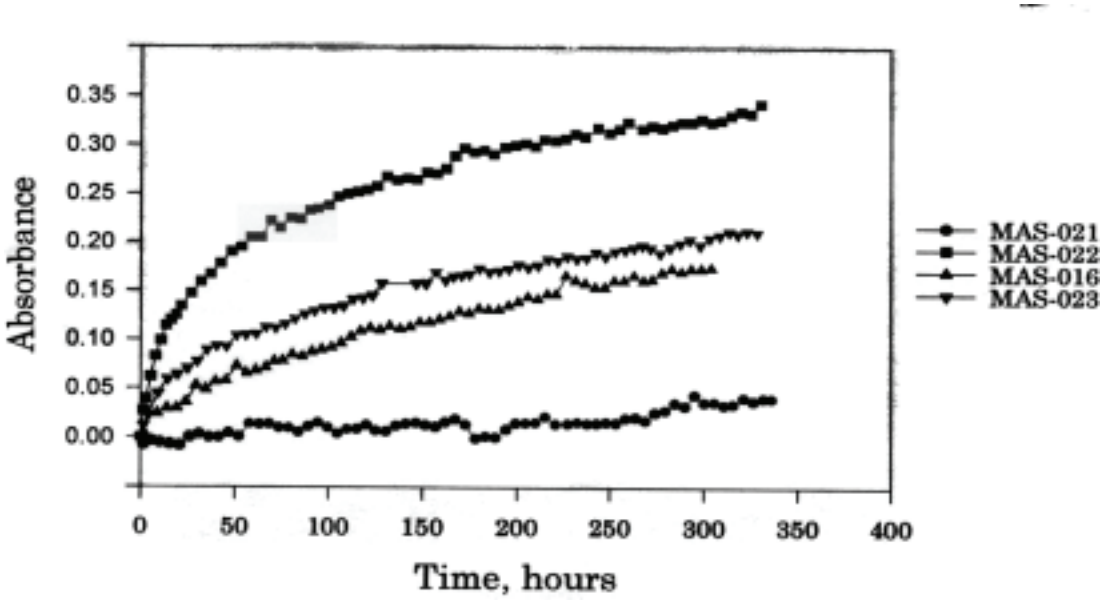


Figure 1

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

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

NCHRP-IDEA Project 3

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

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

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

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

Figure 1

Field installation, Bahia Honda Bridge, Florida Keys.

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

NCHRP-IDEA Project 4

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

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

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

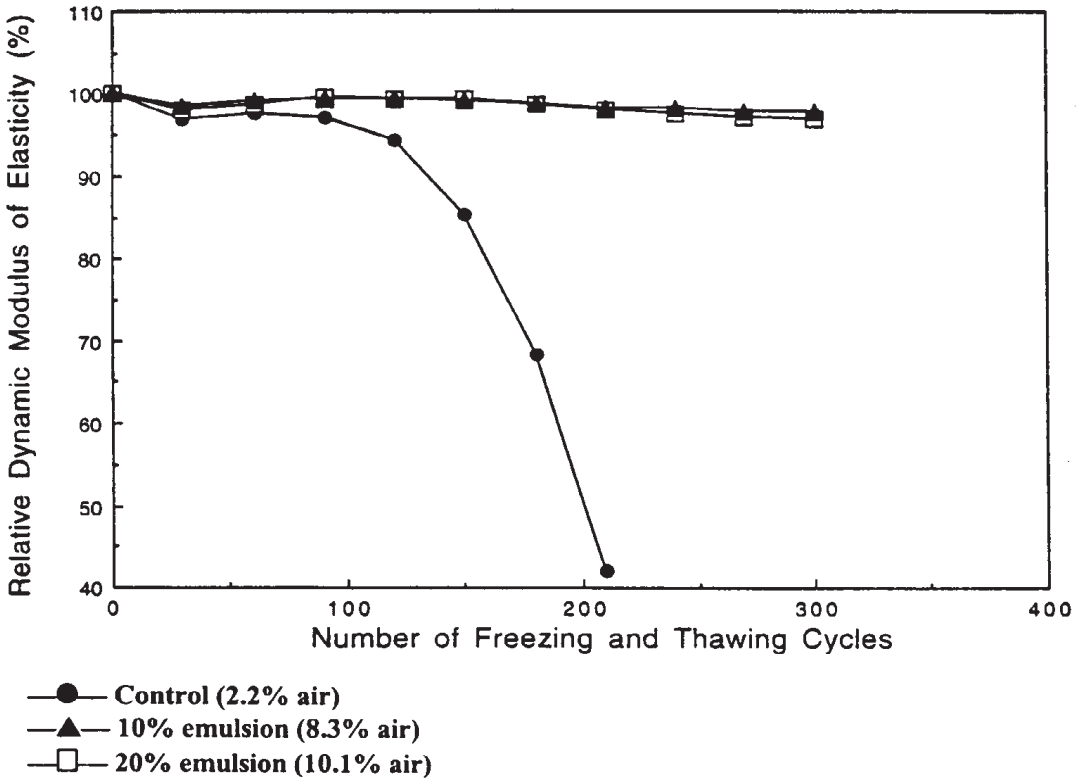


Figure 1

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

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

NCHRP-IDEA Project 5

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

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

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

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

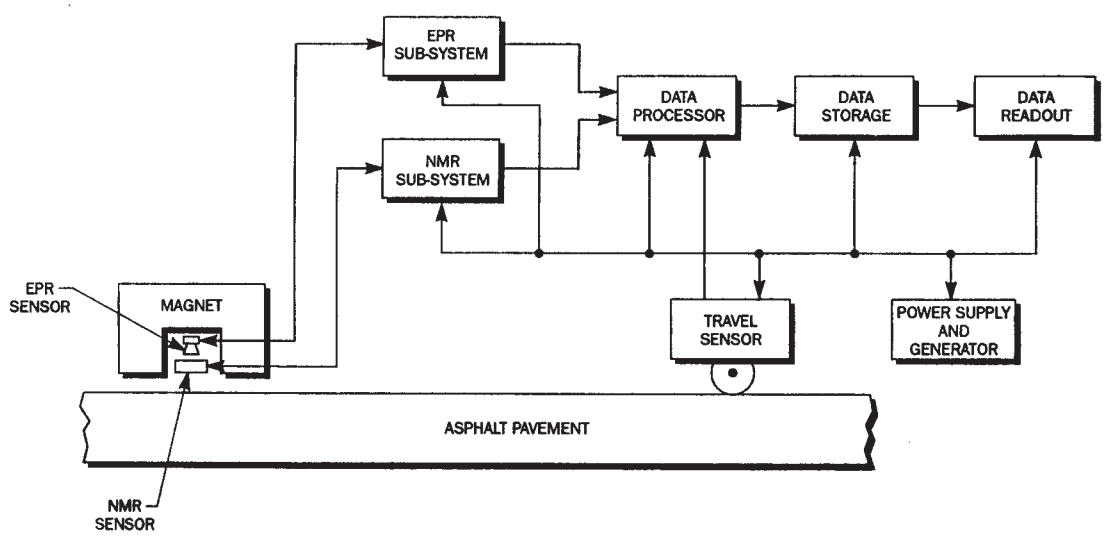


Figure 1

MR system for in situ asphalt inspection.

EXCOGITATED COMPOSITE MULTIFUNCTIONAL LAYER FOR PAVEMENT SYSTEMS

NCHRP-IDEA Project 6

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

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

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

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

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

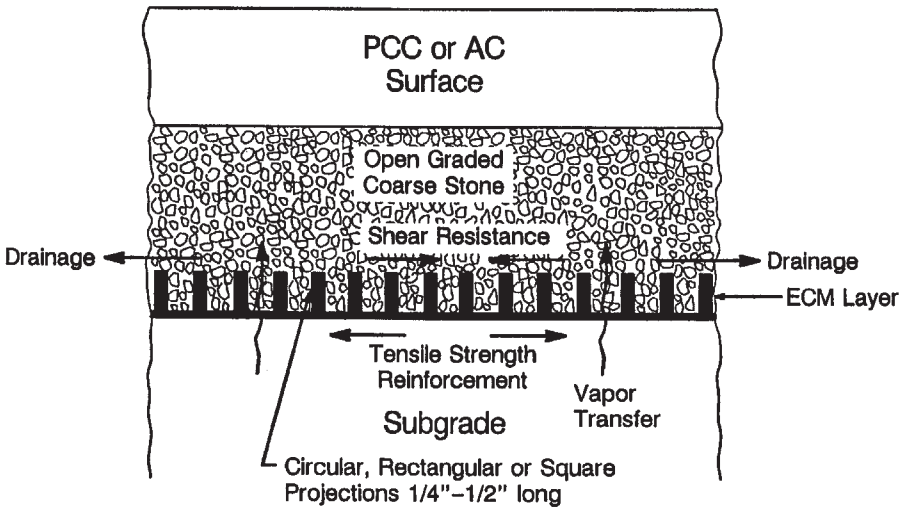


Figure 1

ECM layer concept and functions.

STRATEGY FOR COATING STRUCTURAL STEEL WITHOUT STRINGENT BLASTING REGULATIONS

NCHRP-IDEA Project 7

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

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

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

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

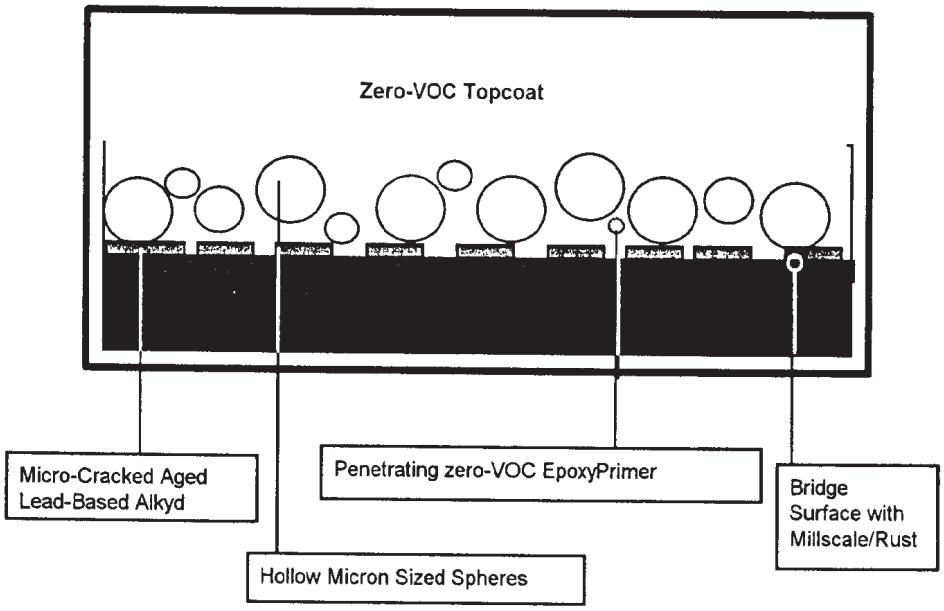


Figure 1

Product applied to bridge use.

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

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

CONSERVATION TRAFFIC CONTROL LOAD SWITCH

NCHRP-IDEA Project 8

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

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

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

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

Figure 1

Installation of conservation load switch in standard cabinet.

CORROSION-RESISTANT STEEL REINFORCING BARS

NCHRP-IDEA Project 9

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

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

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

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

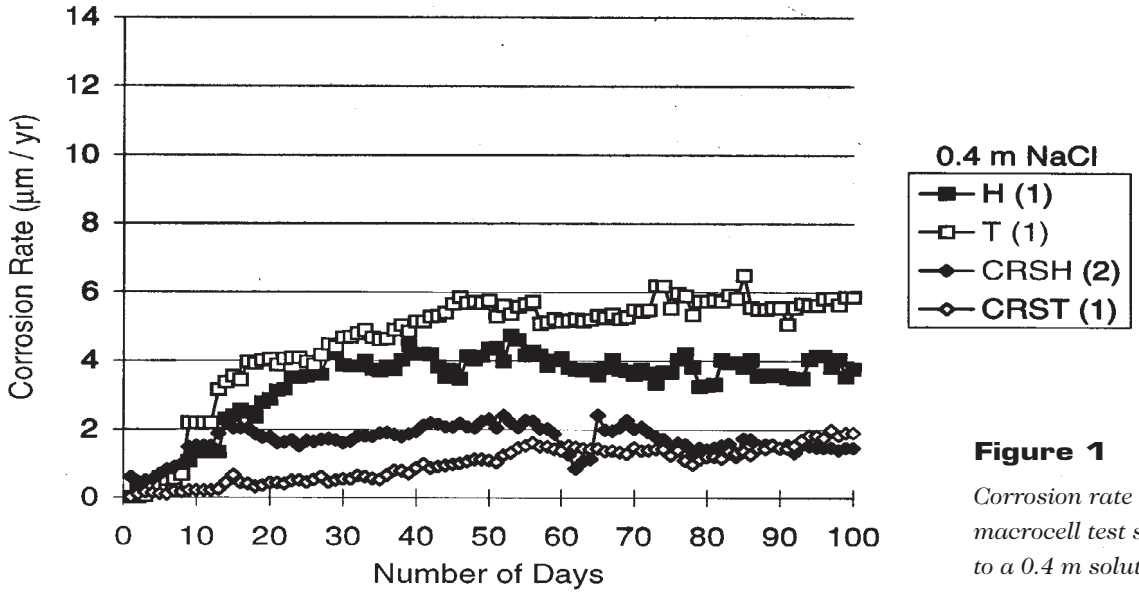


Figure 1

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

METALLIC COATING FOR CORROSION PROTECTION OF STEEL REBARS

NCHRP-IDEA Project 10

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

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

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

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

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

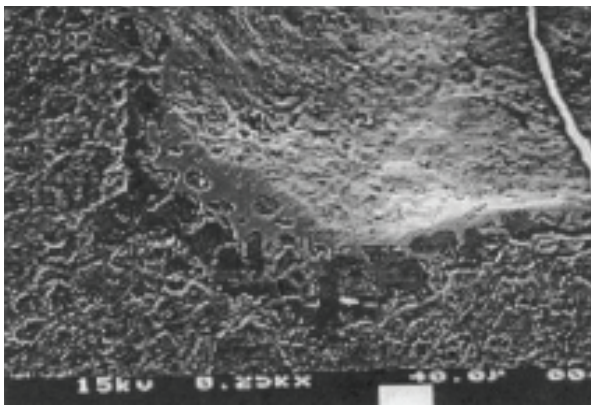


Figure 1

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

REHABILITATION OF STEEL BRIDGES THROUGH THE APPLICATION OF ADVANCED COMPOSITE MATERIALS

NCHRP-IDEA Project 11

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

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

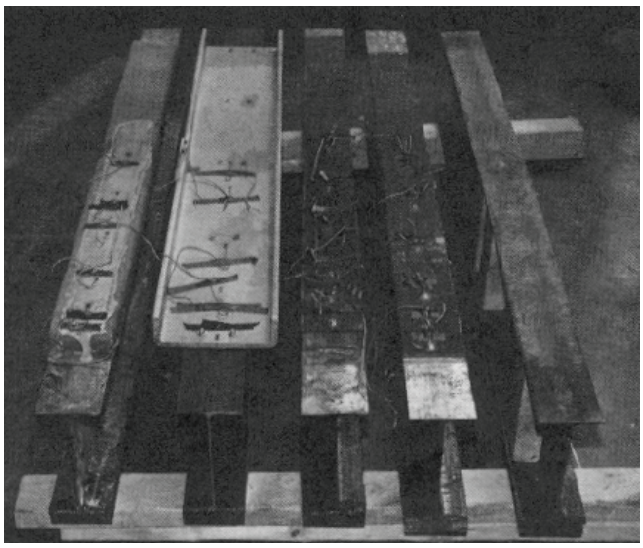


Figure 1

Basic rehabilitation geometries.

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

NCHRP-IDEA Project 12

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

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

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

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

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

Figure 1

Automated road inspection vehicle during field testing.

NEW ADDITIVE FOR IMPROVED DURABILITY OF CONCRETE

NCHRP-IDEA Project 13

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

James R. Humphrey
Todd Chemical, Cheshire, Connecticut

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

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

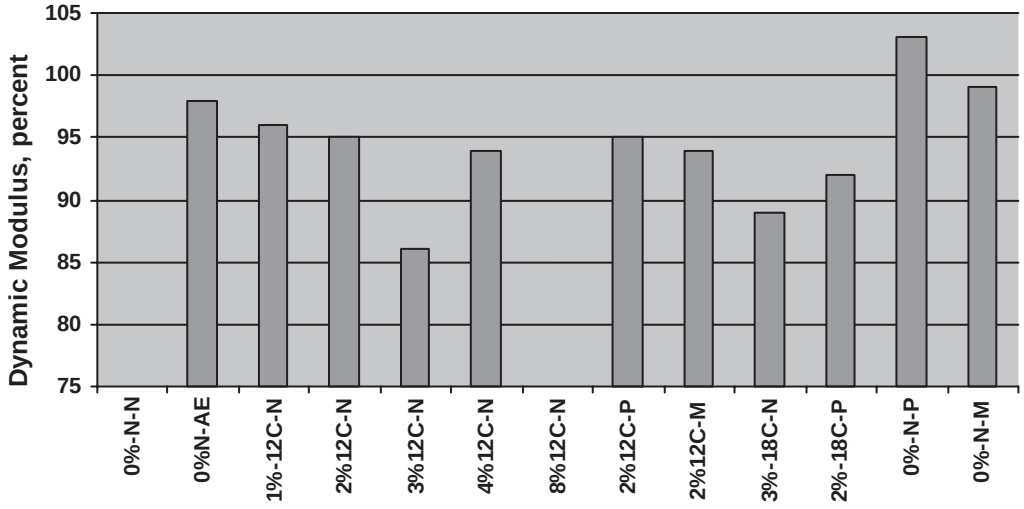


Figure 1

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

UNREINFORCED, CENTRALLY PRESTRESSED CONCRETE COLUMNS AND PILES

NCHRP-IDEA Project 14

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

Paul F. Csagoly
Clearwater, Florida

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

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

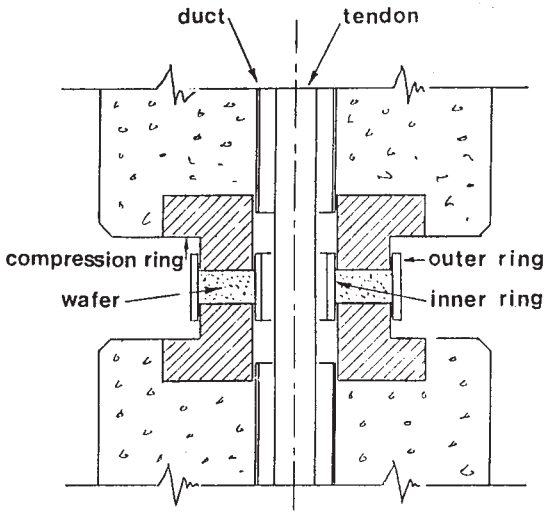


Figure 1

EPF device schematic.

PORTABLE LASER ROAD CREW WARNING SYSTEM

NCHRP-IDEA Project 15

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

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

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

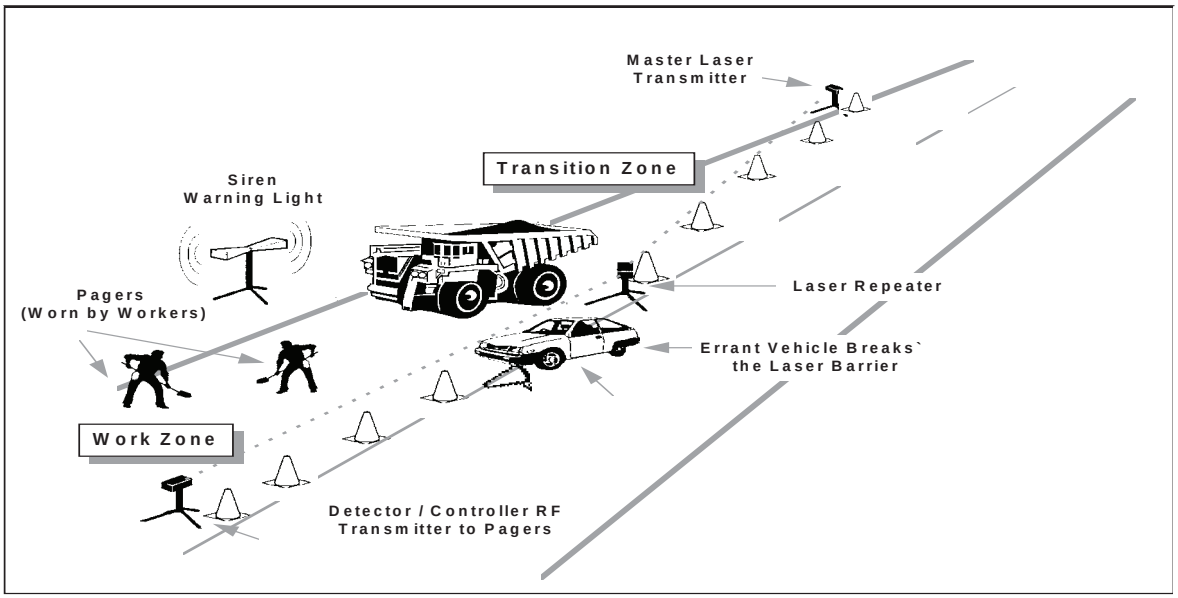


Figure 1

Road crew portable laser warning system.

LASER REMOVAL OF PAINT ON PAVEMENT

NCHRP-IDEA Project 16

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

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

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

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

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

NCHRP-IDEA Project 17

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

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

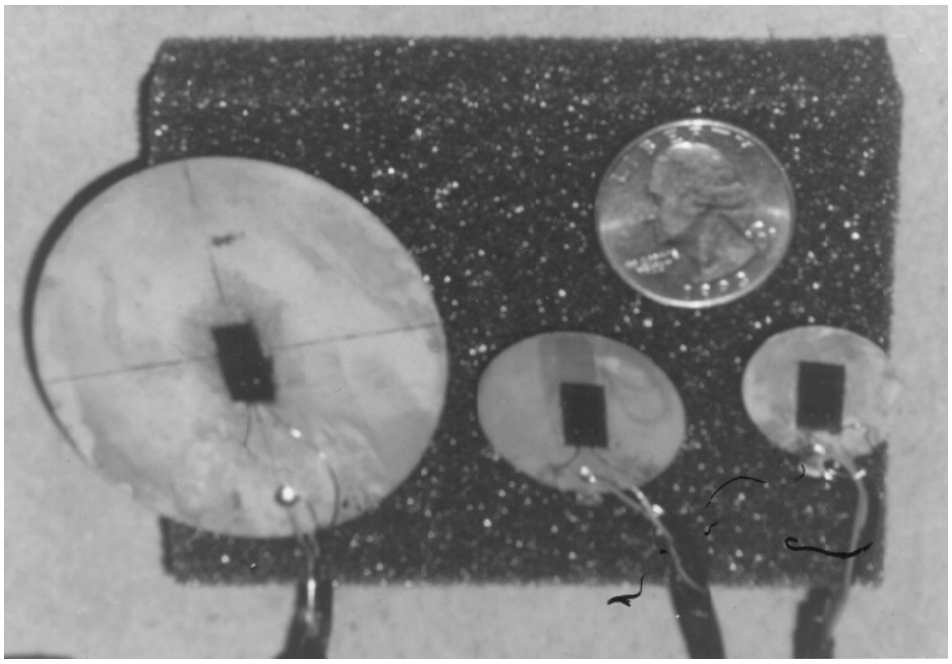


Figure 1

Duomorph assemblies.

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

NCHRP-IDEA Project 18

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

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

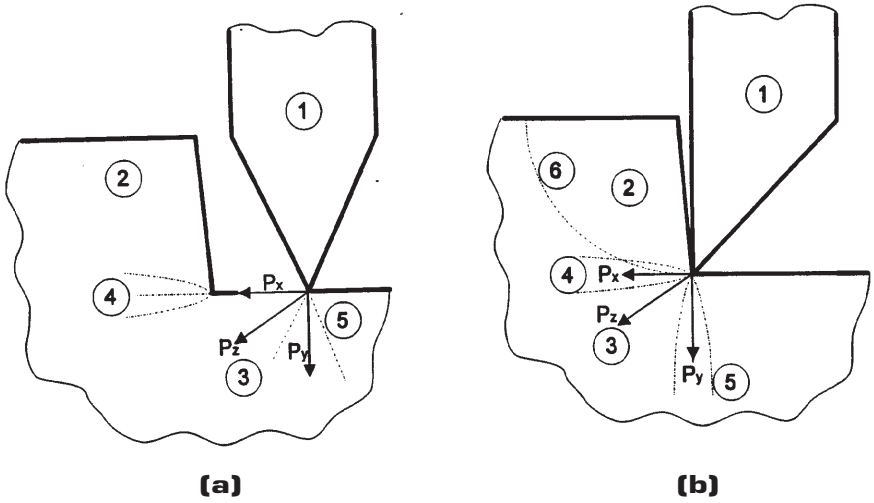


Figure 1

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

ALUMINUM BRONZE ALLOY FOR CORROSION-RESISTANT REBAR

NCHRP-IDEA Project 19

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

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

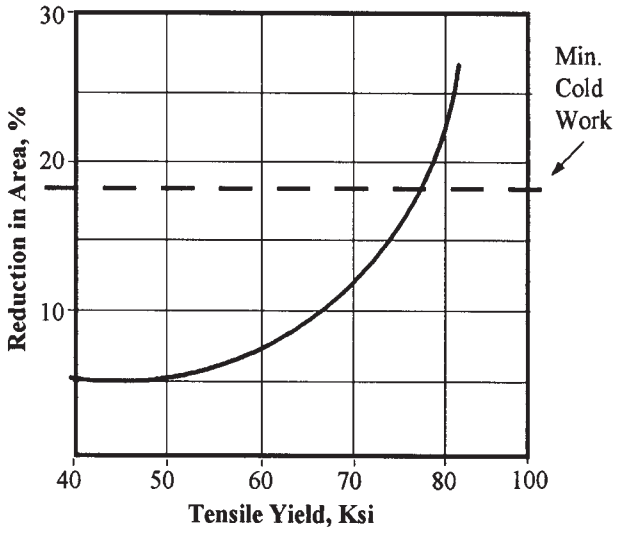


Figure 1

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

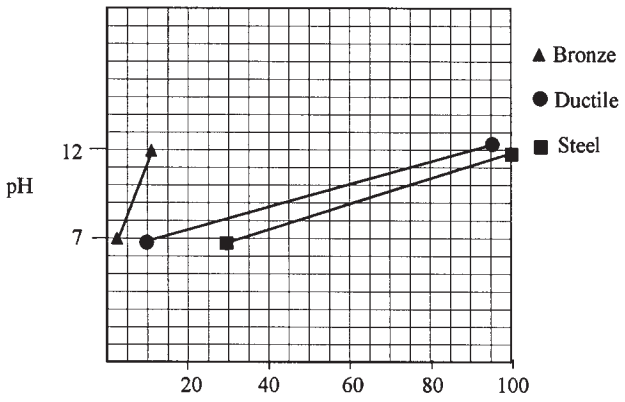


Figure 2

Corrosion rates of three alloys to chloride ion corrosion.

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

NCHRP-IDEA Project 20

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

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

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

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

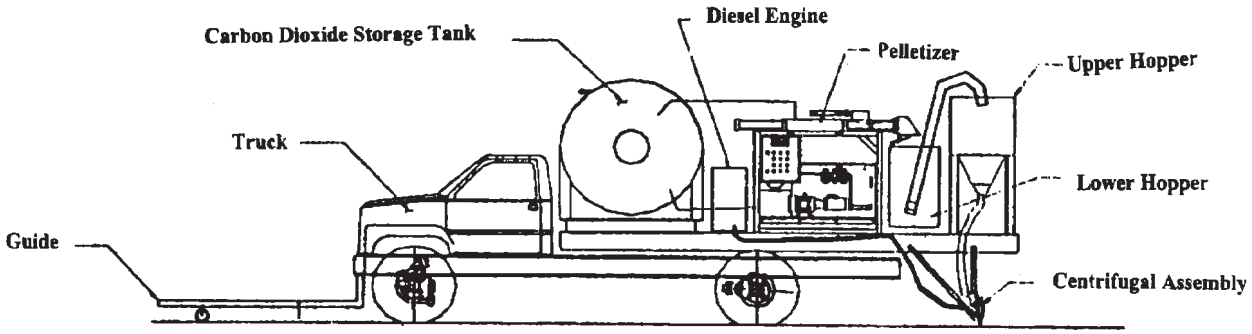


Figure 1

Drawing of proposed centrifugal transport.

DEVELOPMENT OF LED LIGHT SOURCE FOR TRAFFIC CONTROL DEVICES

NCHRP-IDEA Project 21

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

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

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

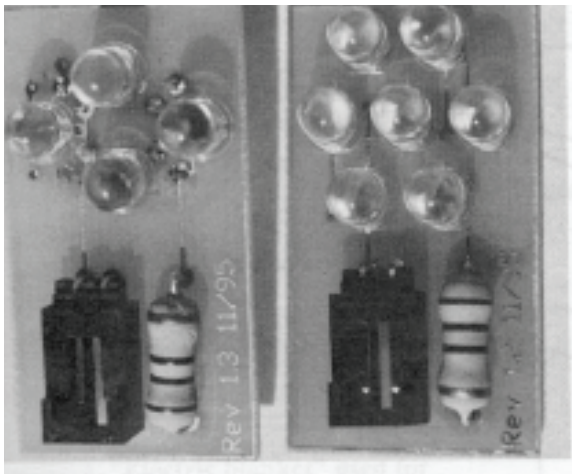


Figure 1

High- and low-intensity LED devices.

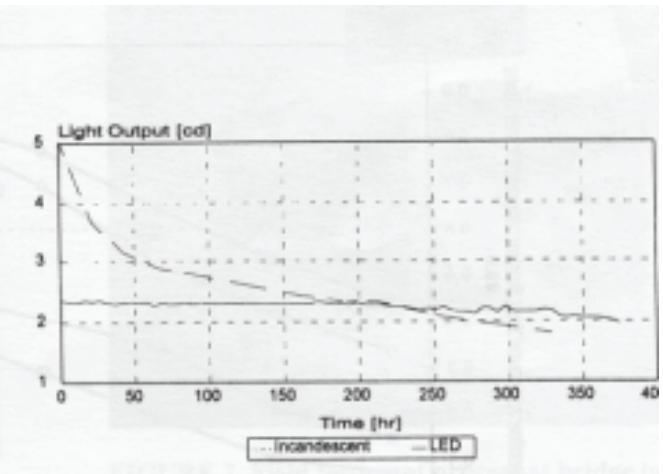


Figure 2

Results of endurance testing.

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

NCHRP-IDEA Project 22

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

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

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

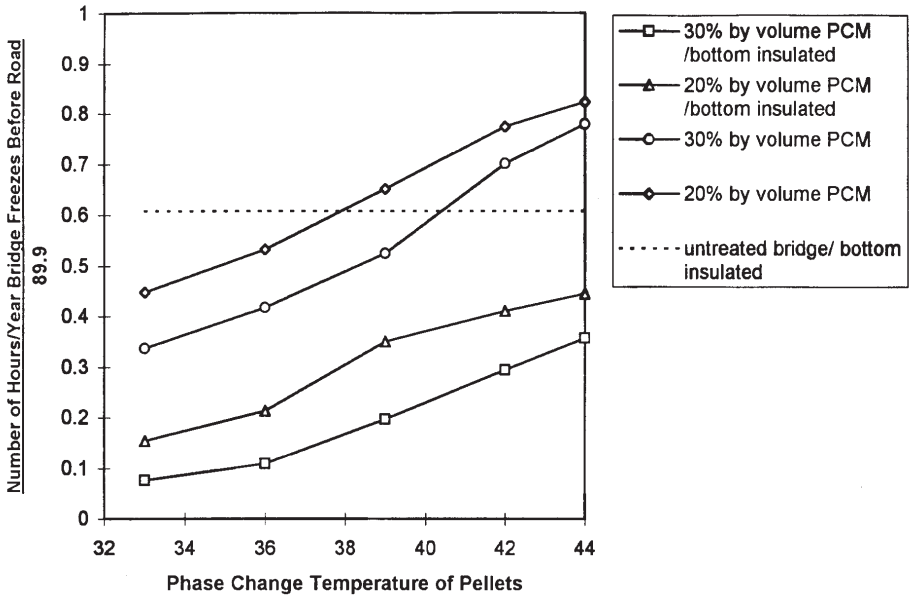


Figure 1

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

LEAD-BASED PAINT REMOVAL FROM STEEL STRUCTURES

NCHRP-IDEA Project 23

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

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

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

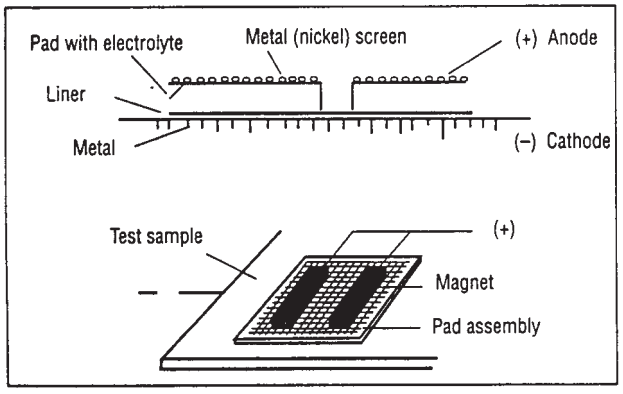


Figure 1

"Electric blanket" used for electrochemically assisted paint removal.

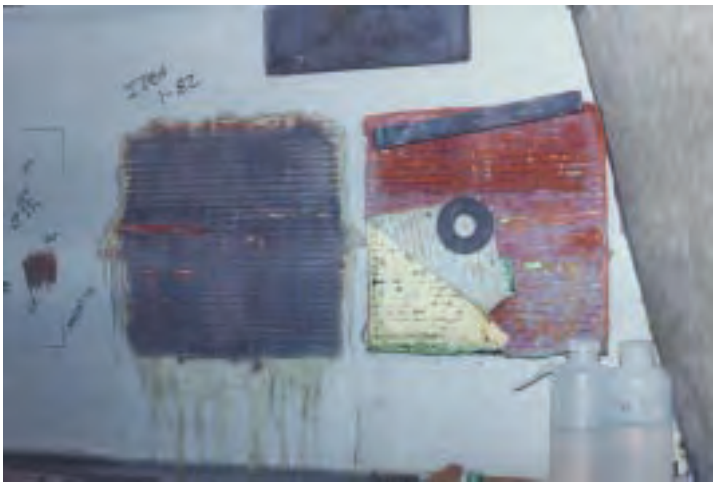


Figure 2

Field testing of process at bridge in Pennsylvania.

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

NCHRP-IDEA Project 24

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

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

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

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

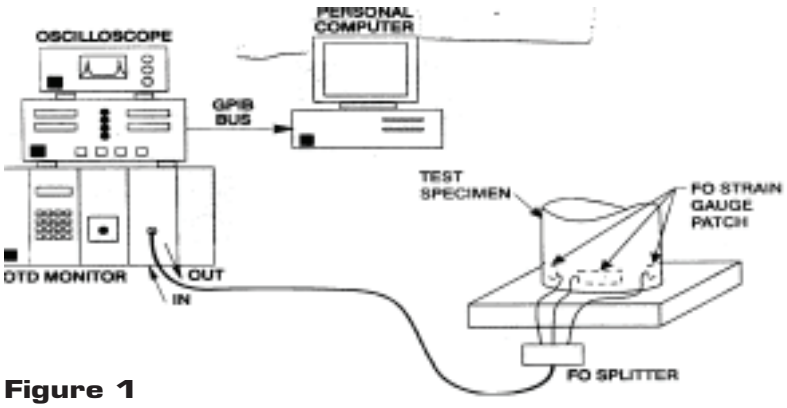


Figure 1

Fiber-optic sensor data acquisition system.

BASALT FIBER COMPOSITE REINFORCEMENT FOR CONCRETE

NCHRP-IDEA Project 25

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

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

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

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

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

Figure 1

Basalt fiber composite rebars.

CONSERVATION CONTROL LOAD SWITCH OPERATIONAL TESTS

NCHRP-IDEA Project 26

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

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

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

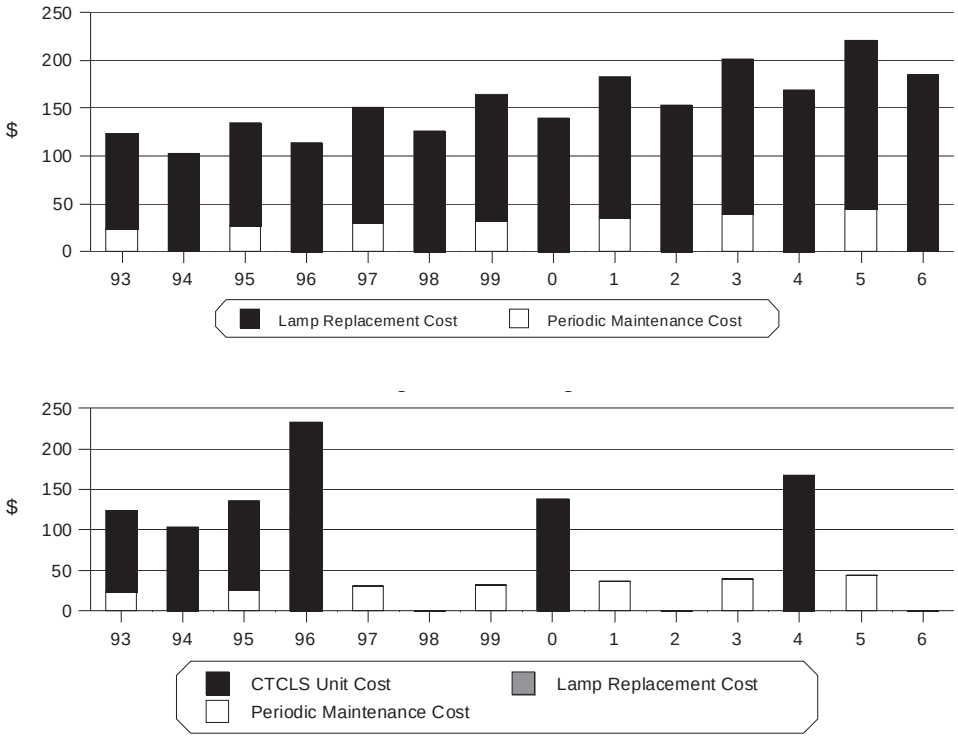


Figure 1

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

AUTOMATED BRIDGE DECK ANTI- AND DEICING SYSTEM

NCHRP-IDEA Project 27

Rand Decker
University of Utah, Salt Lake City, Utah

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

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

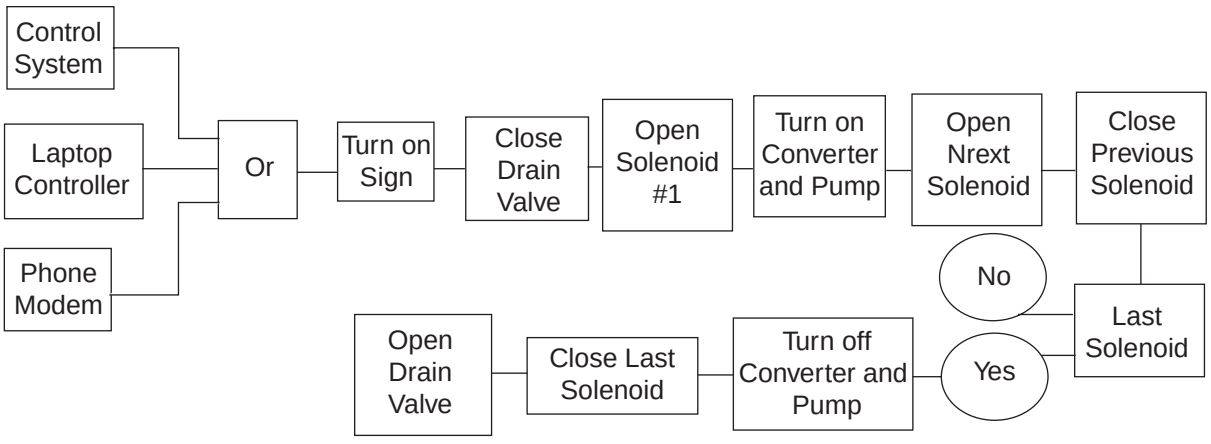


Figure 1

Spray system controller flowchart.

CORROSION-RESISTANT LOW-CARBON STEELS FOR CONCRETE REINFORCEMENT

NCHRP-IDEA Project 28

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

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

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

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

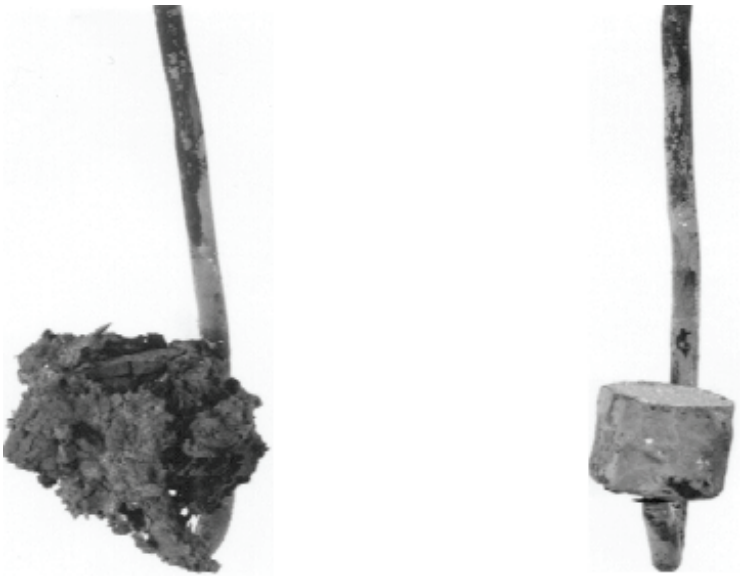


Figure 1

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

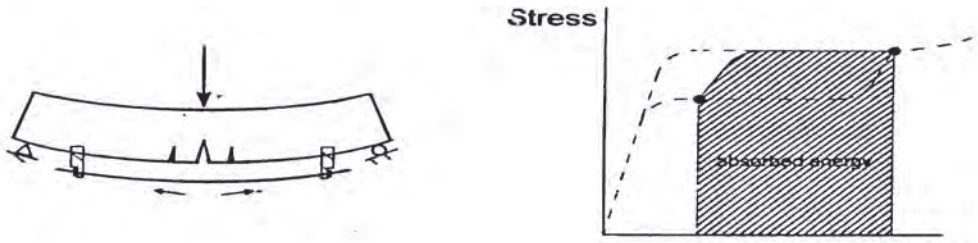
SUPERELASTICITY-BASED MATERIALS FOR BRIDGE REHABILITATION

NCHRP-IDEA Project 29

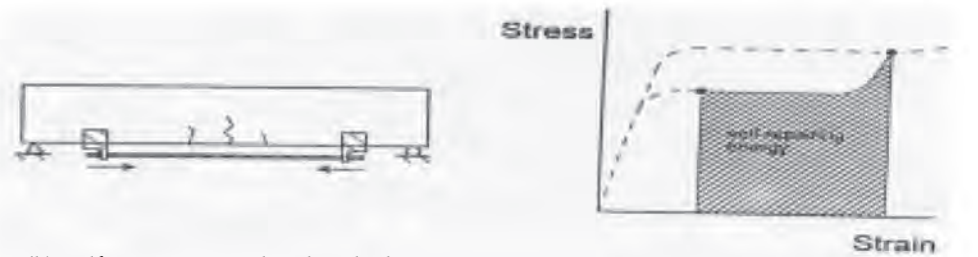
Jer-Wen Hsu and Ken Ostowari [Tel.: (517) 349-5653, Fax: (517) 349-5653]
DPD Inc., Lansing, Michigan

Parviz Souroushian
Michigan State University, East Lansing, Michigan

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



(a) Superelastic energy absorption under damaging loads



(b) Self-repair using the absorbed energy

Figure 1

Schematics of the superelasticity-based post-tensioning system.

RAPID REPLACEMENT COMPOSITE BRIDGE NO. 1

NCHRP-IDEA Project 30

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

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

Figure 1

Composite bridge under test in Russell, Kansas.

COST-EFFECTIVE MICROWAVE SENSOR TO DETECT HIGHWAY ROAD CONDITIONS

NCHRP-IDEA Project 31

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

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

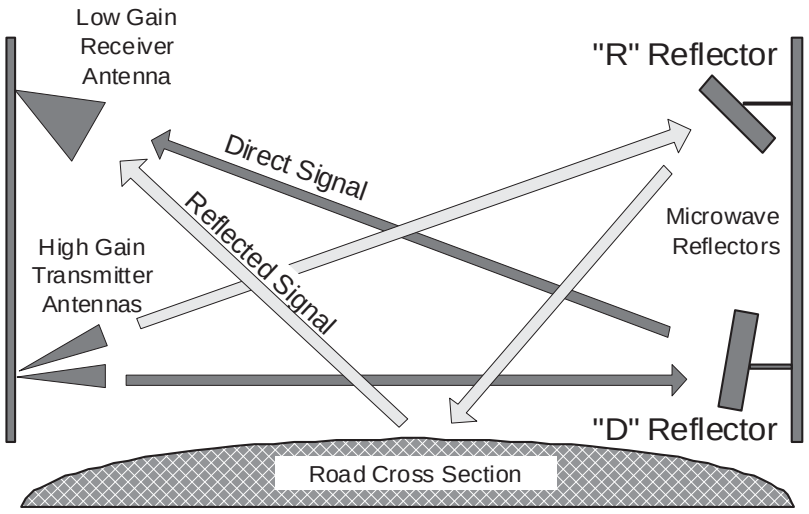


Figure 1

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

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

NCHRP-IDEA Project 32

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

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

Figure 1

Advanced prototype of TransTech System's pavement quality indicator.

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

NCHRP-IDEA Project 33

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

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

Application of fiber composite wrap on Pond Creek Bridge.

Pier concrete column after wrapping.

Figure 1

Field installation of the composite wrap rehabilitation technology.

HIGHWAY GUARDRAIL INFRASTRUCTURE: SAFER TERMINAL DESIGNS

NCHRP-IDEA Project 34

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

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

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

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

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

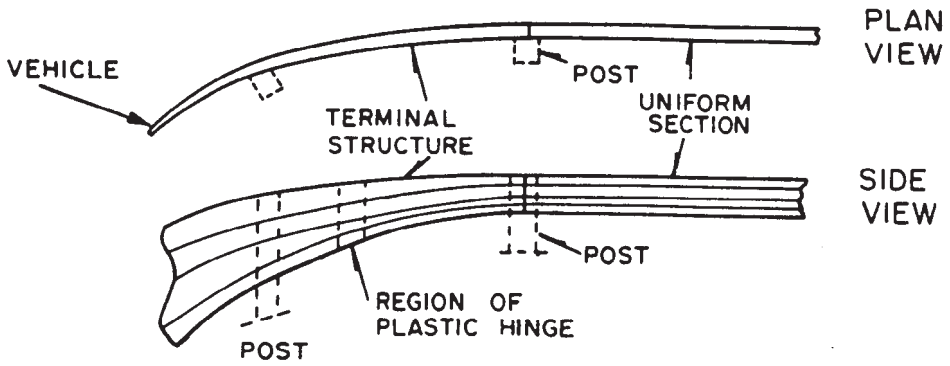


Figure 1

A terminal structure concept designed to avoid vehicle spearing.

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

NCHRP-IDEA Project 37

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

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

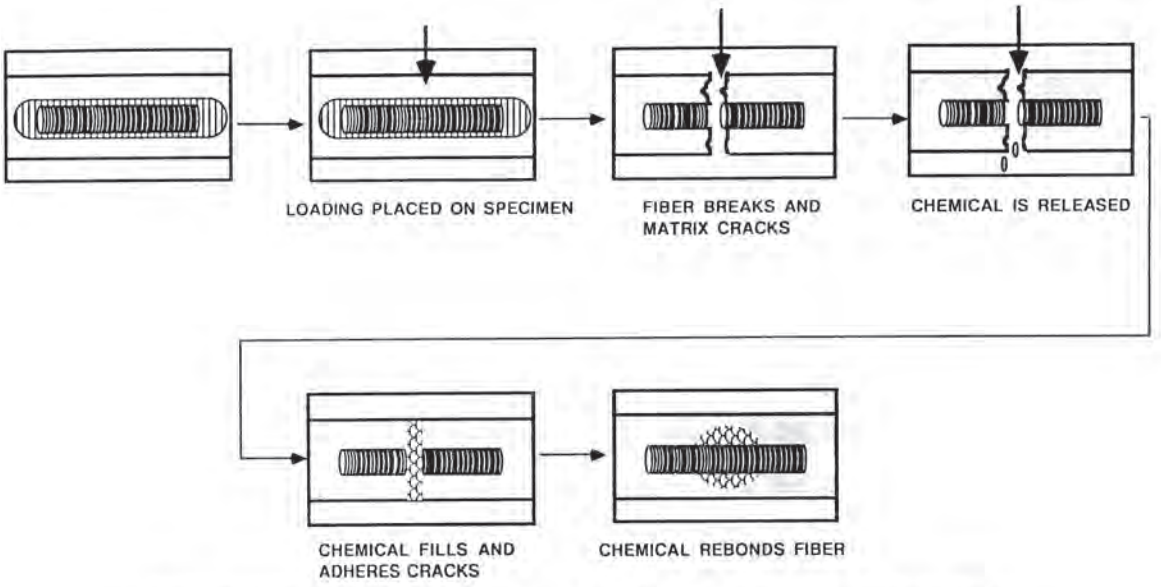


Figure 1

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

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

NCHRP-IDEA Project 38

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

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

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

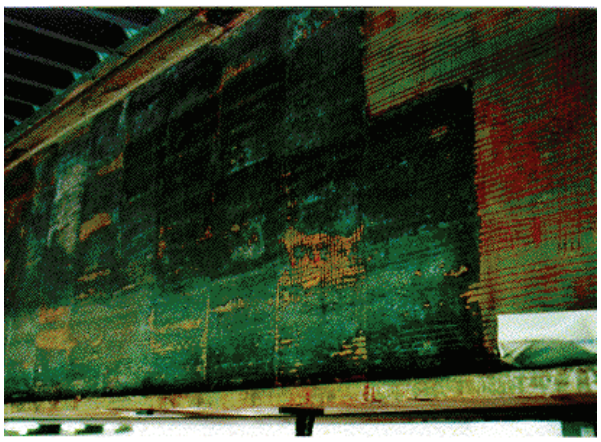


Figure 1

Treated area after initial cleaning.

ESTIMATING TRUCK ATTRIBUTES FROM BRIDGE STRAIN DATA USING NEURAL NETWORKS

NCHRP-IDEA Project 40

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

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

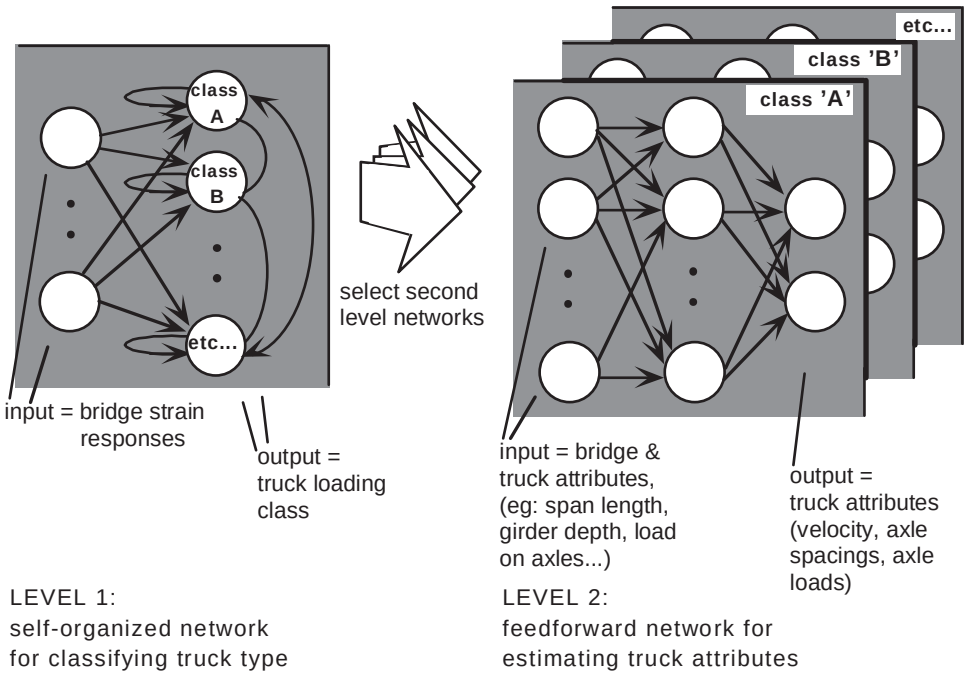


Figure 1

Architecture of proposed networking system.

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

NCHRP-IDEA Project 41

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

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

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

DUAL-CORE FIBER OPTIC WIM SYSTEM

NCHRP-IDEA Project 42

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

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

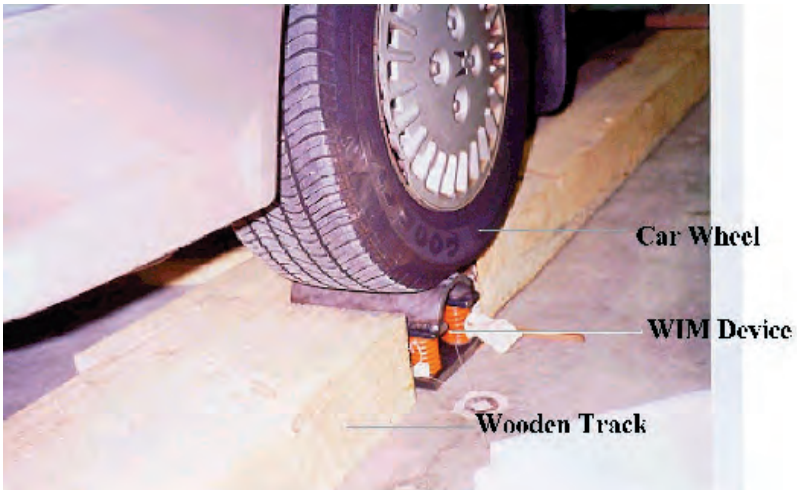


Figure 1

Car wheel testing in progress.

ROBOTIC SYSTEM FOR UNDERWATER BRIDGE INSPECTION AND SCOUR EVALUATION

NCHRP-IDEA Project 43

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

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

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

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

Figure 1

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

ROLLER-MOUNTABLE ASPHALT PAVEMENT QUALITY INDICATOR USING DIFFERENTIAL MICROWAVE SIGNALS

NCHRP-IDEA Project 44

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

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

Figure 1

Prototype system for asphalt pavement density determination.

PERFORMANCE EVALUATION OF BASALT FIBERS AND COMPOSITE REBARS AS CONCRETE REINFORCEMENT

NCHRP-IDEA Project 45

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

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

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

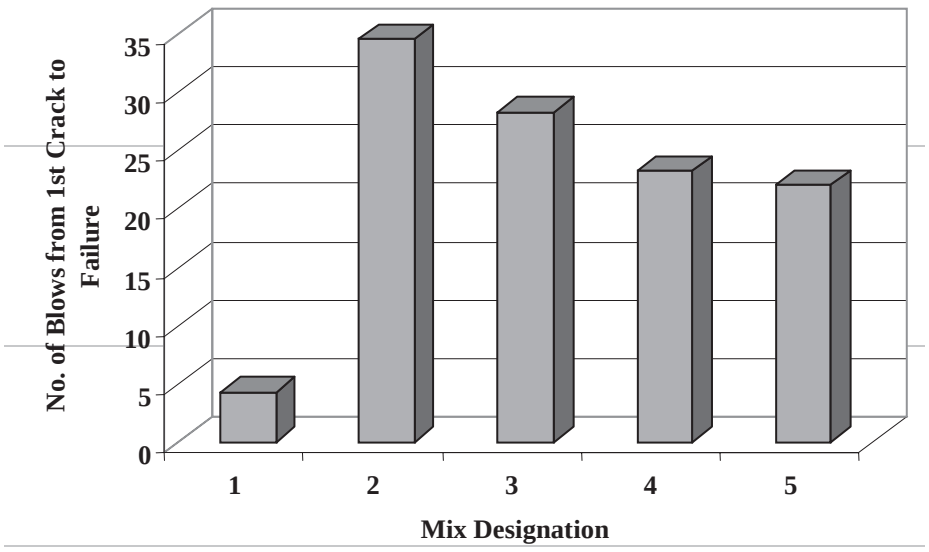


Figure 1

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

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

NCHRP-IDEA Project 46

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

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

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

PAVEMENT QUALITY INDICATOR: FIELD OPERATIONAL TESTING AND PRODUCT TRANSFER

NCHRP-IDEA Project 47

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

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

Figure 1

Pavement quality indicator prototype.

FIELD TRIAL OF SHAPE MEMORY-BASED REHABILITATION SYSTEM

NCHRP-IDEA Project 48

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

Parviz Soroushian
Michigan State University, East Lansing, Michigan

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

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

Figure 1

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

AUTOMATION OF LEGENDS PAINTING

NCHRP-IDEA Project 49

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

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

Figure 1

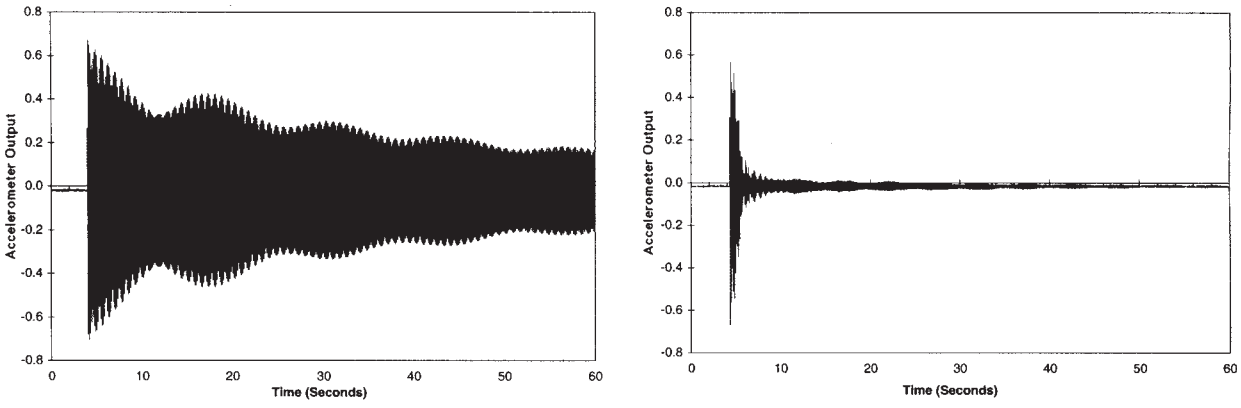
Truck-mounted RoadWriter™ prototype system in field operation.

DAMPER SYSTEMS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

NCHRP-IDEA Project 50

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

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



(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

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

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

Figure 1

Bridge girders rehabilitated with carbon fiber-reinforced polymer plates.

ENVIRONMENTALLY FRIENDLY PASSIVATING COATINGS FOR STEEL REBARS

NCHRP-IDEA Project 52

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

Alberto Sagues
University of South Florida, Tampa, Florida,

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

Richard Brown
University of Rhode Island, Kingston, Rhode Island

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

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

NOVEL APPROACH FOR PREDICTING REMAINING LIFE OF CONCRETE BRIDGE STRUCTURES

NCHRP-IDEA Project 54

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

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

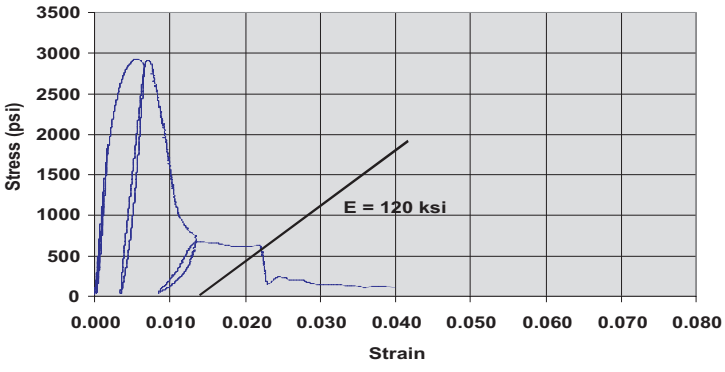


Figure 1

Stress strain response—compression test.

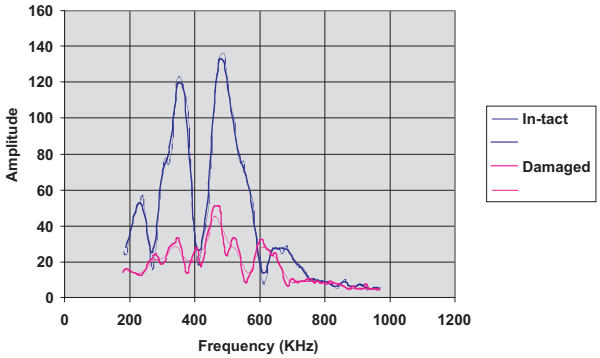


Figure 2

Voltage amplitude vs frequency: Incidence angle 25 deg.

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

NCHRP-IDEA Project 55

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

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

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

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

Figure 1

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

BRIDGE INSPECTION WITH SERPENTINE ROBOTS

NCHRP-IDEA Project 56

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

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

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

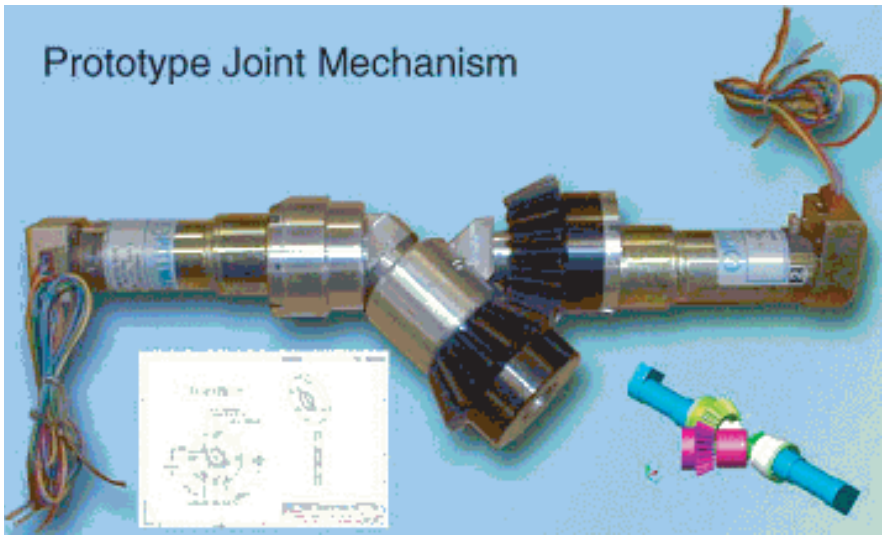


Figure 1

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

STABILIZATION OF LANDSLIDES USING HORIZONTAL WICK DRAINS

NCHRP-IDEA Project 57

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

C. Dale Elifrits
University of Missouri, Rolla, Missouri

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

Figure 1

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

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

NCHRP-IDEA Project 58

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

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

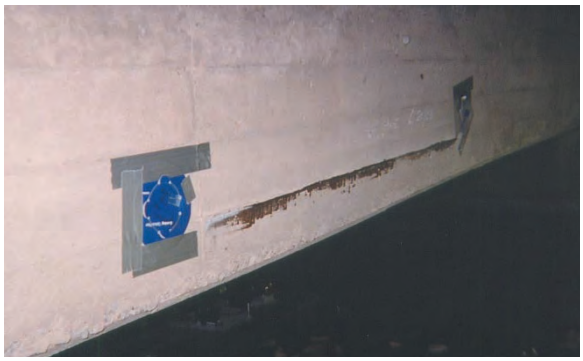


Figure 1

Installed optical sensor.

CONTROL SYSTEMS FOR LIVE LOAD AND LIVE LOAD EFFECTS ON BRIDGES

NCHRP-IDEA Project 59

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

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

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

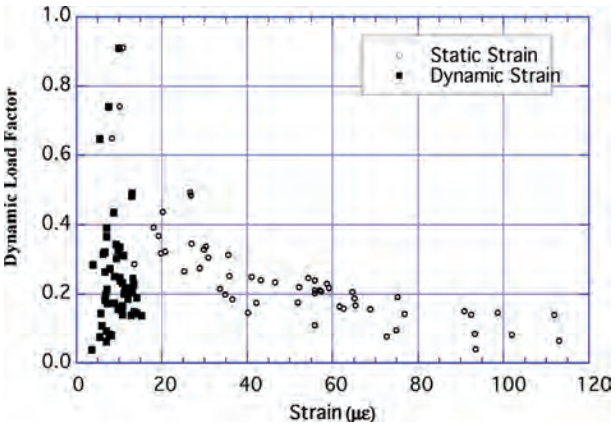


Figure 1

DLF vs. static and dynamic strain.

PRODUCT APPLICATION OF A HYBRID COMPOSITE BEAM SYSTEM

NCHRP-IDEA Project 60

John Hillman [Tel.: (312) 616-7495, Fax: (312) 616-6069, Email: HillmanJR@teng.com]
Teng & Associates, Chicago, Illinois

This project, jointly funded by NCHRP IDEA and High Speed Rail IDEA programs involved the manufacturing and testing of a prototype Hybrid-Composite Beam (HCB) bridge for railroad and highway applications. The beam (Figure 1a) consists of an outer fiber-reinforced plastic shell, a compression reinforcement (provided by concrete pumped into an arch conduit within the beam shell) and a tension reinforcement (provided by high-strength steel prestressing strands running along the bottom flanges of the beam shell). The HCB is not only corrosion resistant but also lightweight (only about one-seventh the weight of precast concrete and one-third the weight of steel for the same size bridge) making it easier and less costly to ship and erect bridges with HCB than with traditional materials. The beam, after a successful test at a rail test track in Pueblo, Colorado (Figure 1b), was installed on highway bridges in Illinois (6-beam 57-foot, Lockport Township) and New Jersey (6-beam 32-foot, Cedar Grove), and it is currently being used in the construction of the 8-beam 540-foot Knickerbocker Bridge in Boothbay, Maine. Missouri is using HCB in three demonstration bridge projects with support from FHWA's Highways for LIFE Program, and Utah plans to do the same on one of its projects. The IDEA product was one of the top 25 inventions of the *2006–2007 Modern Marvels Invent Now Challenge,* an annual contest sponsored by the History Channel and the National Inventors Hall of Fame Foundation. The IDEA investigator also received the Engineering New Record's 2010 Award of Excellence for his invention. AASHTO's Technology Implementation Group selected HCB as one of the focus technologies for implementation in 2011.

(a) *(b)*

Figure 1

(a) Components of the hybrid composite beam, and (b) bridge under test.

THE PAVEMENT THICKNESS DENSITY METER

NCHRP-IDEA Project 61

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

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

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

Figure 1

Portable PTDM.

A NEW TECHNIQUE FOR CHARACTERIZING PAVEMENT SURFACE PROFILES AND TEXTURES

NCHRP-IDEA Project 62

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

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

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

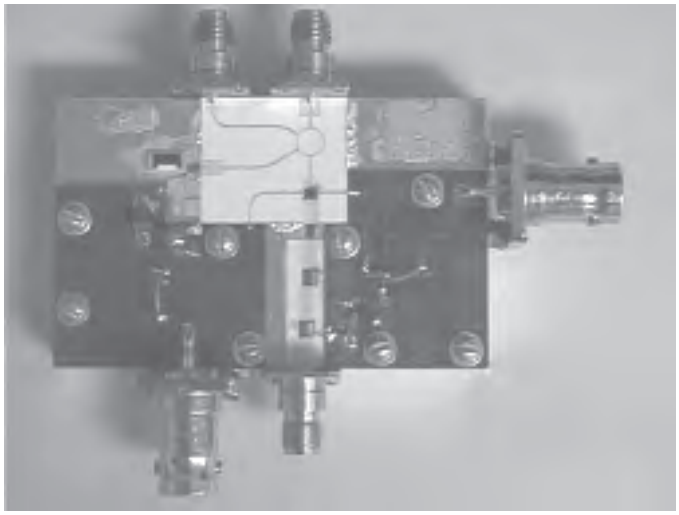


Figure 1

The millimeter-wave sensor prototype.

MANUFACTURE AND TESTING OF A FILAMENT WOUND COMPOSITE BRIDGE SUPERSTRUCTURE

NCHRP-IDEA Project 63

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

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

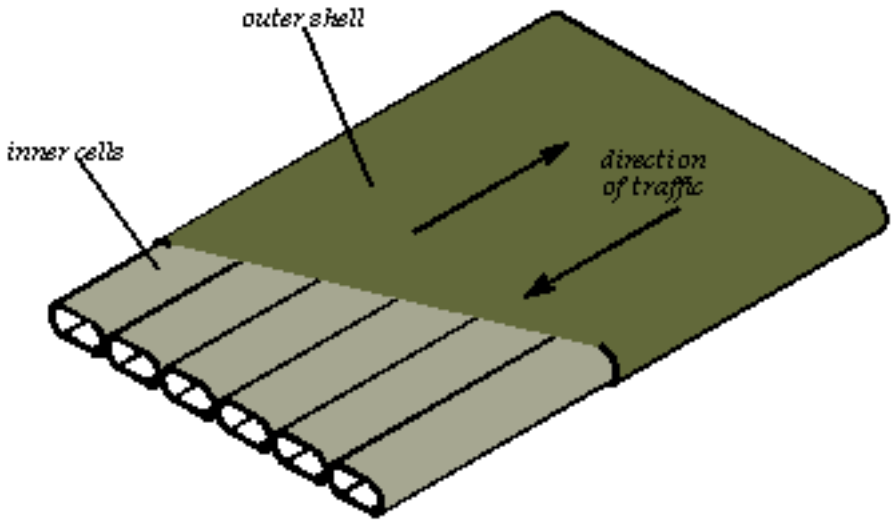


Figure 1

Bridge structural system.

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

NCHRP-IDEA Project 64

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

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

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

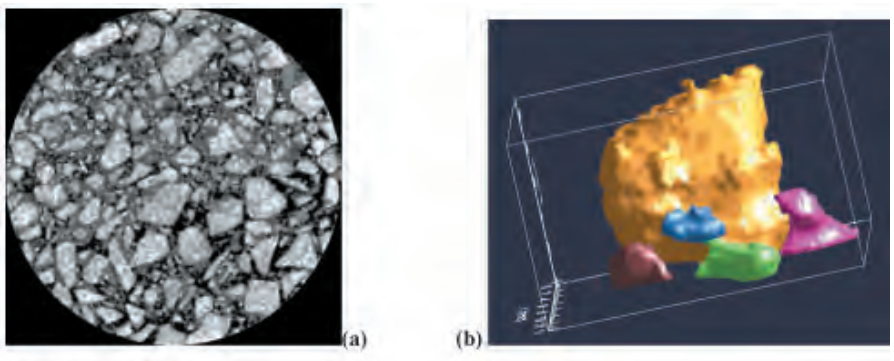


Figure 1

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

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 65

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

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

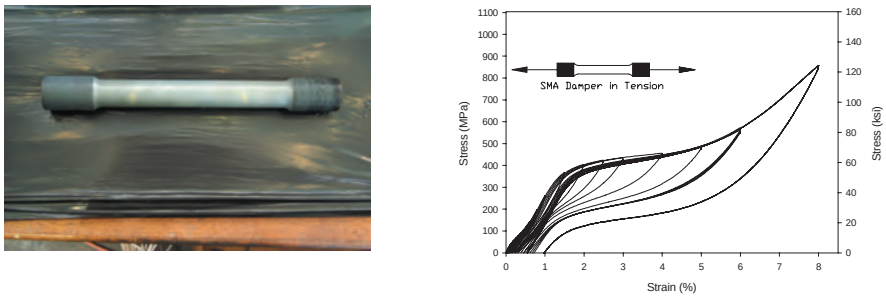


Figure 1

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

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

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

NCHRP-IDEA Project 66

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

Pizhong Qiao
The University of Akron, Akron, Ohio

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

Figure 1

Photo of steel-sleeve connector.

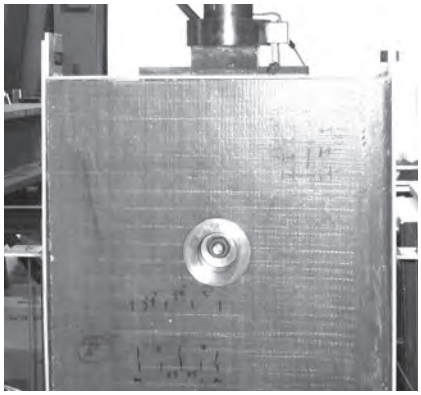


Figure 2

Photo of FRP panel and connector.

ALL COMPOSITE BRIDGE SIDEWALK

NCHRP-IDEA Project 67

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

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

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

Figure 1

E. T. Techtonics composite pedestrian bridge.

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

NCHRP-IDEA Project 68

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

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

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

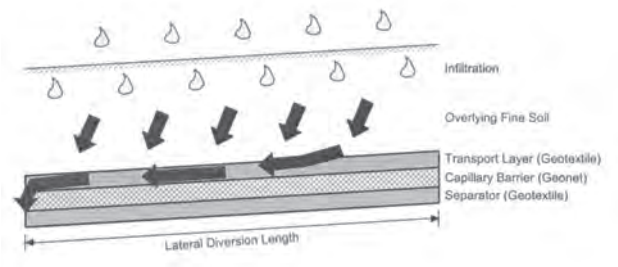


Figure 1

Geocomposite capillary barrier drain.

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

NCHRP-IDEA Project 69

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

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

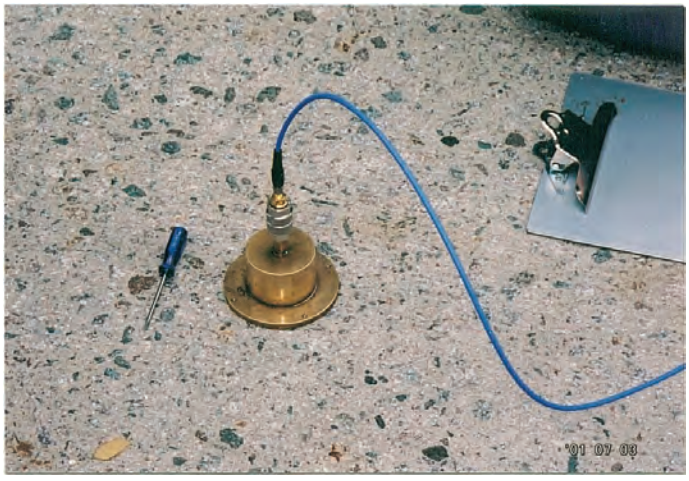


Figure 1

CSP probe.

FLAMESPRAY COATING AS AN ENVIRONMENTALLY ACCEPTABLE PAVEMENT MARKING TECHNIQUE

NCHRP-IDEA PROJECT 70

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

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

IMPLEMENTATION OF TUNED DAMPERS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

NCHRP-IDEA Project 71

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

Habib Tabatabai
University of Wisconsin, Milwaukee, Wisconsin

Niket M. Telang
Construction Technology Laboratories Inc.

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

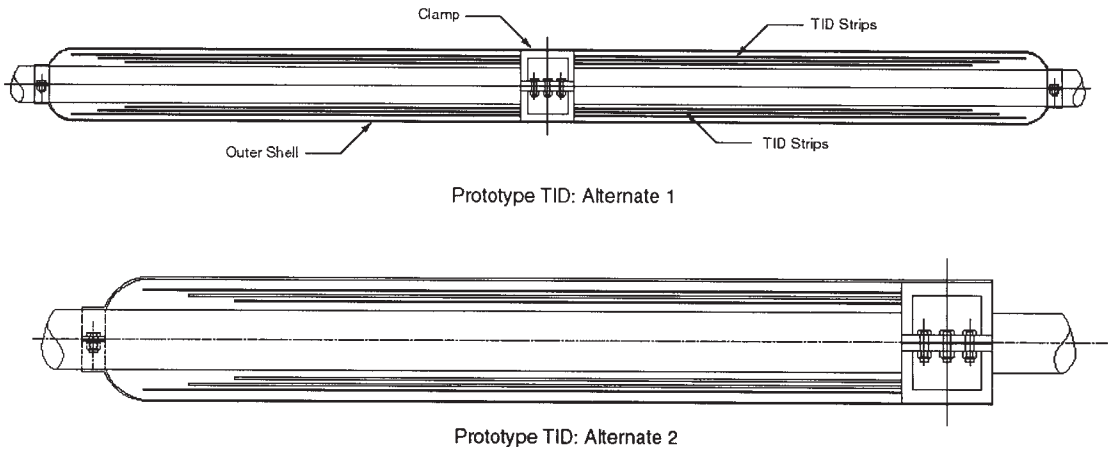


Figure 1

Tuned Induced Damper (TID) system.

IMPROVED FILTRATION OF WASH WATER GENERATED DURING BRIDGE MAINTENANCE PAINTING

NCHRP-IDEA Project 72

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

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

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

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

Figure 1

Wash water filtration system.

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

NCHRP-IDEA Project 73

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

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

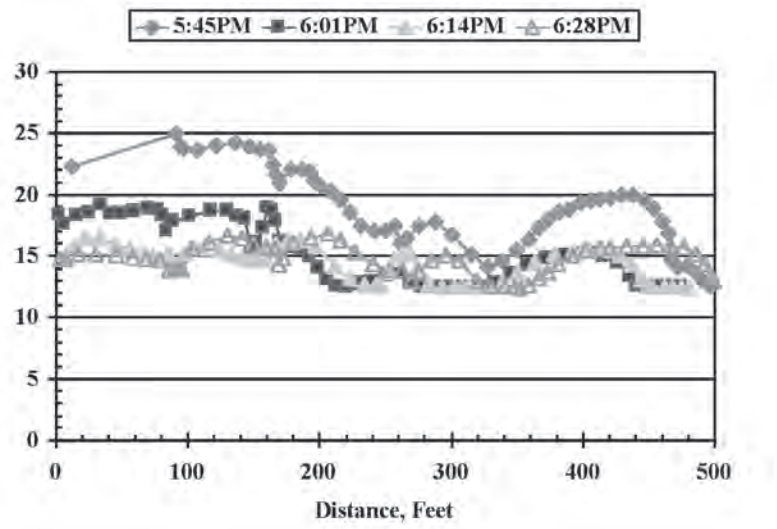


Figure 1

Temperature ranges for four runs on an existing pavement.

ADHESION TOOL FOR OVERCOATING RISK-REDUCTION ANALYSIS

NCHRP-IDEA Project 74

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

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

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

AUTOMATED MOBILE HIGHWAY SIGN RETROREFLECTIVITY MEASUREMENT

NCHRP-IDEA Project 75

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

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

Figure 1

Imaging equipment mounted in a vehicle.

STABILIZATION OF LANSDLIDES USING HORIZONTAL WICK DRAINS

NCHRP-IDEA Project 76

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

C. Dale Elifrits
University of Missouri, Rolla, Missouri

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

Figure 1

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

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

NCHRP-IDEA Project 77

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

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

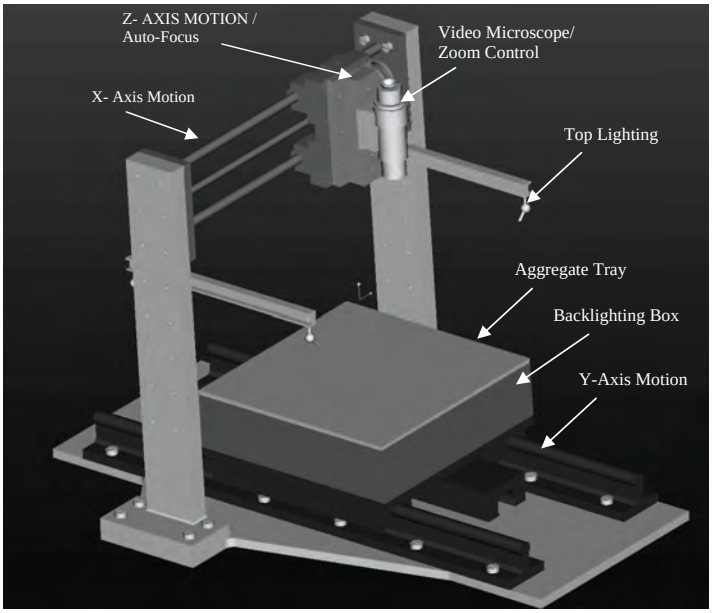


Figure 1

3-D graphical model of AIMS.

AGGREGATE SHAPE CHARACTERIZATION USING DIGITAL IMAGE PROCESSING

NCHRP-IDEA Project 78

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

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

Figure 1

New flat and elongated image analyzer.

CONCRETE ROAD RECYCLER—HAMMER-ANVIL TEST RIG

NCHRP-IDEA Project 79

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

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

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

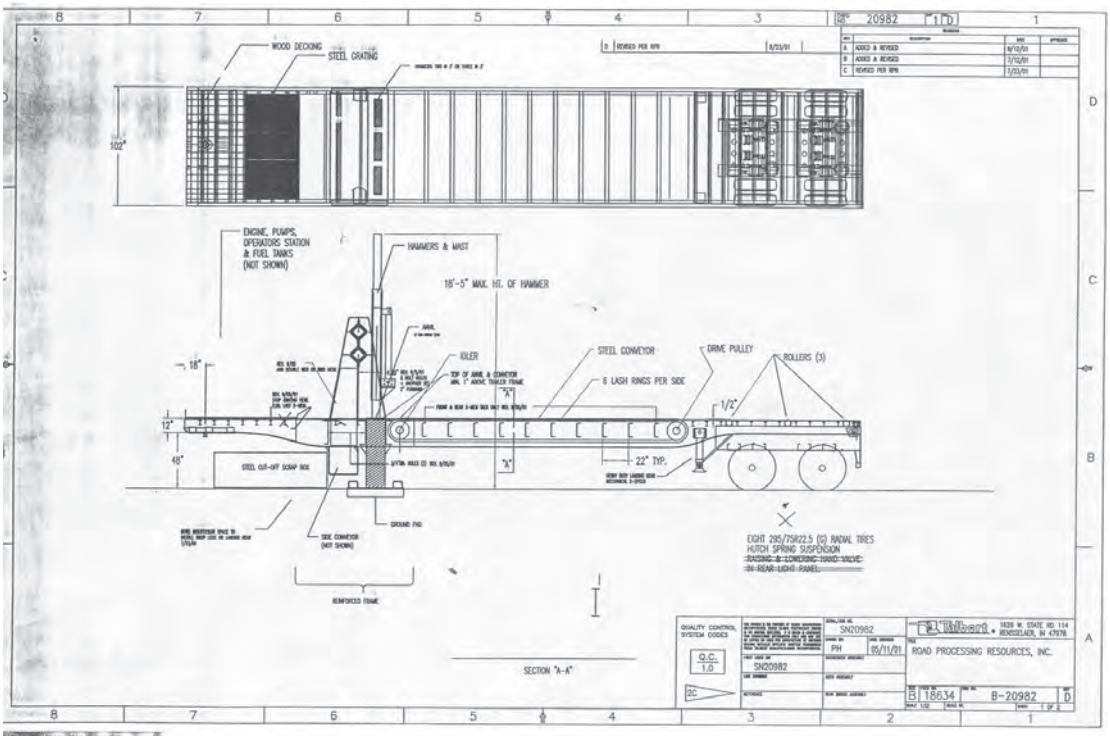


Figure 1

Schematic diagram of road recycling machine.

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

NCHRP-IDEA Project 80

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

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

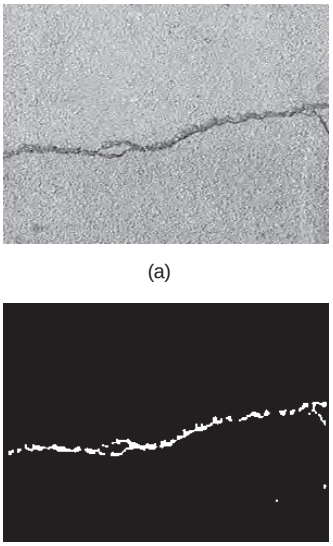
AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION SYSTEM

NCHRP-IDEA Project 81

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

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

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

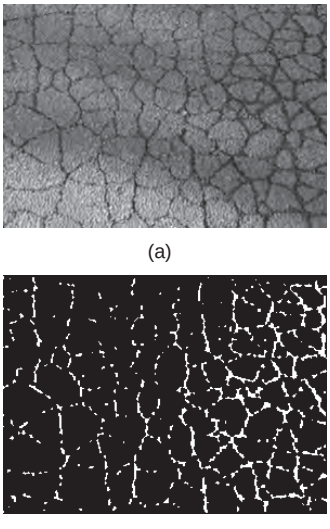


(a)

(b)

Figure 1

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



(a)

(b)

Figure 2

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

DEVELOPMENT AND FIELD VERIFICATION OF TORSIONAL CYLINDRICAL IMPULSE SHEAR TEST

NCHRP-IDEA Project 82

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

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

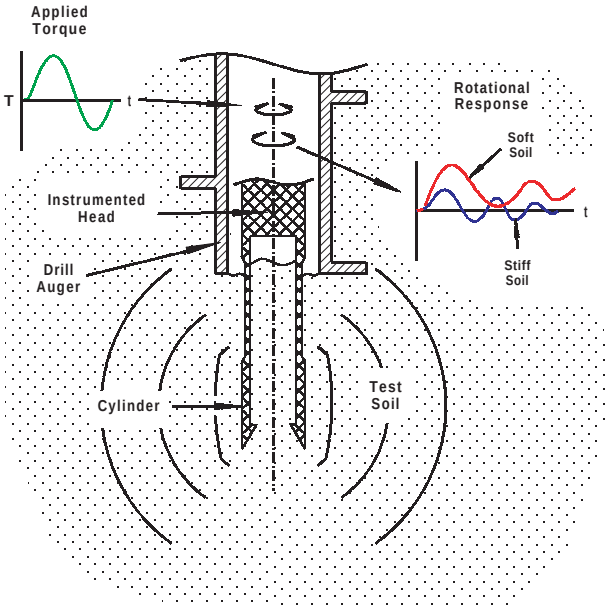


Figure 1

Basic idea of impulse shear test.

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

NCHRP-IDEA Project 83

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

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

Figure 1

Prototype ice detection system.

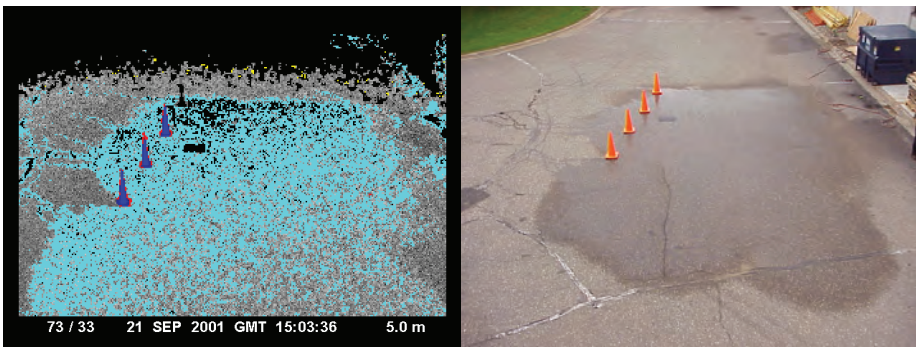


Figure 2

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

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

NCHRP-IDEA Project 84

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

Mihai O. Marasteanu
University of Minnesota, Minneapolis, Minnesota

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

WATERPROOFING CONCRETE HIGHWAYS

NCHRP-IDEA Project 85

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

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

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

ADVANCED CONCEPT CONCRETE USING BASALT FIBER/BF COMPOSITE REBAR REINFORCEMENT

NCHRP-IDEA Project 86

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

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

AN IN SITU SHEAR TEST FACILITY FOR ASPHALT CONCRETE PAVEMENTS

NCHRP-IDEA Project 87

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

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

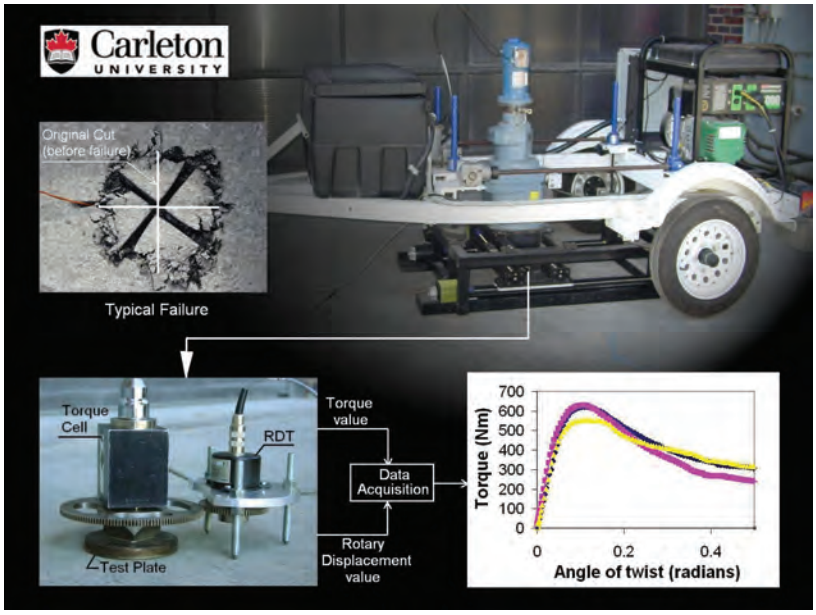


Figure 1

The InSiSST™ system.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION

NCHRP-IDEA Project 88

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

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

Figure 1

The dual-camera subsystem.

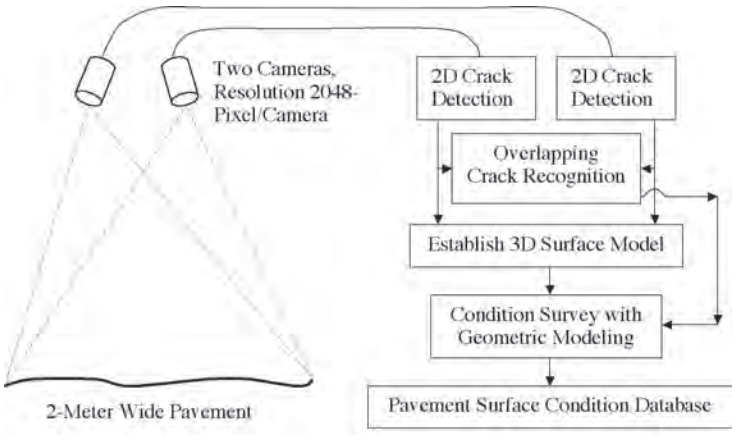


Figure 2

General procedures for automated condition survey with stereovision.

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

NCHRP-IDEA Project 89

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

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

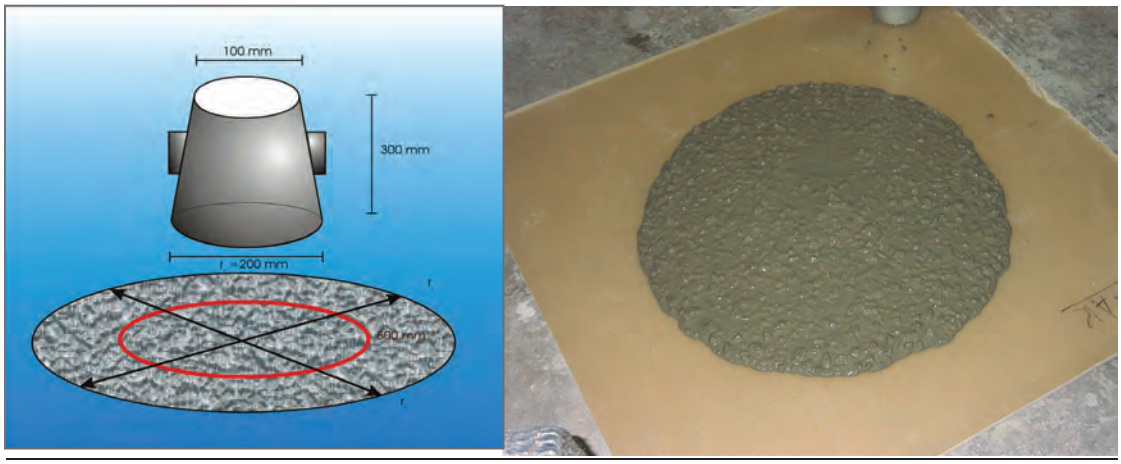


Figure 1

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

ROBOTIC HIGHWAY SAFETY MARKERS

NCHRP-IDEA Project 90

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

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

Figure 1

A robotic highway safety marker.

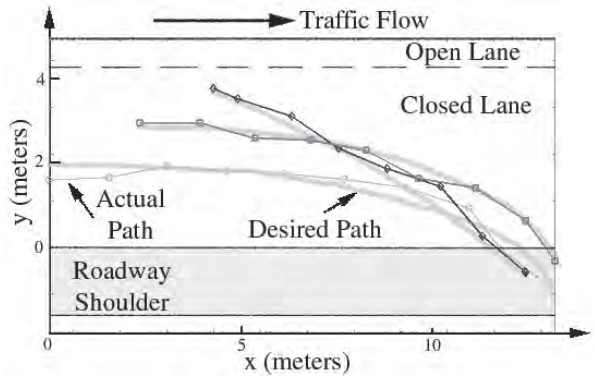


Figure 2

Desired and actual paths during field test.

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 91

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

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

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

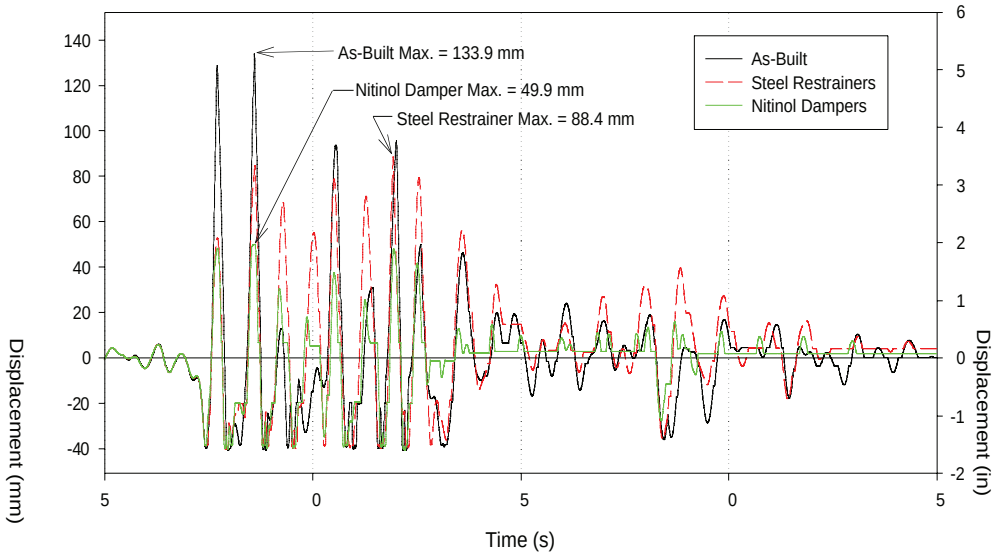


Figure 1

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

DEVELOPMENT OF AN ADAPTIVE DAMPER FOR CABLE VIBRATION CONTROL

NCHRP-IDEA Project 92

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

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

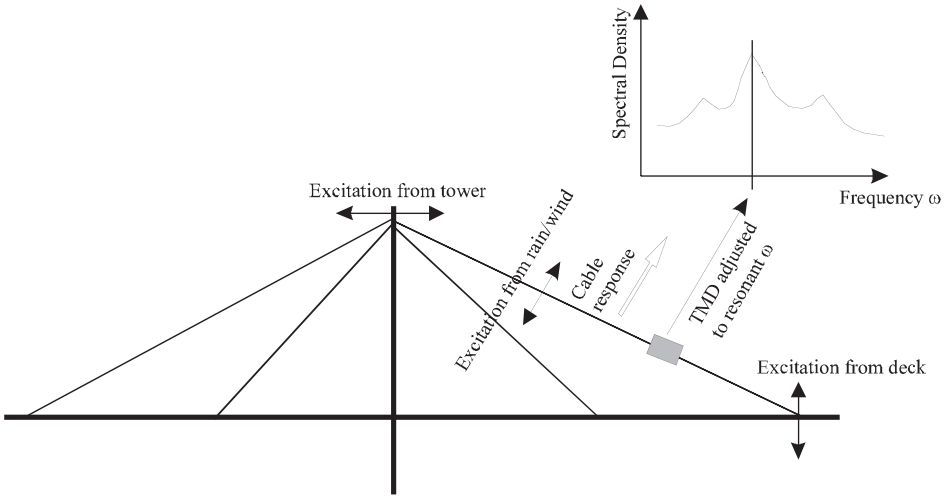


Figure 1

Sketch of cable vibration control strategy.

ADVANCED RELOCATABLE TRAFFIC SENSOR SYSTEM (ARTS)

NCHRP-IDEA Project 93

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

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

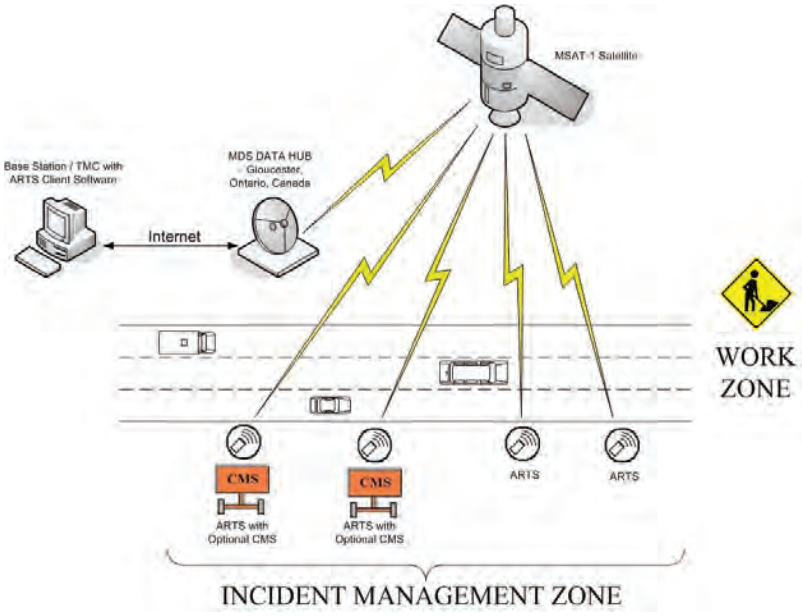


Figure 1

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

LIQUEFACTION MITIGATION USING VERTICAL DRAINAGE: FULL-SCALE TESTING

NCHRP-IDEA Project 94

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

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

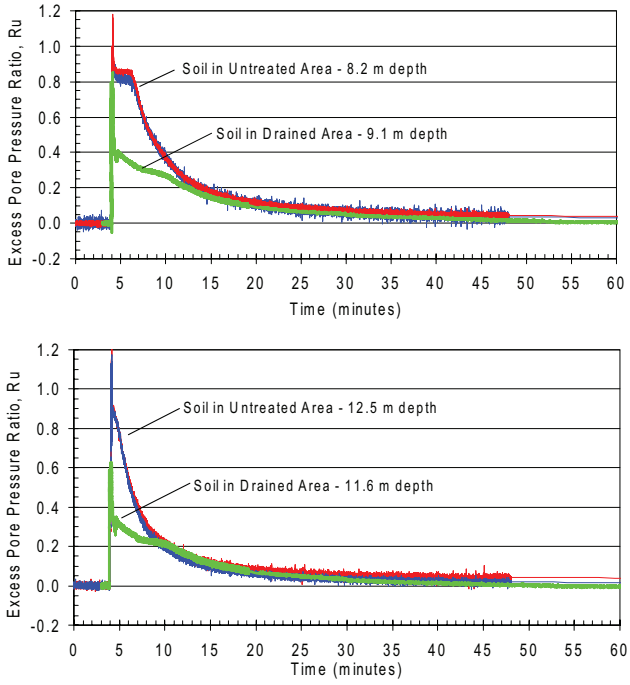


Figure 1

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

pore pressure

CONCRETE ROAD RECYCLER—HAMMER-ANVIL TEST

NCHRP-IDEA Project 95

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

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

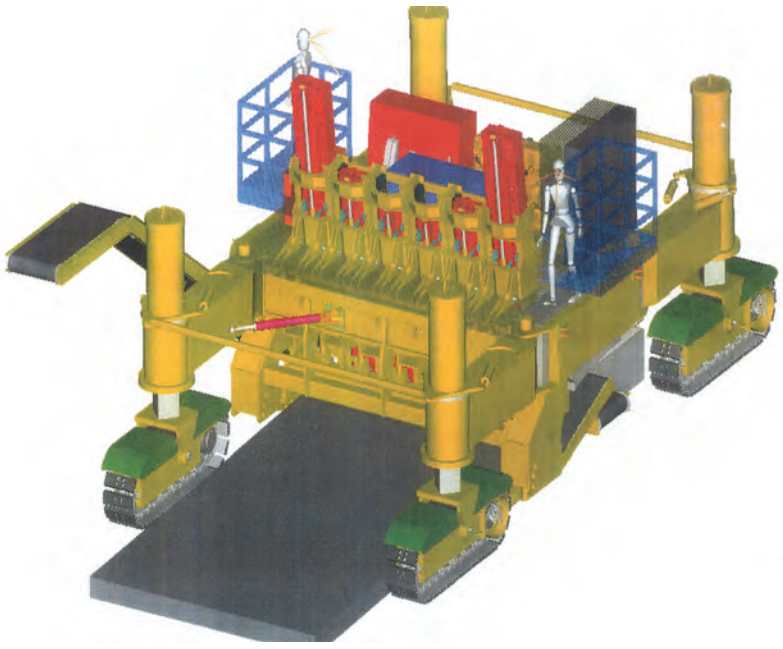


Figure 1

USING ULTRASOUND OF MHZ FREQUENCY FOR TESTING CONCRETE

NCHRP-IDEA Project 96

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

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

FIBER-REINFORCED PLASTICS FOR SEISMIC BRIDGE RESTRAINERS

NCHRP-IDEA Project 97

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

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

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

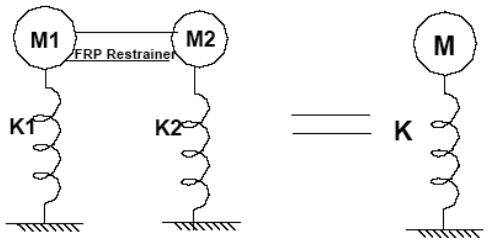


Figure 1

New restrainer design method.

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

NCHRP-IDEA Project 98

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

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

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

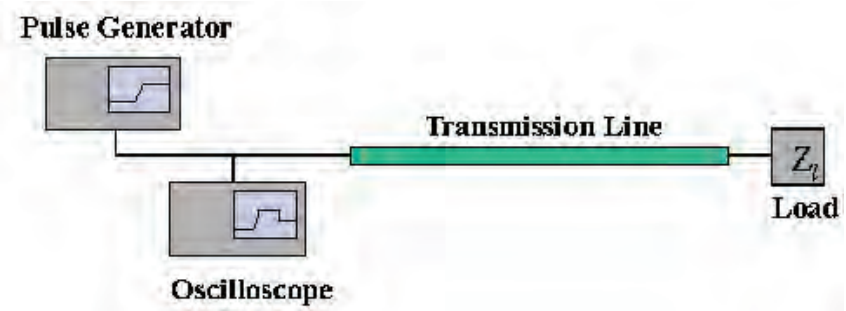


Figure 1

Time domain reflectometry measurement apparatus.

DEVELOPMENT OF ASPHALT BINDER CRACKING DEVICE

NCHRP-IDEA Project 99

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

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

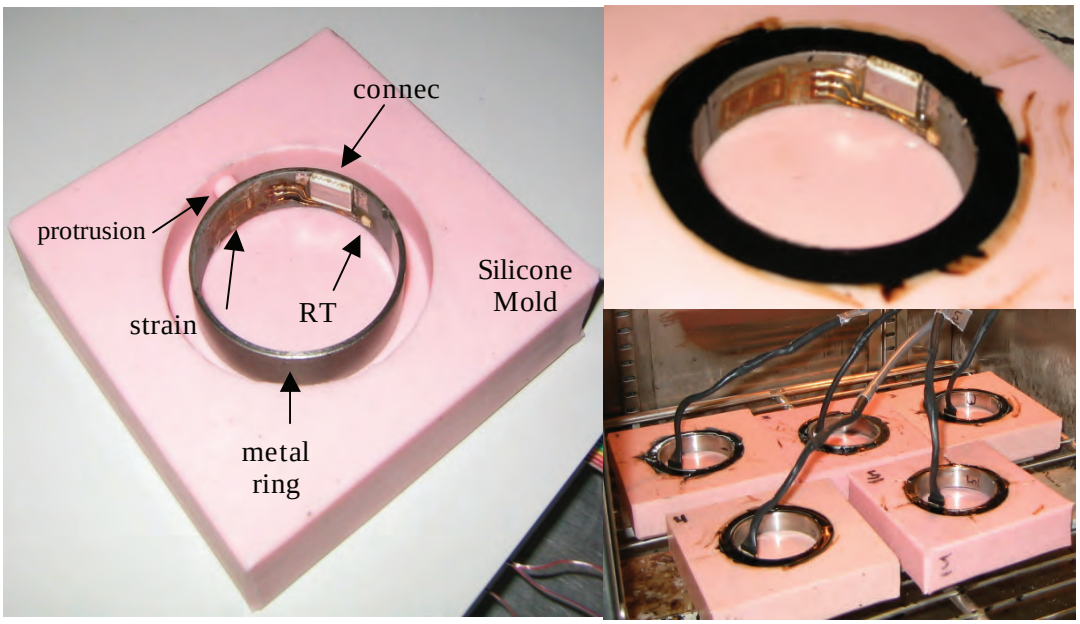


Figure 1

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

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

NCHRP-IDEA Project 100

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

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

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

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

ACTIVE HEATING INFRARED THERMOGRAPHY FOR DETECTION OF SUBSURFACE BRIDGE DECK DETERIORATION

NCHRP-IDEA Project 101

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

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

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

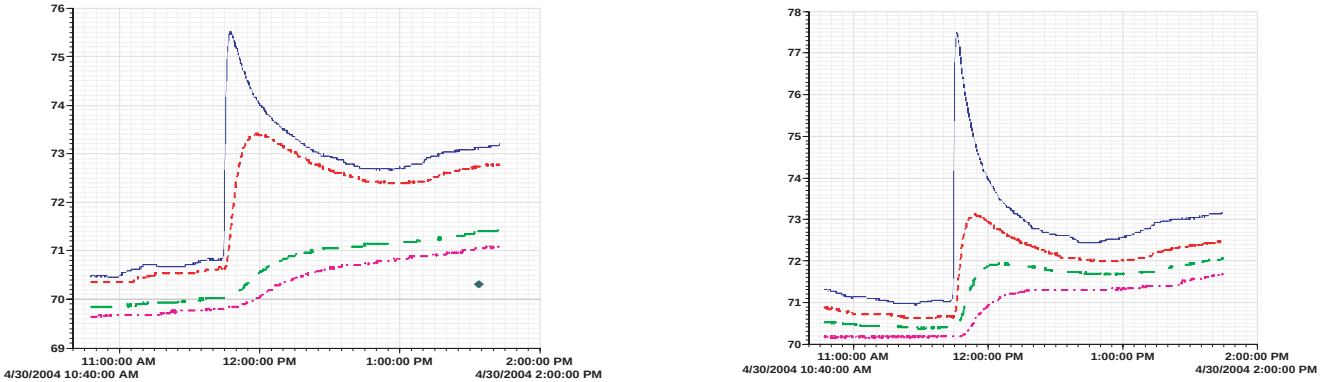


Figure 1

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

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

NCHRP-IDEA Project 102

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

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

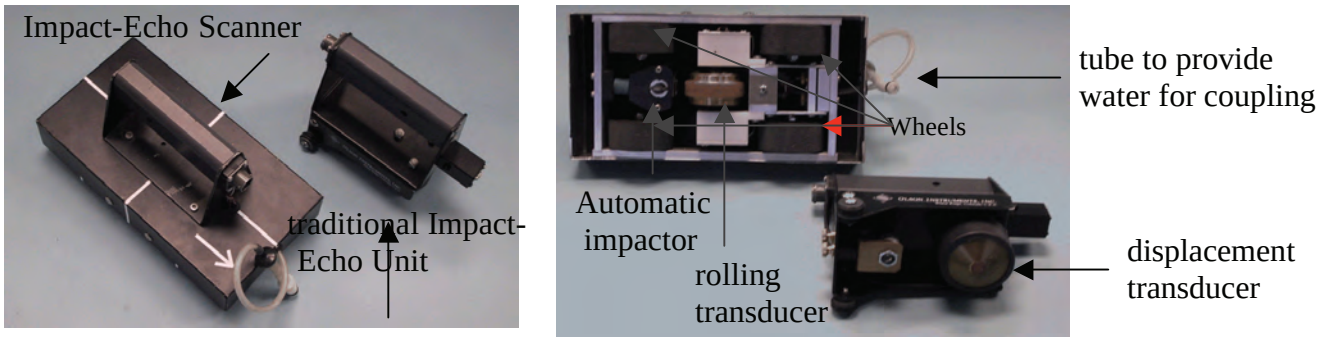


Figure 1

Impact Echo Scanning Unit and Traditional Impact Echo Unit.

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

NCHRP-IDEA Project 103

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

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

Figure 1

Installation of slotted drain pipe within vibrating mandrel.

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

NCHRP-IDEA Project 104

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

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

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

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

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

NCHRP-IDEA Project 105

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

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

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

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

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

AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION

NCHRP-IDEA Project 106

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

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

Figure 1

Integrated pavement crack analysis system installed on a vehicle.

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

NCHRP-IDEA Project 107

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

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

Figure 1

Mobile geophysical subsurface scoping equipment.

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

NCHRP-IDEA Project 108

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

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

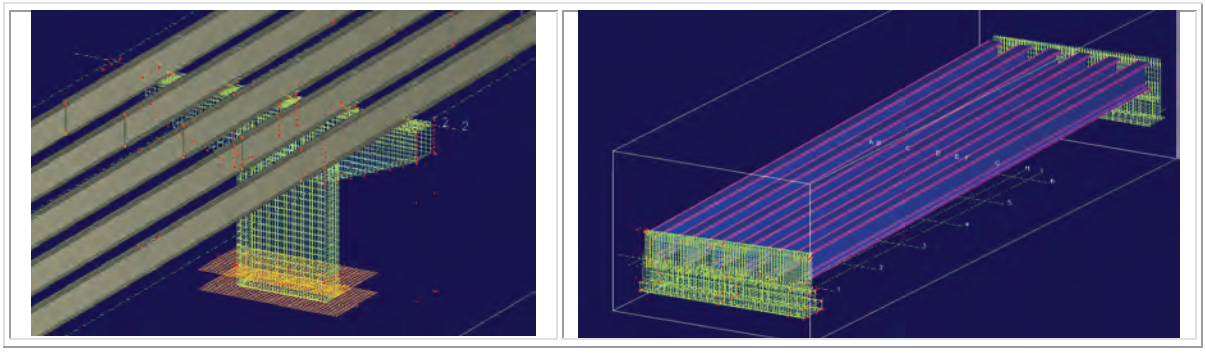


Figure 1

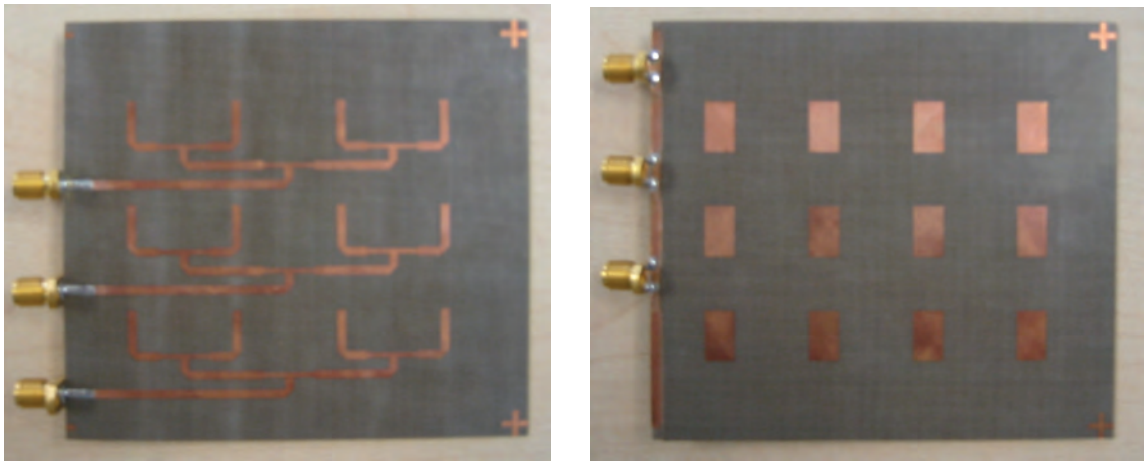
Portions of steel and concrete bridge models.

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

NCHRP-IDEA Project 109

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

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



Microstrip feed *Patch*

Figure 1

One of the six array antennas.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION

NCHRP IDEA Project 111

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

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

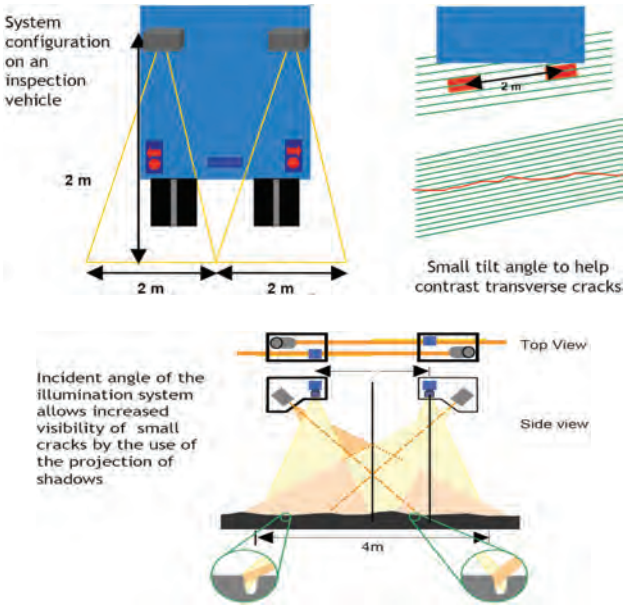


Figure 1

Working principle of the Laser Road Imaging System.

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

NCHRP-IDEA Project 112

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

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

Figure 1

The cone penetrometer equipped with piezoelectric sensors.

GEOCOMPOSITE CAPILLARY BARRIER DRAIN FOR LIMITING MOISTURE CHANGES IN PAVEMENTS

NCHRP-IDEA Project 113

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

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

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

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

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

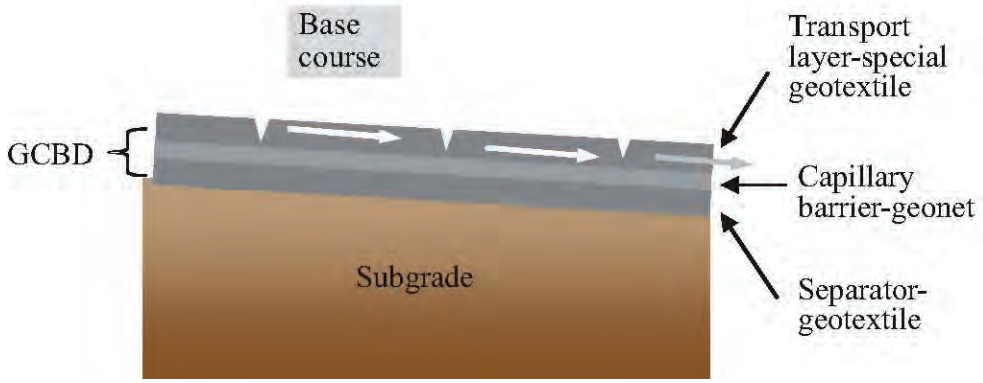


Figure 1

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

RELATIONSHIP OF ASPHALT PAVEMENT MICROTEXTURE USING IMAGE ANALYSIS OF AGGREGATE SHAPE

NCHRP-IDEA Project 114

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

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

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

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

NCHRP-IDEA Project 115

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

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

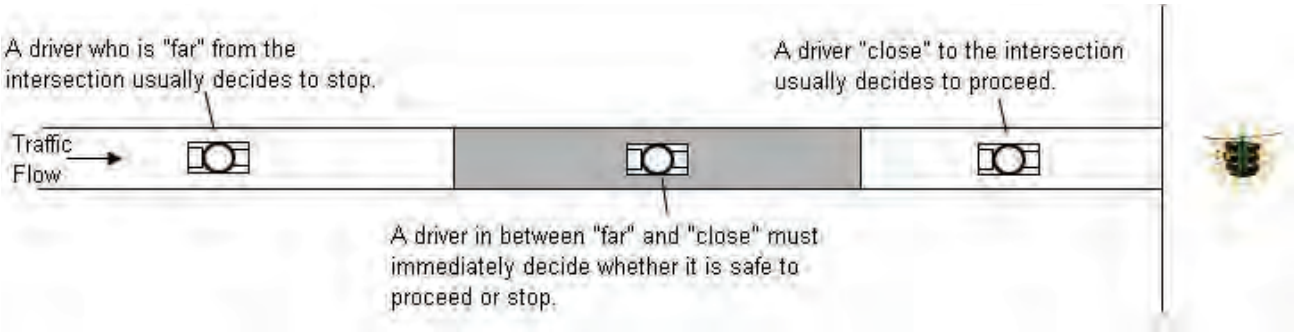


Figure 1

Driver decisions approaching an intersection.

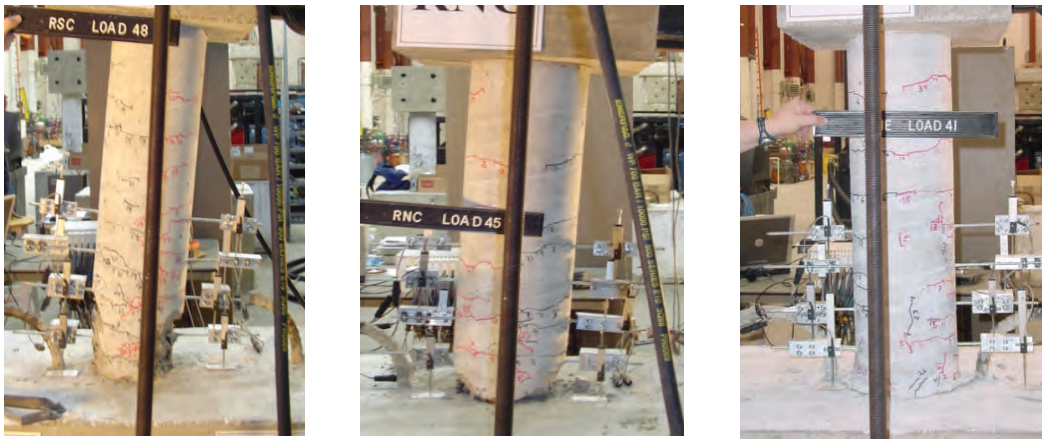
SEISMIC RESPONSE OF BRIDGE COLUMNS WITH ENGINEERED CEMENTITIOUS COMPOSITES AND SHAPE MEMORY ALLOYS IN PLASTIC HINGE ZONE

NCHRP-IDEA Project 116

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

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

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



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

Figure 1

Residual displacement and damage after 10 percent maximum drift.

SELF-POWERED SENSORS AND ACTUATORS FOR BRIDGES

NCHRP-IDEA Project 117

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

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

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

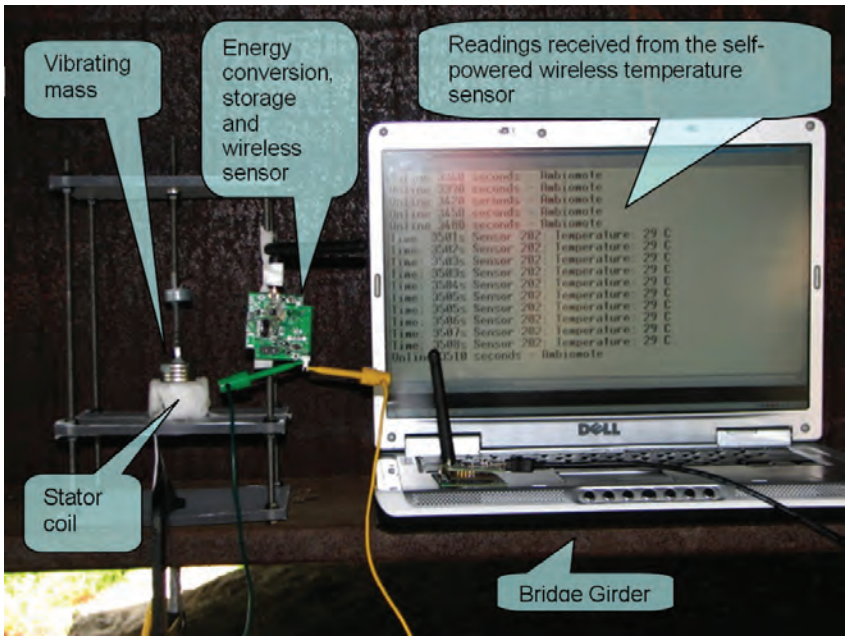


Figure 1

Prototype of the self-powered wireless sensor.

THE BCD: A NEW INSTRUMENT FOR COMPACTION CONTROL

NCHRP-IDEA Project 118

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

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

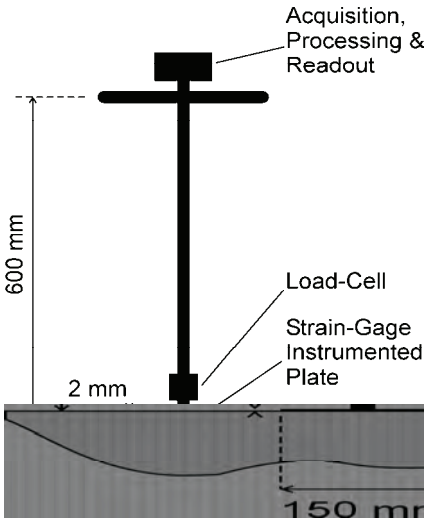


Figure 1

Conceptual Sketch of a BCD.

Figure 2

BCD-4.

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

NCHRP-IDEA Project 119

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

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

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

(a) (b)

Figure 1

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

ACTIVE SENSING FOR ONLINE HIGHWAY BRIDGE MONITORING

NCHRP-IDEA Project 120

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

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

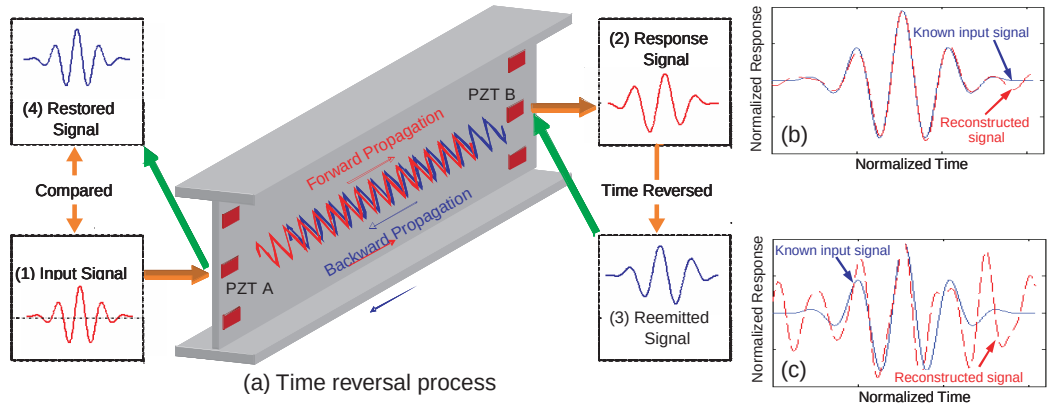


Figure 1

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

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

NCHRP-IDEA Project 121

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

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

(a) Image containing speed limit sign

(b) Processed binary image after color segmentation

(c) Extracted speed limit digits

Figure 1

Speed limit sign extraction.

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

NCHRP-IDEA Project 122

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

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

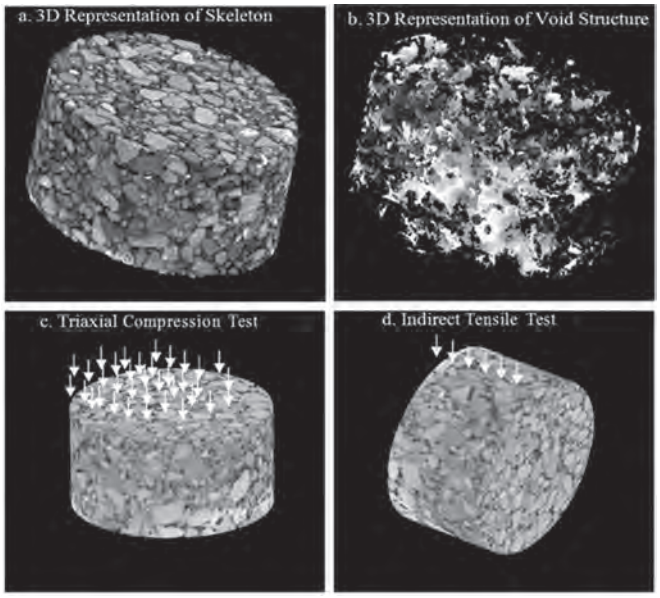


Figure 1

Illustration of the concepts of digital specimen and digital test.

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

LONG-TERM REMOTE SENSING SYSTEM FOR BRIDGE PIERS

NCHRP-IDEA Project 123

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

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

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

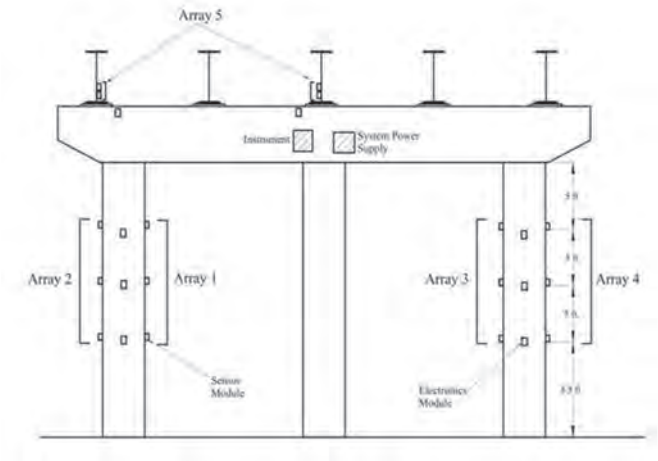


Figure 1

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

NOVEL OPTICAL FIBER SENSORS FOR MONITORING BRIDGE STRUCTURAL INTEGRITY

NCHRP-IDEA Project 124

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

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

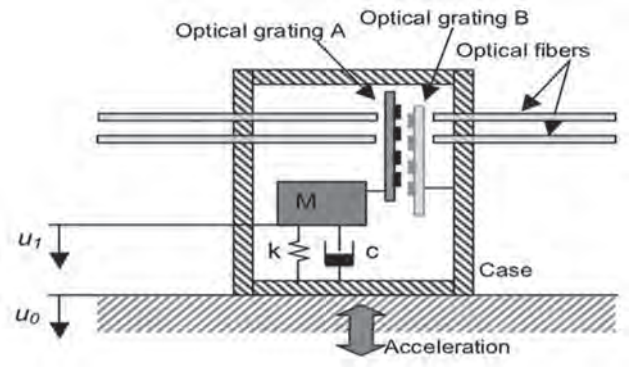


Figure 1

Design of fiber optic accelerometer.

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

NCHRP-IDEA Project 125

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

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

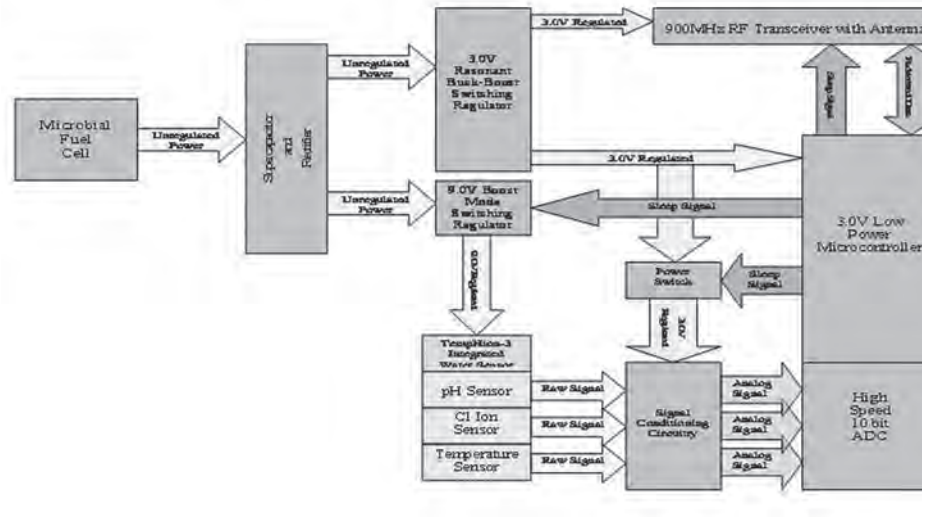


Figure 1

System block diagram

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

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

NCHRP-IDEA Project 126

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

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

(a) *(b)*

Figure 1

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

INSTRUMENTATION TO AID IN STEEL BRIDGE FABRICATION

NCHRP-IDEA Project 127

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

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

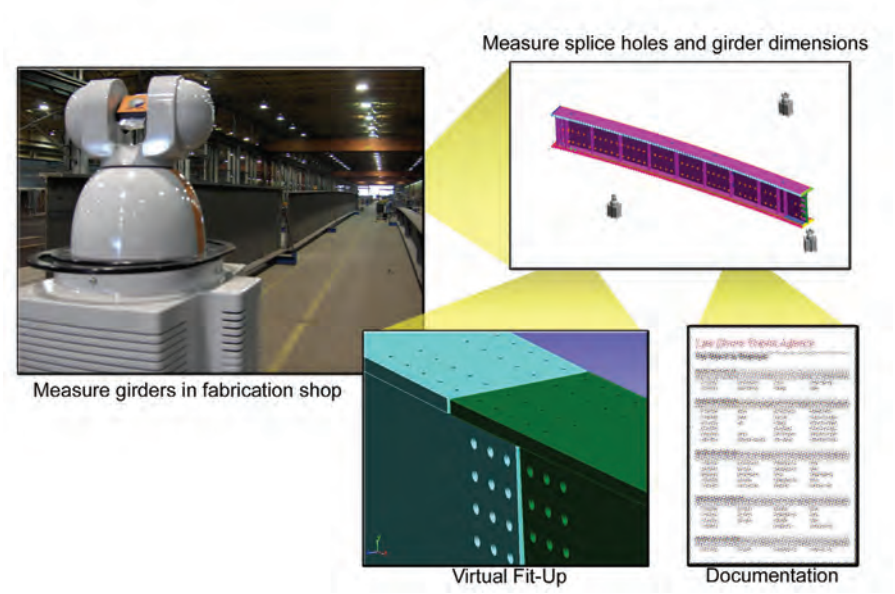


Figure 1

System concept for laser measurements of steel bridge girders.

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

NCHRP-IDEA Project 128

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

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

Figure 1

Pressure bagging for enhancing FRP-concrete bond

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

NCHRP-IDEA Project 129

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

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

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

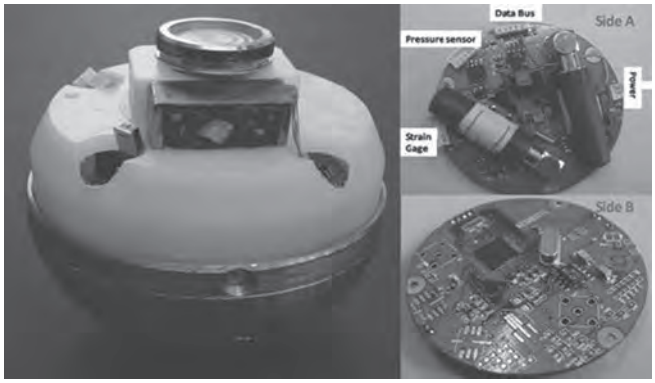


Figure 1

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

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

NCHRP-IDEA Project 130

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

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

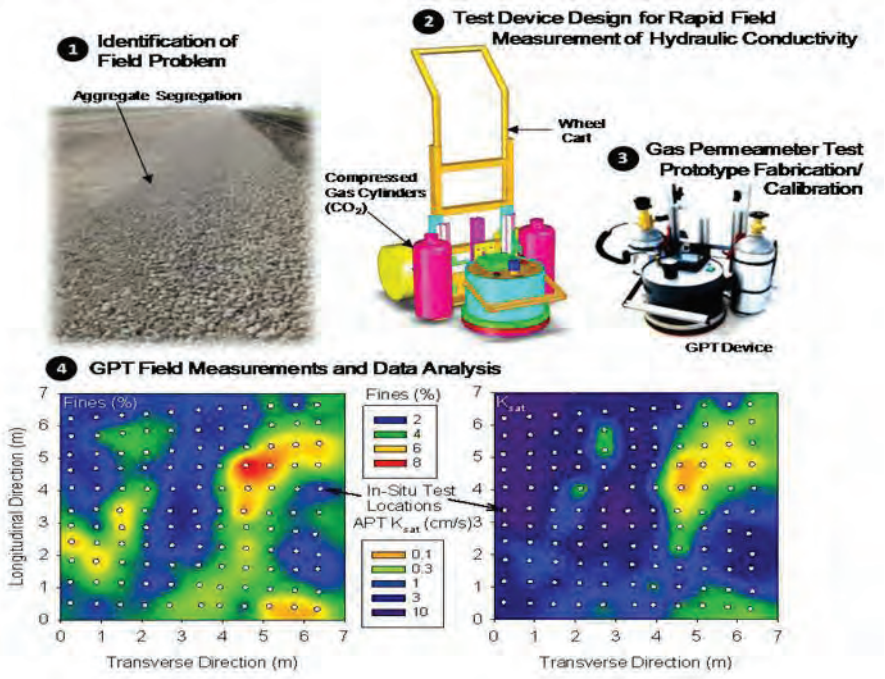


Figure 1

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

SMART SENSOR FOR AUTONOMOUS NOISE MONITORING

NCHRP-IDEA Project 131

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

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

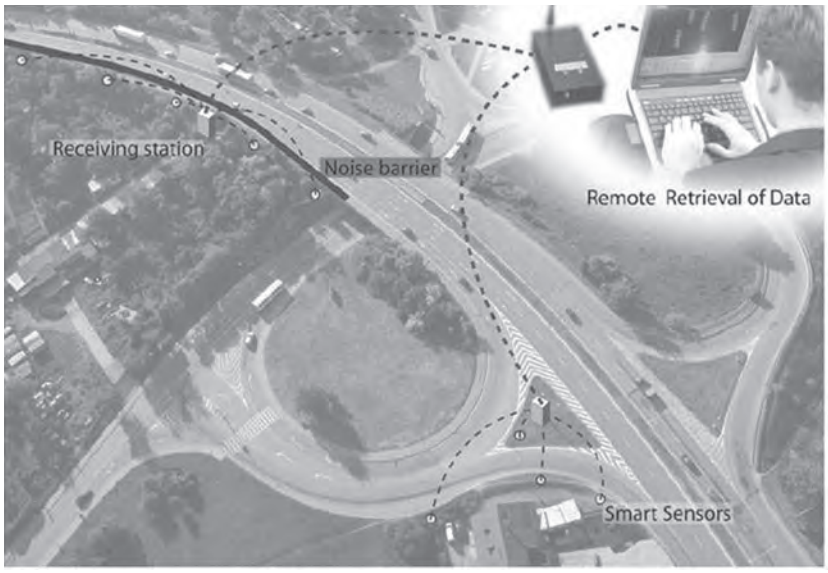


Figure 1

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

VEHICLE-MOUNTED BRIDGE DECK SCANNER

NCHRP-IDEA Project 132

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

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

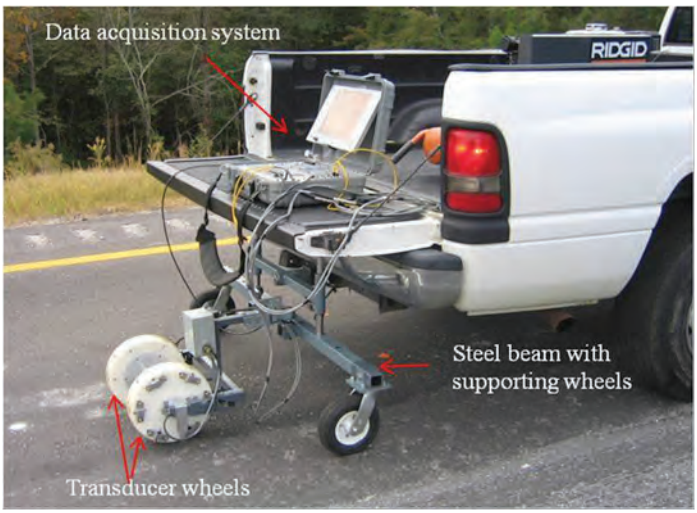


Figure 1

Bridge deck scanner (BDS) prototype.

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

NCHRP-IDEA Project 133

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

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

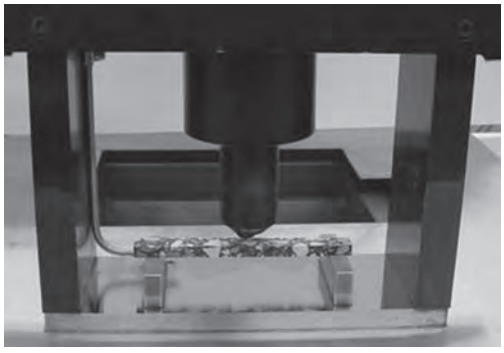


Figure 1

Bending Beam Rheometer (BBR) with thin asphalt mixture.

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

NCHRP-IDEA Project 134

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

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

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

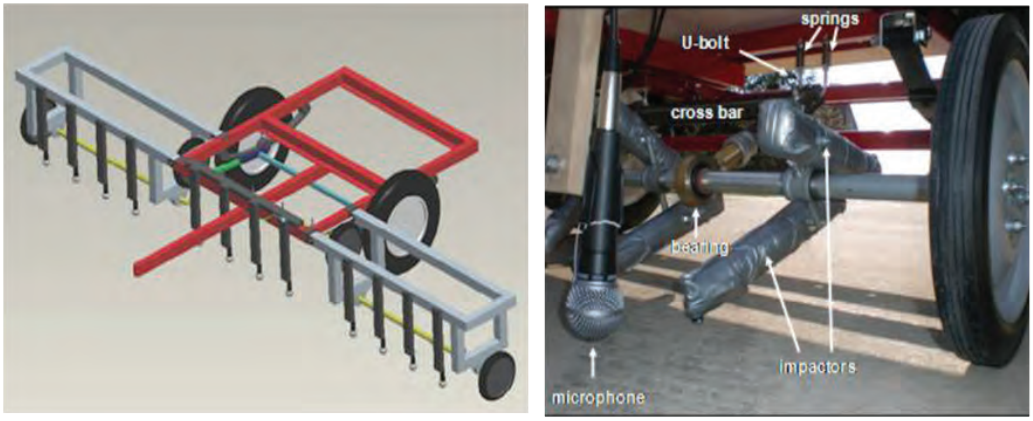


Figure 1

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

ACTIVE CONFINEMENT OF BRIDGE PIERS USING SHAPE MEMORY ALLOYS

NCHRP-IDEA Project 135

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

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

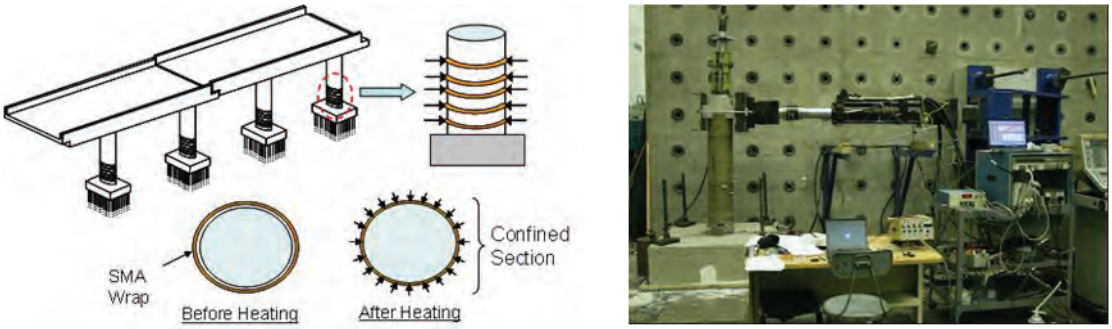


Figure 1

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

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

NCHRP-IDEA Project 137

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

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

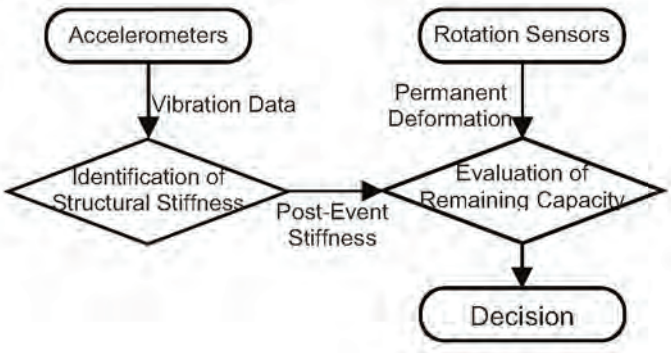


Figure 1

Proposed damage assessment and capacity estimation method.

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

NCHRP-IDEA Project 138

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

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

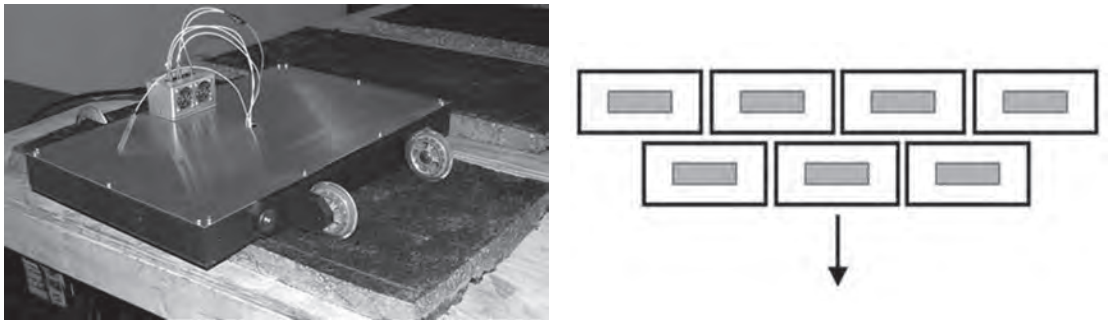


Figure 1

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

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

NCHRP-IDEA Project 140

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

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

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

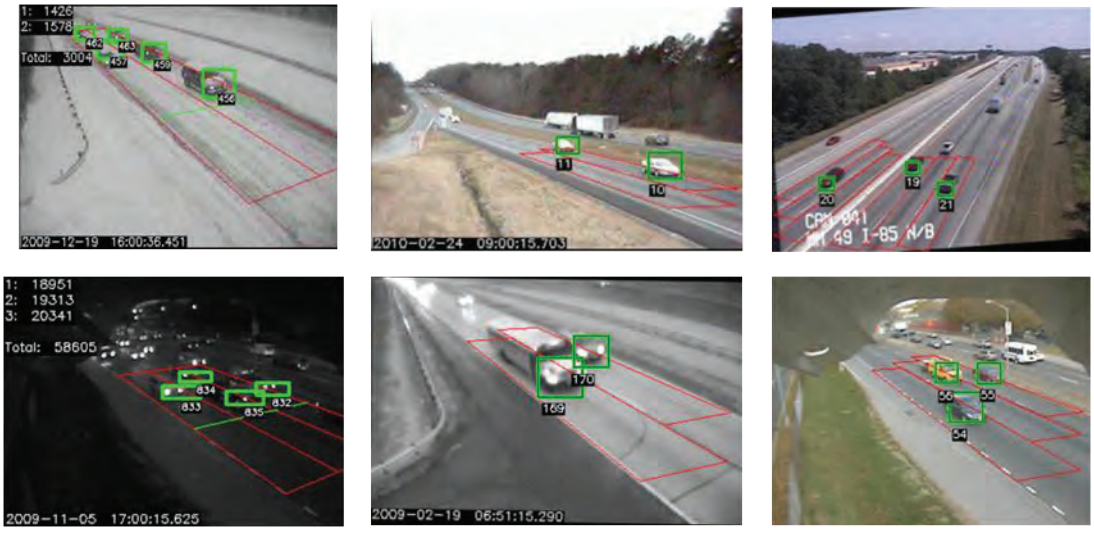


Figure 1

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

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

NCHRP-IDEA Project 141

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

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

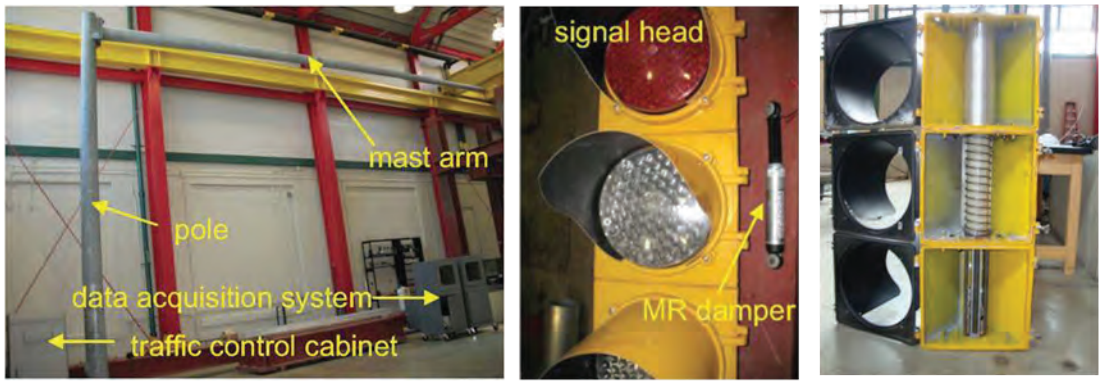


Figure 1

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

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

NCHRP-IDEA Project 144

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

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

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

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

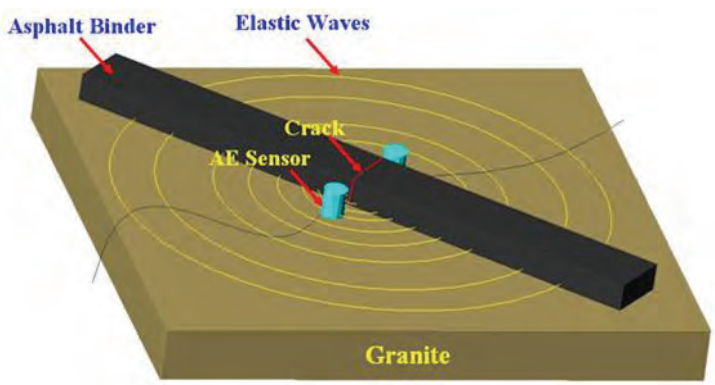


Figure 1

Schematic representation of AE asphalt binder sample during the test.

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).

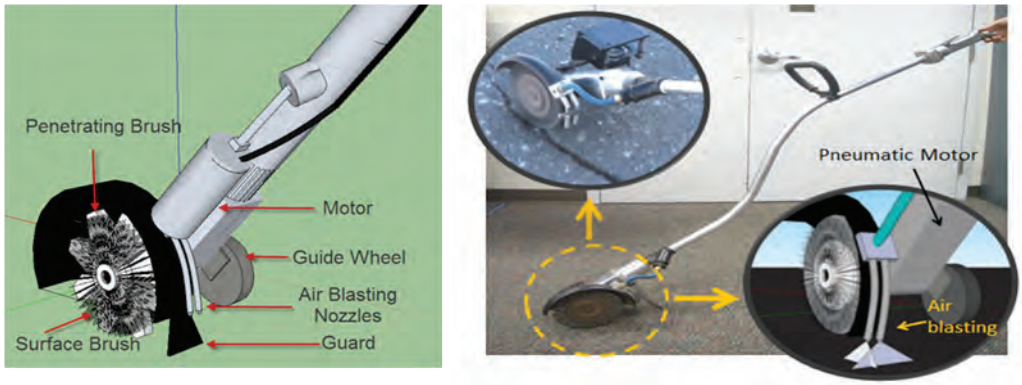


Figure 1

Crack cleaning device concept and product.

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all NCHRP-IDEA projects that were completed or active during the 2012 program year.

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

NCHRP-IDEA Project 136

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

IDEA Concept and Project

Prompt-gamma neutron activation or PGNA is an elemental analysis method based on a portable neutron source such as the radioisotope 252Cf. In this method, the neutrons are captured by the atoms in the target material, causing the neutrons to give off characteristic gamma-rays, which are then detected. The result is a gamma-ray energy spectrum with various peaks representing the individual elements in the material. It is especially sensitive to chlorides and thus provides a nondestructive alternative to the conventional destructive and time-consuming chemical test method.

This NCHRP-IDEA project is developing an improved neutron-based chloride detector system that makes use of an electronic collimator subsystem to improve directionality and reduce background noise (Figure 1). It consists of a large high-purity germanium (HPGe) detector for high-resolution measurement of gamma-ray energies. In front of this detector is a thin sodium iodide (NaI) detector. The electronics enable counting in the coincidence mode so that only gamma-rays that first pass through the NaI detector are then measured by the HPGe detector. This limits the field of view of the system to approximately the area of the NaI detector,

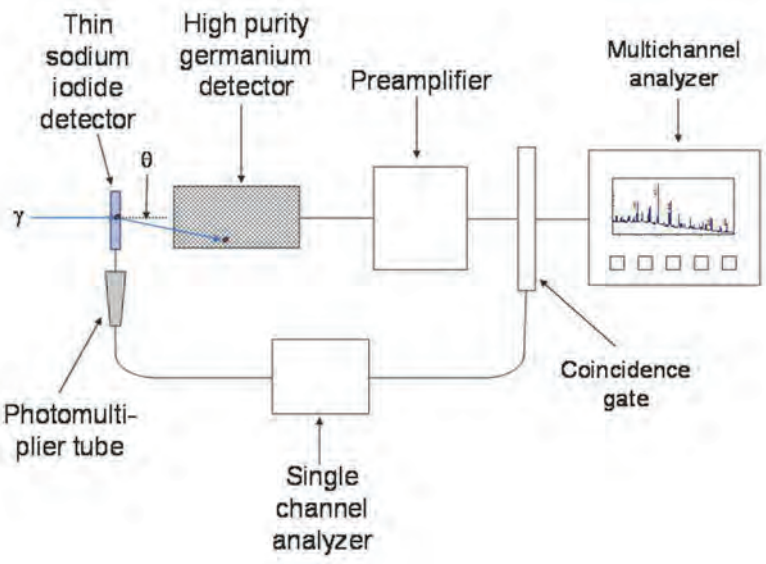


Figure 1

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

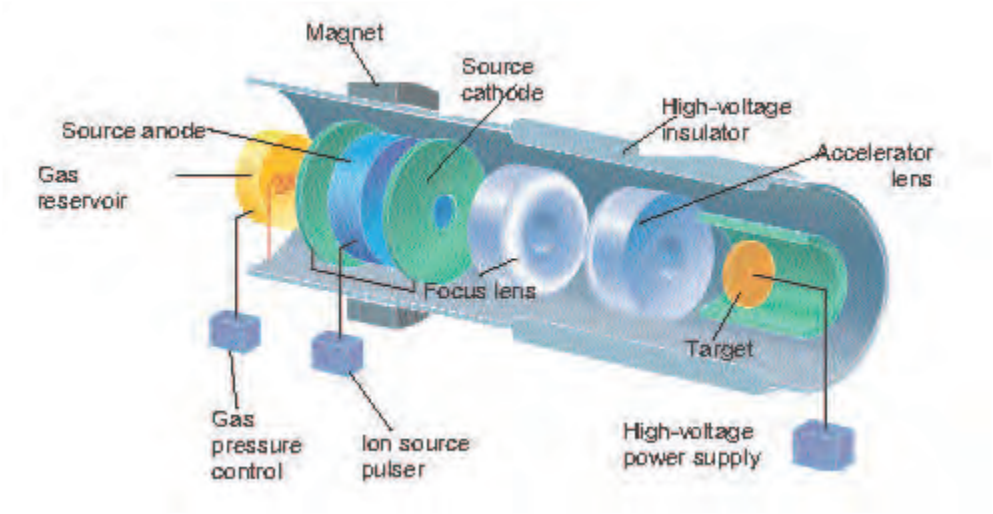


Figure 2

Schematic diagram of the compact portable neutron generator.

which can be as small as 0.39 inches2. Depending on the material composition, the depth of penetration can be several inches.

In order to compensate for the lower count rate created by the introduction of the second detector, a neutron generator was selected in place of the 252Cf radioisotope source. The portable neutron generator uses the deuterium-tritium (D-T) fusion reaction to generate the neutrons and can produce neutron currents as high as 3×108 n/s, which is about 30 times greater than the maximum from the 252Cf radioisotope source. A schematic diagram of a neutron generator is given in Figure 2. In addition to providing a higher neutron flux, the use of the neutron generator would minimize the need for shielding requirements during transport.

Project Results

Research this year focused on assembling the electronic collimator and evaluating its performance by using a radioisotope gamma-ray source to simulate the gamma rays produced by PGNA. The source was placed at various positions around the electronic collimator to demonstrate the proof of principle and to map out the angular dependent detector response function. The proof of principle of electronic collimation is illustrated by the graph in Figure 3. The ^{137}Cs source was placed at the side of the HPGe detector to simulate background radiation. With the coincidence circuit off, the count rate in the 0.661 MeV peak was 44.32 cps. When it was turned on, the rate dropped to 0.03 cps, a reduction factor of roughly 1480. Achieving the same level of background rejection with a physical collimator would require a lead shield weighing 32 kg.

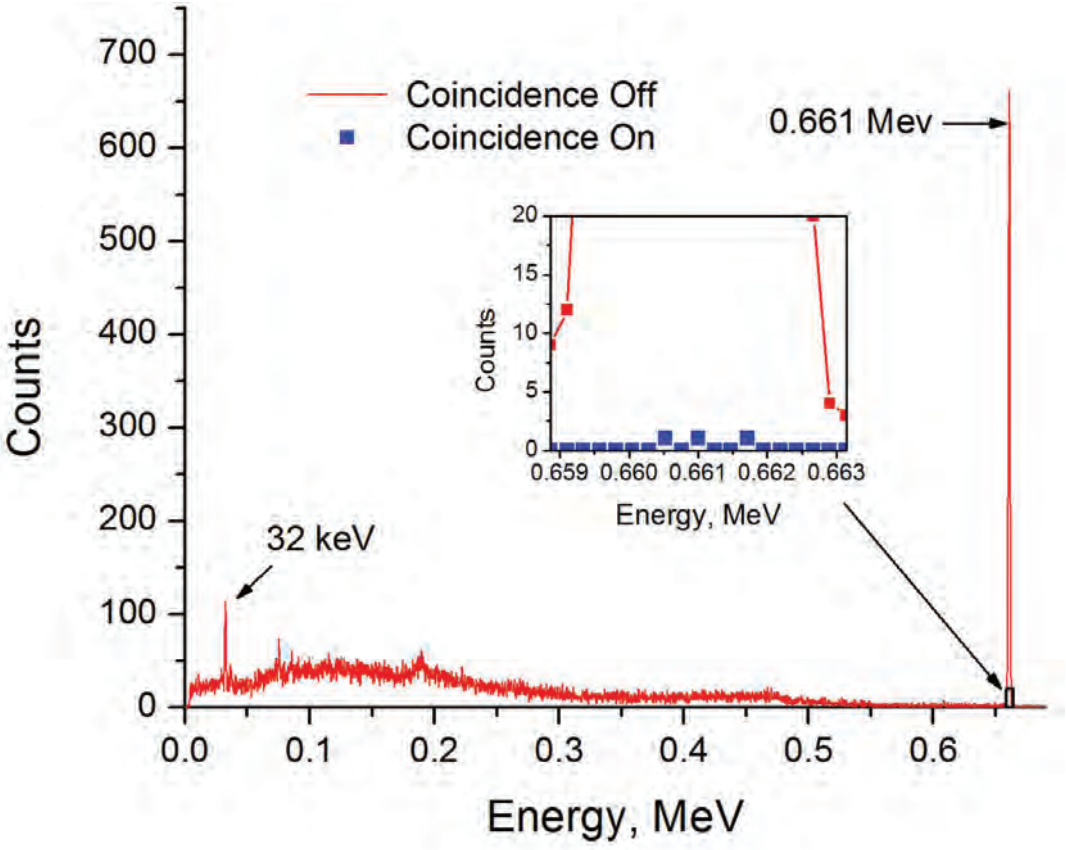


Figure 3

Proof of principle of electronic collimation. Gamma ray spectra of ^{137}Cs source place alongside the HPGe detector. Both coincidence off and coincidence on spectra are plotted. The inset shows the counts in the main peak with coincidence on.

Product Payoff Potential

The average bridge is more than 40 years old, and many state DOTs have used chlorides to deice bridge decks for decades. This has provided an extended opportunity for chlorides to diffuse into bridges' steel reinforcement bars. This nondestructive method of chloride detection is more accurate than existing neutron detectors, and it allows the depth of the chloride spread and the water/cement ratio in concrete to be detected. In addition to measuring chlorides, the system can also be used to simultaneously measure other elements that cause deterioration of concrete, including sulfates and alkalis, which can cause damage in nonreinforced concrete structures such as airport runways.

Product Transfer

The main users of this technology will be consulting engineering companies that perform nondestructive testing of concrete. Several of these companies have been contacted about using the PGNA system. In addition a number of state DOTs have expressed interest in field testing the system.

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

NCHRP-IDEA Project 139

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

IDEA Concept and Product

Work zones create significant safety concerns that have recently intensified because of the increasing number of roadway widening, rehabilitation, and reconstruction projects. There is an urgent need to develop technologies to improve work zone safety. With the advancement of sensor and information technologies, it has become feasible to develop an intelligent and reliable sensing system that automatically detects potential hazards and alerts workers before an accident occurs. Therefore, a methodology employing sensing technology is proposed in this study to improve work zone safety.

The project focus is to create a vision-based sensing methodology that can (1) detect a vehicle intruding into work zone areas and provide early warning to improve safety of workers and (2) detect missing work zone channelization traffic control devices (e.g., cones) to ensure safety of drivers and workers and to prevent lawsuits against state DOTs. Some existing technologies, such as the laser switch, are able to detect intrusion of vehicles; however, the laser switch is not reliable enough to function practically. Again, system intelligence and reliability are the keys to ensuring the effectiveness a hazard awareness system.

The objective of this project is to maximize detection of potential work zone hazards without excessively triggering false alarms. The methodology will develop a vehicle surveillance algorithm that uses vision technology to detect and recognize vehicles in work zones and then keep track of them. Afterwards, by extracting and analyzing vehicle trajectories and surrogate data, the hazard decision-support model can be provided. Figure 1 shows how a protection zone with the proposed awareness system could be established by using an intelligent vision and sensing system (IVSS). The IVSS could be located behind the barrel taper or along the shoulder.

Project Results

Researchers divided the system development into four steps and expected different intermediate results at each of the steps. In the first step, a reliable vehicle detection, recognition and tracking algorithm was developed. This algorithm can provide 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 keep track of 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. Finally, with the aforementioned algorithms, a surveillance system including a 30-ft surveillance tower and cameras were developed and tested on an actual pavement resurfacing work zone on I-95

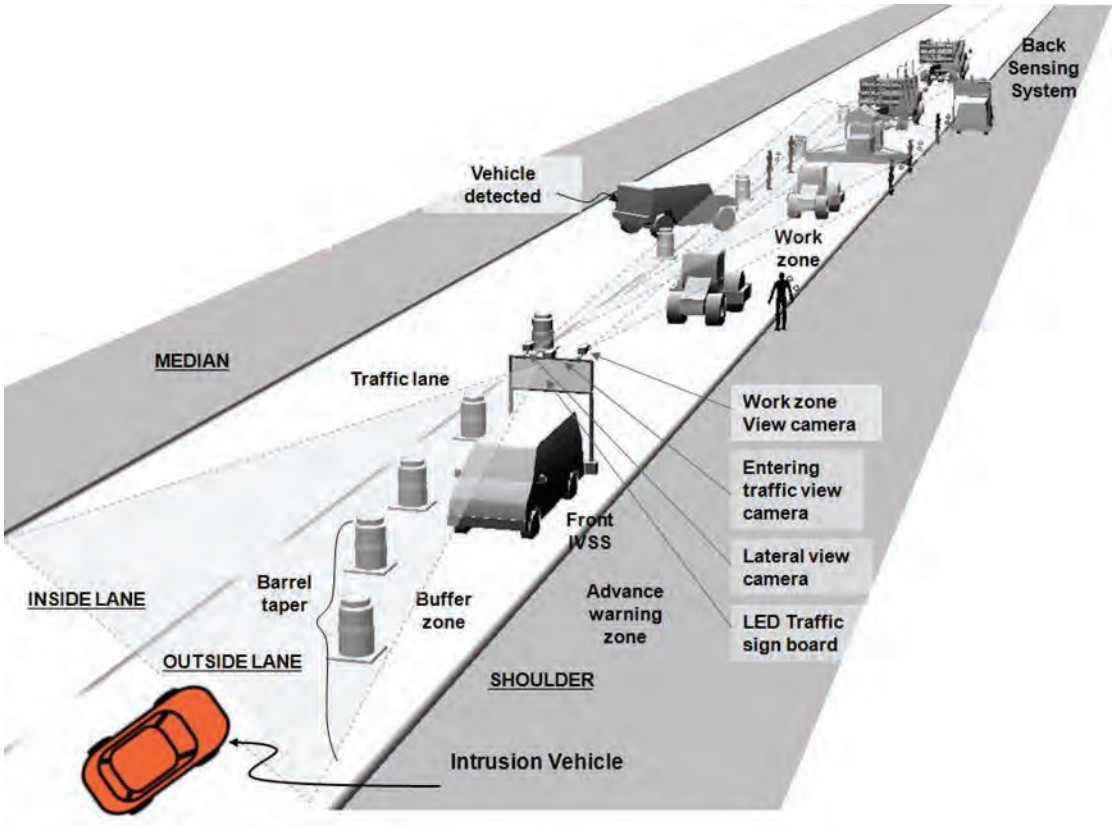


Figure 1

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

Figure 2

Surveillance system in an actual work zone on I-95 near Savannah, Georgia.

near Savannah, Georgia, as shown in Figure 2. The final report is available from the National Technical Information Service (NTIS Report # PB2012-110781).

Product Payoff Potential

This new, advanced warning system has the potential to intelligently and reliably improve work zone safety. With the development of emerging sensing technologies and the proposed methodology, the developed work zone hazard awareness system is able to automatically detect potential hazards and provide a safer environment to workers and road users in work zones. In addition to the computed driver trajectories, the proposed system is capable of quantitatively studying work zone driver behaviors, which previously has been difficult to do. This can provide an effective means for engineers to quantitatively evaluate the performance of different work zone traffic control devices and traffic control configurations in terms of their impact on driver behaviors, traffic safety, and mobility in work zones.

Product Transfer

Georgia Department of Transportation (GDOT) has supported and participated in this research by providing not only monetary and personnel support, but also their expertise in work zone operations and safety issues to help the Georgia Tech research team better evaluate the developed algorithms and applications. The product of this study will be transferred to GDOT and will continue to be developed by the Georgia Tech research team.

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

NCHRP-IDEA Project 142

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

IDEA Concept and Product

The concept of this study is to use the confined shape recovery functionality of a shape memory polymer-based syntactic foam sealant for the purposes of self-sealing cohesive damage and eliminating adhesive failure in expansion joints. Through a programming or educating process, the foam sealant can be tailored to self-seal cohesive damage by a confined shape recovery process and the adhesive failure or interfacial debonding failure can be avoided by consistently and autonomously applying a compressive stress to the edges of the concrete decking/pavement regardless of the service temperature conditions. The problem of sealant squeezing out of the joint can also be minimized by proper two-dimensional (2-D) programming. Because the shape recovery process is driven by conformational entropy and only reversible physical phase change (frozen phase and active phase) is accompanied in the thermomechanical cycle, the self-sealing would be repeatable and almost autonomous. It is expected that this project would provide a novel and effective sealant for improving the performance of bridge decks and concrete pavement.

Project Results

The proposed sealant was fabricated by dispersing glass microballoons into a thermosetting shape memory polymer. The uniformity was achieved with the assistance of an ultrasound mixer and three-roll mill. A differential scanning calorimetry (DSC) test was conducted to determine the glass transition temperature (Tg) of the sealant. It is found that the Tg of the sealant is close to the pure shape memory polymer with a much flattened peak. A flatwise uniaxial compression test was also conducted. It is found that the stress-strain behaves in three distinct regions: a linear elastic region, corresponding to full recovery of the deformation after removal of the load; a plateau region, corresponding to the yielding deformation of the foam matrix; and a consolidation region, corresponding to the crushing and densification of the microballoons. Compared with regular syntactic foam, it is obvious that the deformation in the plateau region is much higher, suggesting that the smart sealant would be able to absorb more energy without disintegration. A 1-D stress-controlled compression programming and free-shape recovery were conducted on the sealant. The entire 4-step thermomechanical cycle is shown in Figure 1, where steps 1–3 suggest stress-controlled programming and step 4 means free-shape recovery. From Figure 1, it is calculated that the shape fixity ratio of the foam sealant is 96.7% and the shape recovery ratio is 83.9%, indicating good shape memory functionality. A 2-D (compression in vertical direction and tension in horizontal direction) stress controlled programming and free shape recovery were also conducted using cruciform sealant specimens. Again, very good shape memory functionality was achieved; see Figure 2.

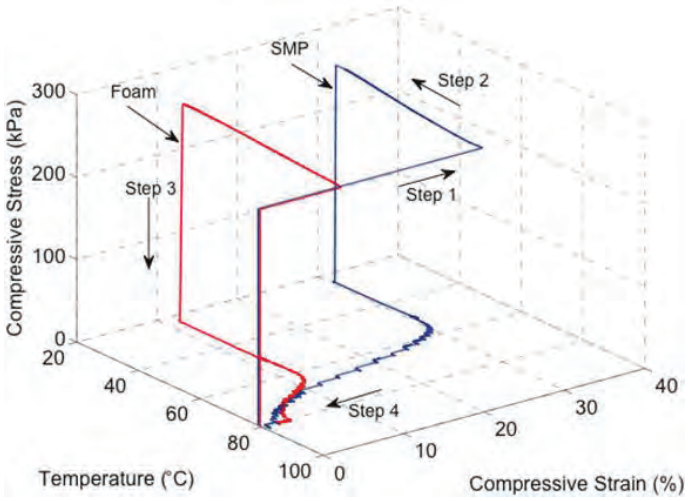


Figure 1

A typical 4-step stress-controlled programming and free shape recovery of a shape memory polymer (SMP) and the corresponding syntactic foam sealant.

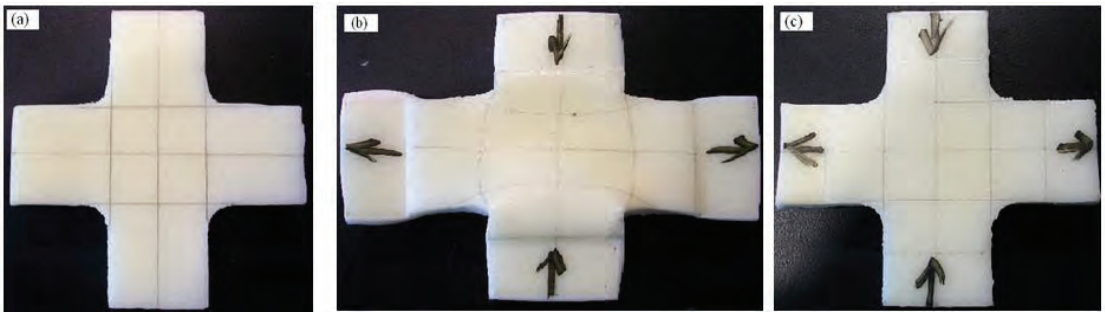


Figure 2

Cruciform sealant specimen (a) original, (b) after programming, and (c)after free shape recovery.

Laboratory-scale performance evaluation of the developed syntactic foam as a smart sealant for bridge deck and concrete pavement joints was conducted, including uniaxial compression, tension and shear tests, cyclic loading tests, water immersion tests, and functional stability tests under ultraviolet radiation. The feasibility of using two-step 1-D programming to replace one-step 2-D programming was established. Shape memory polymer-based sealant was fabricated, programmed, and installed in two expansion joints at the Louisiana State University campus in January 2012 (Figure 3). The final report is available from the National Technical Information Service (NTIS Report # 2013-100223).

Figure 3

A schematic of installed sealant in expansion joint (T-38: glass transition temperature of 38°C; T-29: glass transition temperature of 29°C; 2-D: two-dimensional programming).

Product Pay-Off Potential

Given the incredibly large number of expansion joints in bridges and pavements, and the well-established unsatisfactory performance of the existing joint sealants, the result of the proposed research could have a significant impact on enhancing the performance of the expansion joints that are ubiquitous in the nation's transportation network. A successful demonstration and reliable analysis of the smart joint sealant would not only serve the civil infrastructure but would also be transferable to other high-value structures (e.g., aircraft, automobiles, ships, piping systems) because joints that need to be sealed are present in most engineered structures.

Product Transfer

In the final phase of this project, Louisiana Transportation Research Center, in coordination with Louisiana Department of Transportation and Development, will continuously monitor the performance of two installed expansion joints. This observation will provide field-level performance data for analysis and will be a critical step toward practical acceptance and widespread application of the results of the proposed project.

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

NCHRP-IDEA Project 143

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

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

IDEA Concept and Product

The concept is to design a functional flexible pavement mixture (FPM) produced with little-to-no virgin petroleum-based binder (asphalt). In place of virgin asphalt, guayule-based materials (resins or other extracts) and high percentages of reclaimed asphalt pavement (RAP) and/or reclaimed asphalt roofing shingles (RAS), materials that already contain petroleum-based binder, would be used.

The guayule (pronounced 'why-YOU-lee') plant (Figure 1) is a perennial that grows in arid and semi-arid regions (e.g., the southwestern United States) and is a source of natural rubber. Currently, three basic products are obtained from the guayule plant: 1) rubber in latex or bulk (dried latex) form, 2) bagasse (post-rubber-extraction fibrous residue), and 3) resin. Guayule is currently being cultivated and processed primarily for the manufacture of hypoallergenic latex used in medical products (such as gloves and catheters), but it has a long history, including the use of the bulk rubber during World War II.

During this project, numerous extraction/recovery procedures were developed and performed using different guayule feedstocks and solvents. For each feedstock-solvent combination, the recovered product was evaluated through testing. Two of the many guayule-based materials

Figure 1

Arizona Guayule Fields (Permission of the Yulex Corporation).

produced became the focus of the work: 1) an acetone-extracted resin that is a residuum in the bulk rubber, and 2) a hexane-extract from the leaf and attached stems (currently a rubber-extraction waste product).

Project Results

Laboratory testing showed that when blended with RAP and/or RAS binders, both products served as a recycling agent, in that they lowered the viscosity and restored depleted chemical compounds in age-hardened RAP/RAS binders. Comparisons were made of the two guayule-based materials to two petroleum-based binders with similar viscosity-temperature relationships: 1) the acetone-extracted rubber resin (RR) was compared to a commercially-available recycling agent (a product called Cyclogen L, abbreviated as CycL) and 2) the hexane-extract from the leaf/stems (LF) was compared to a performance-graded (PG) 52-28 binder, which is often utilized for high-RAP/ RAS FPMs where the specified binder grade is stiffer than a PG52-28. Numerous procedures and protocols were developed and used in the evaluation process—including extraction of the resins—from the guayule-based feedstocks and binder from the RAP/RAS, viscosity, rolling thin film oven (RTFO) conditioning, mass change, specific gravity, flash point, pressure aging vessel (PAV) conditioning, clay-gel chromatography, gas chromatography-mass spectrometry, complex shear modulus and phase angle determination (dynamic shear rheometer testing), low-temperature creep stiffness determination (bending beam rheometer testing), multiple stress creep recovery (dynamic shear rheometer testing), and Hamburg wheel-track testing of compacted FPMs.

Binder-blending mixture experiments were developed to determine the relative effects of the guayule-based materials versus the petroleum-based binders when blended with RAP/ RAS binders and to develop response surface models (RSMs) required for FPM design. For each of the four materials that were evaluated, just less than 20 different experimental design software-generated blends were physically created that contained varying proportions of two different RAP binders (RAP1 and RAP2), one RAS binder, and guayule-based or petroleum-based materials. For each of the 74 blends ultimately created, the high critical temperature (T_cH) and low critical temperature (T_cL) were determined. T_cH is an indicator of FPM rutting potential and T_cL is an indicator of FPM cold-temperature (thermal) cracking potential. For the RR, CycL, LF, and PG52-28 materials, RSMs were generated where the component proportions of each blend were the independent variables and T_cH and T_cL were the response or dependent variables. T_cH and T_cL relate directly to the PG binder designation in that a PG64-22 binder, for example, must have a T_cH greater than (warmer) or equal to 64°C and a T_cL less than (colder) or equal to -12°C; there is a 10°C offset built into the T_cL test procedure. The absolute temperature spread between T_cH and T_cL (T_cH - T_cL) is a parameter that is useful to asphalt technologists in that it indicates the basic performance capability of a binder (i.e., the wider the absolute temperature spread, the greater the performance potential). This was the primary comparative analysis tool used for the RR vs. CycL and the LF vs. PG52-28 binder-blending mixture experiments. Figure 2 shows the results of the LF vs. PG52-28 comparison using the absolute temperature spread parameter. Note that only blends that contained LF or PG52-28 were used in this analysis. Of the 19 blends used to develop the RSMs for the LF vs. PG52-28 comparison, 10 contained only RAP and/or RAS binder.

As indicated in Figure 2, the PG52-28-RAP/RAS blends had, generally, larger absolute temperature spreads than the proportionally-identical LF-RAP/RAS blends. Although these results were discouraging, it should be understood that even though the LF did not favorably compare in a direct manner to the PG52-28 binder, the LF material could still prove to be useful in a

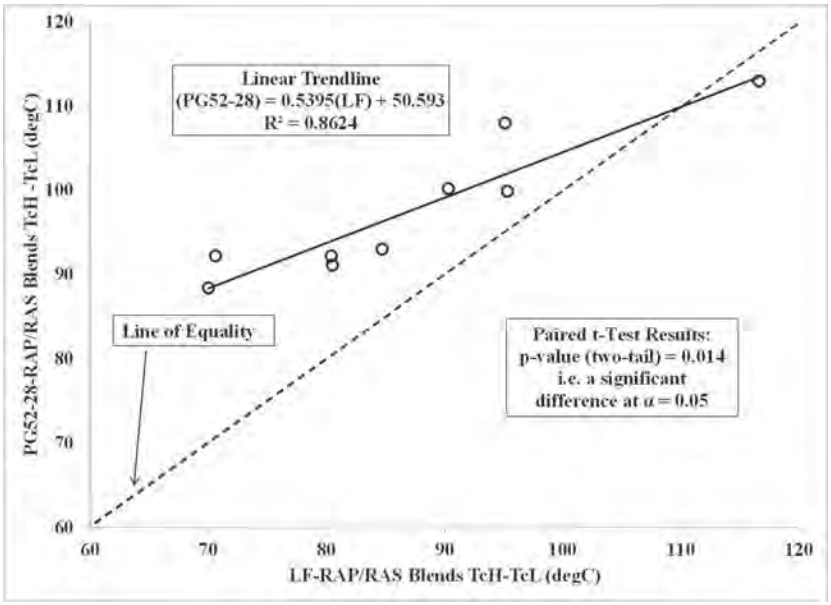


Figure 2

Hexane extract from leaf/stem (LF) vs. performance-graded binder (PG) 52-28 comparison.

different type of FPM application. Nonetheless, these results focused the remaining effort in the project on the RR. Figure 3 shows the same analysis for the RR vs. CycL comparison.

The plot in Figure 3 clearly shows that the RR vs. CycL direct comparison is much better than the LF vs. PG52-28. Although not shown, the T_cH correlation is almost perfect but slightly favors the RR, and the T_cL correlation definitely favors the CycL even though the bias is only a degree or two, on average. The absolute temperature spread data shown in Figure 3 is significantly different at an alpha value of 0.05, but is only slightly biased toward the CycL, though not for every blend. These results demonstrated that the RR could be used in a practical sense as a recycling agent and prompted the move to start FPM design, production, and testing.

FPM design began by using the RSMs to generate a RR-RAP/RAS blend that would meet specifications for a PG64-22 binder. Using an optimization procedure in the experimental mixture design software, a blend of 42.4% RAP1 binder, 17.8% RAP2 binder, 15.0% RAS binder, and 24.8% RR was produced that was estimated by the RSM, then verified through testing, to meet all specifications for a PG64-22 binder, except mass change (loss, in this case) upon short-term aging (i.e., RTFO testing, which involves heating a moving thin film of the binder in the presence of air at 163°C). Mass loss at typical binder/FPM testing/production temperatures, as it turns out, was the only major issue encountered during testing of the various guayule-based materials produced during this study. However, this phenomenon is reported in the literature and is consistent with other bio-based extracts/products utilized as property modifiers in FPMs.

Using the RR-RAP/RAS binder blend, a RR-based FPM was designed and produced that met the gradation specification for a particular Missouri Department of Transportation (MoDOT) moderate-quality FPM, but did not, on average, meet all of the volumetric requirements: per-

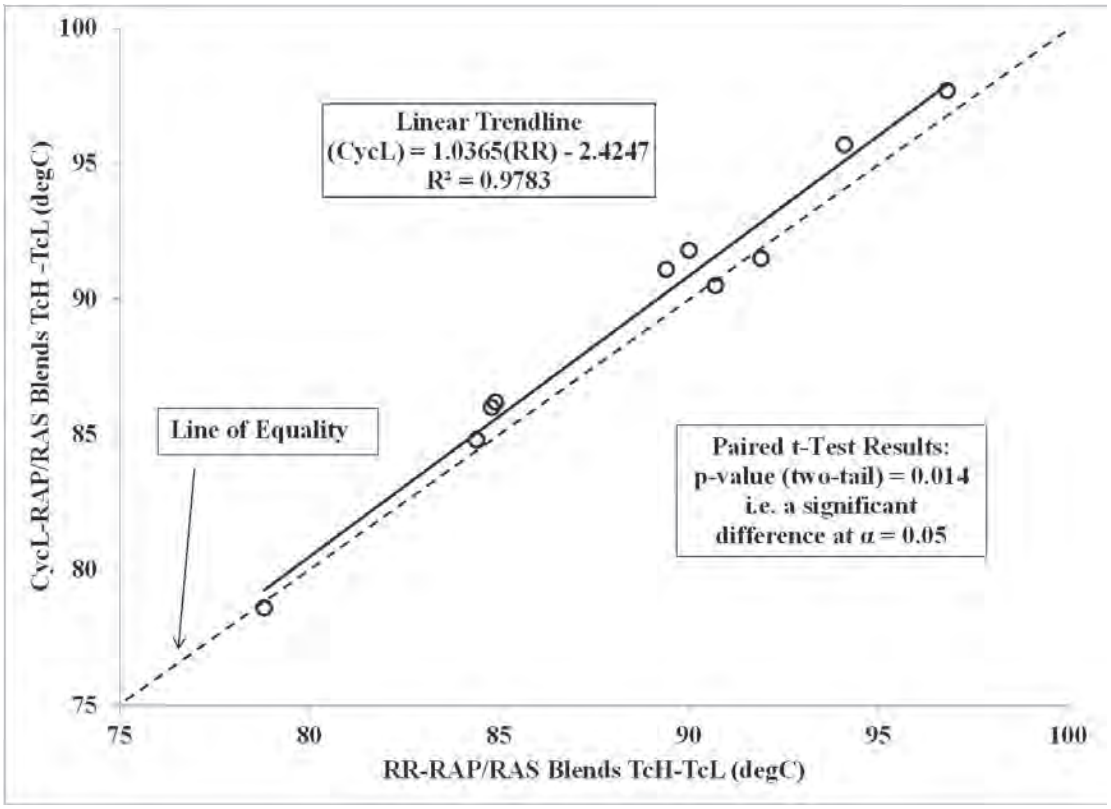


Figure 3

Acetone-extracted rubber resin (RR) vs. recycling agent Cyclogen L (CycL) comparison.

centage of air voids were high, voids in the mineral aggregate (VMA) were slightly low, but the voids filled with asphalt (VFA) met specification.

This FPM utilized 53% reclaimed aggregate (from the RAPs and RAS) and, therefore, 47% virgin aggregate. More importantly, and in relation to the project concept, only 0.23% of the total FPM mass (or 5.62% of total binder mass) was virgin, PG64-22 binder. The rest of the binder was RAP/RAS binder and RR.

Hamburg wheel-track testing of the FPM commenced, using RR as a recycling agent in one instance and CycL in the other instance. Percentages/masses of the CycL used were the same as the RR mixture. Figure 4 shows the Hamburg test results.

Hamburg wheel-track testing is a good indicator of rutting and stripping (moisture damage) potential of a FPM. There are four basic parameters identified in Figure 4: (1) post-compaction consolidation, (2) creep slope, (3) strip slope, and (4) stripping inflection point. Post-compaction consolidation is usually taken at 1,000 wheel passes and is considered to be the result of the wheel load densifying the mixture. Creep slope is a measure of the rutting susceptibility due to factors such as gradation, binder stiffness, and particle shape, but not moisture damage. The stripping inflection point and strip slope are measures of moisture damage. Where the strip slope is a measure of accumulated deformation due to moisture damage, the stripping

inflection point is a way to identify when the mixture performance becomes mostly a function of moisture damage. The Colorado Department of Transportation reports that a stripping inflection point occurring before 10,000 wheel passes indicates a stripping susceptible FPM.

The test data from two Hamburg specimens (i.e., four SGC specimens) was averaged to produce the curves shown in Figure 4. The test method specifies a void content of 7±1% for the test specimens. The average voids content, based on four SGC specimens, for each mix is indicated in Figure 4 and shows that the voids compare very closely with the RR mix having slightly higher voids. Variability among the SGC specimen voids content is essentially the same for each mix.

In making conclusions about the results shown in Figure 4, one must consider that the short-term aged viscosity of the pure RR is slightly higher than the short-term aged viscosity of the pure CycL. The increased post-compaction consolidation of the CycL FPM relative to the RR FPM could be due to this viscosity differential. All other major properties of the two FPMs (aggregate gradation, particle shape and geology, binder content, and volumetrics) are, however, essentially the same. The creep and strip slopes of both FPMs are parallel indicating that the rates of deformation due to nonmoisture and moisture-induced damage are identical.

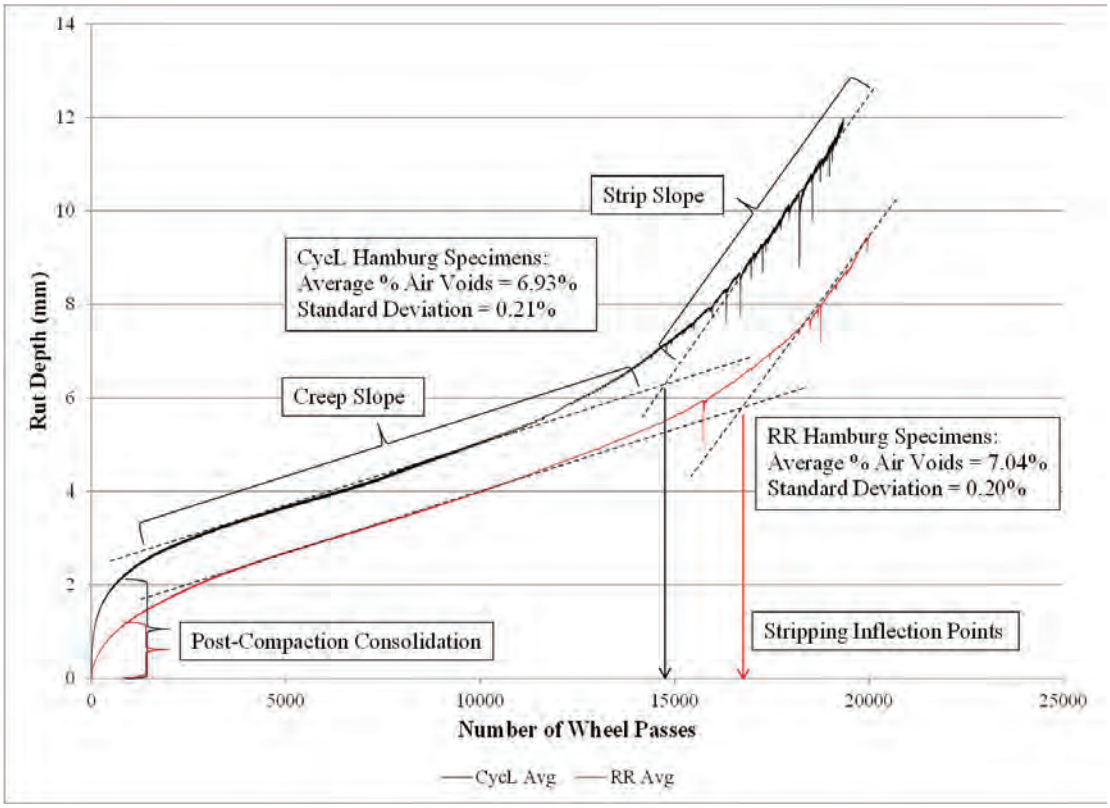


Figure 4

Acetone-extracted rubber resin (RR) vs. recycling agent Cyclogen L (CycL) flexible pavement mixture-Hamburg Testing Comparison.

However, the locations of the stripping inflection points indicate that the RR FPM performed somewhat better than the CycL FPM insofar as the onset of moisture damage is concerned. Therefore, because of the slight short-term aged viscosity differential between the pure RR and the pure CycL, one can conclude that the RR FPM performed as well as the CycL FPM in the Hamburg tests.

In conclusion, the RR can be used, in a practical sense, as a recycling agent in FPMs with high contents of RAP and/or RAS.

Product Pay-Off Potential

The guayule-based products could potentially lower the cost of highway construction. Also, FPMs produced using guayule-based products are likely to be more environmentally friendly and can reduce use of petroleum-based products. Additionally, the guayule industry could benefit through the opening of a new market for its products, and farmers could experience more opportunities/options from the increased demand for guayule cultivation. The Yulex Corporation, the only United States company currently processing guayule for commercial use, is planning to add more processing facilities in the near future, and Bridgestone and Cooper Tire are also planning to begin research into and production of guayule-based products as a renewable, domestic source of binder materials for FPMs.

Product Transfer

Now that the concept has been validated, pilot projects in Missouri can be pursued as a step in transferring the technology to practice. The Missouri Asphalt Pavement Association, MoDOT, and the Yulex Corporation have agreed to support any such pursuit.

EXTRACTION OF LAYER PROPERTIES FROM INTELLIGENT COMPACTION DATA

NCHRP-IDEA Project 145

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

IDEA Concept and Product

This project addresses a significant limitation of intelligent compaction (IC): Vibratory roller-measured soil stiffness provides a composite measure to a depth of 1.0–1.2 m, which is considerably greater than a 0.15–0.30 m lift/layer thickness of placed subgrade, subbase, or base material. While this composite measure is informative, it is more desirable to measure the stiffness/modulus of a 0.15–0.3 m thick lift. Current spot test-based QC/QA is based on lift assessment. To overcome this limitation, this research project is developing extracting a methodology to extract layer stiffness/moduli and thickness from roller-measured stiffness data sets. Figure 1 presents the conceptual approach that involves using soil stiffness and GPS-based position data from roller passes on multiple earthwork layers/lifts as the subgrade/subbase/base earthwork structure is constructed. To extract layer information, two different approaches are being pursued: (1) inverse analysis using a physical model and (2) statistical modeling.

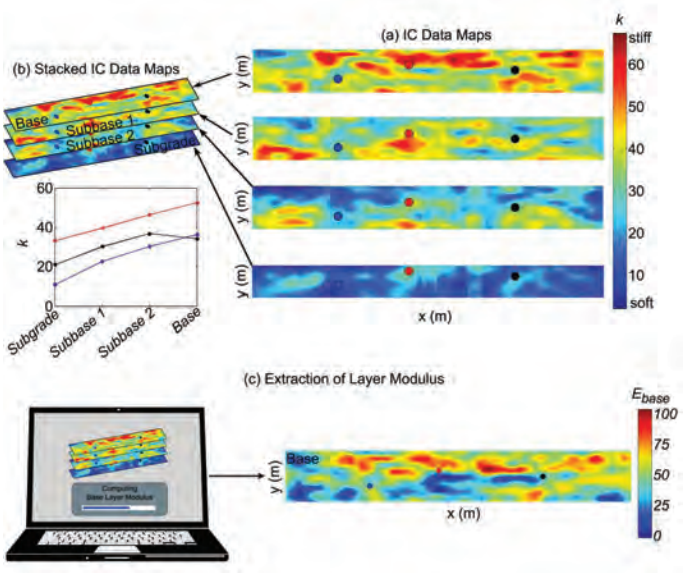


Figure 1

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

Project Results

The project was carried out in two stages of research. In Stage 1, soil properties (as measured with spot test devices, layer thickness from GPS) and excitation force parameters (e.g., force amplitude, frequency) were used as inputs to a model, which in turn predicts machine response (e.g., drum displacement, force transmitted to soil). Roller measured composite stiffness values are based on these machine responses and can therefore be calculated from the model outputs. Modeling in this sense is termed 'forward modeling.' Figure 2 illustrates the forward modeling process where k is the roller measured stiffness, E is the layer modulus, and h is layer thickness.

Both finite element (FE) and boundary element method (BEM) forward models were developed for two-layer systems and calibrated with field data. In addition, these forward model results were used to train statistical based forward models. The advantage of statistical models is run time. Statistical models can provide answers on a time scale required for real-time monitoring, whereas BEM and FEM models are too time intensive for real-time monitoring.

Stage 2 research used these forward models in an inverse analysis or back-calculation approach to estimate layer properties from measured composite stiffness (Figure 2). Under this scenario, roller measured composite stiffness from multiple layers of material and layer thicknesses serve as model inputs. The potential exists for the model outputs to be equivalent to spot test results (e.g., LWD modulus) as would be desired for improved IC, or as stress-dependent modulus functions as would be desired for use in performance-based QA and pavement design.

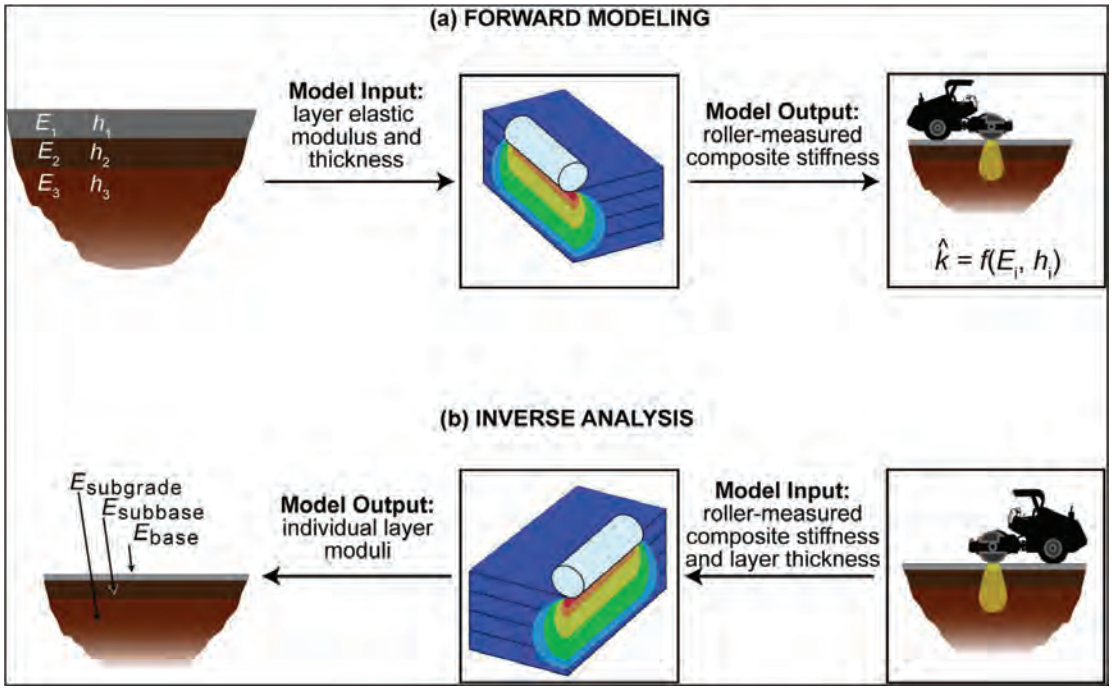


Figure 2

Illustration of forward (i.e., Stage 1) and inverse (i.e., Stage 2) modeling approaches.

Product Pay-Off Potential

This project offers three significant potential benefits. First, continuous assessment of subgrade, subbase, and base layer/lift properties (modulus, thickness) over 100% of earthwork is a dramatic improvement over spot testing of less than 1% of the earthwork. Second, implementation of performance-based specifications over the entire pavement section will enable the linkage between design and construction. There are currently no techniques available for performance-based field assessment of earthwork materials. Finally, the roller based stiffness and IC enables accelerated construction. The assessment of layer properties will further accelerate construction as it pinpoints problems within specific layers. This will enable project personnel to address the specific layer/material immediately and move forward with the project.

Product Transfer

The methodology developed in this project can be implemented via software algorithms that can be integrated into any commercially available IC software offered by roller manufacturers, consultants, andor third-party vendors, (e.g., navigation system providers). IC software is used on-board the roller and/or on mobile and desktop computers. Therefore, the implementation of the methodology would be performed by the IC software companies. Alternatively, software algorithms could be employed independent of existing IC software. In this approach, the IC data (composite soil stiffness and GPS coordinates) from commercially-available software would be fed into a separate program that would provide layer moduli. The implementation of this latter approach could be performed by any interested party. The methodology generated is generic and can be applied to any currently-available proprietary measures of ground stiffness from vibratory rollers.

ADVANCED METHODS FOR MOBILE RETROREFLECTIVITY MEASUREMENT ON PAVEMENT MARKING

NCHRP-IDEA Project 146

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

IDEA Concept and Product

Systems for mobile retroreflectivity measurement on pavement markings have been commercially available for more than 15 years. However, due to measurement reliability issues, those systems are not widely used and have not demonstrated the ability to perform at a satisfactory level in a real-time environment. Such systems have functioned accurately in a stationary and controlled environment; however, when applied to "in situ" road conditions at highway speed, these legacy applications have proven to be problematical. Air temperatures, vehicle dynamics (such as pitch, roll and yaw, traveling speed, road flatness, and sunlight) are some of the uncontrollable variables that cause issues for the current retroreflectivity measurement technologies.

The proposed approach leverages the latest technologies available today to overcome these issues. A much more reliable line scan imaging system will be used in place of the intensifier imaging system. A new real-time tracking system measurement method will be used to provide consistent measurement points. A geometry measurement system will be used to handle the uncontrollable measurement variables (such as pitch, roll and yaw in vehicle dynamics).

This proposed system will lead to vehicle-mounted measurement devices as a final product. Figure 1 shows an overview of the hardware configuration. The system will meet the perfor-

Figure 1

Prototype Retroreflectivity Mobile Unit.

mance requirements of accuracy, repeatability, and reproducibility. A simple daily verification procedure will be used in place of the hourly calibration required of the existing systems. Only a single operator will be required as opposed to two needed to operate the existing technology. Potentially, the system could simultaneously measure two lanes instead of one.

Project Results

An evaluation was performed on small sample strips (stationary). As indicated in Figure 2, the results were closely related between the handheld unit and the vehicle-mounted unit. Road tests from June 2011 indicated that the results are repeatable as illustrated in Figure 3. After additional refinements were implemented on the tracking system, road test results are now

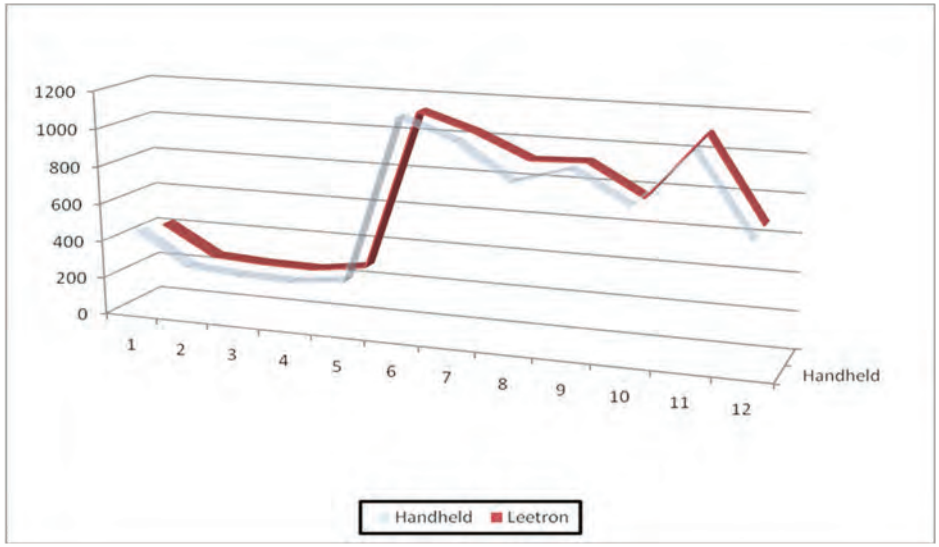


Figure 2

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

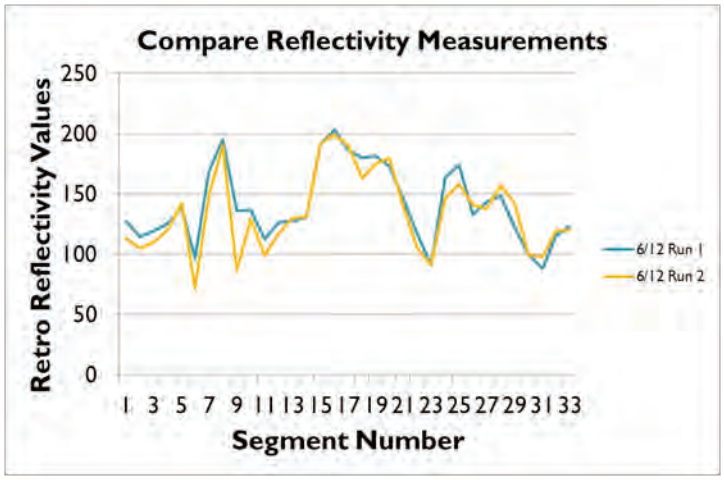


Figure 3

Repeatable road test at 60 MPH

achieving a repeatability error under 1.5%. This is well inside our anticipated design goal of 10%. Road testing has demonstrated that the key technologies used in this system are achieving the expected results. The laser is able to point at the center of a pavement marking and remain fixed on target as the vehicle traveled at highway speed. The final report is available from the National Technical Information Service (NTIS Report # PB2012-110782).

Product Payoff Potential

The retroreflectivity measurement of pavement markings has assumed greater importance to transportation agencies as they have recognized the value of such measurements to maintain quality and to determine cost-effective schedules for repairs where needed. The need for retroreflectivity measurement is further increased by the fact that FHWA will establish a minimum retroreflectivity level in the near future. The traditional method of measurement with handheld retroreflectometers is neither safe nor cost efficient. Existing mobile retroreflectivity measurement units are more cost efficient. However, those units are not widely used because of reliability issues. Successful implementation of the proposed system could benefit the transportation agencies by providing the ability to obtain accurate retroreflectivity data safely and efficiently.

In addition to meeting the minimum retroreflectivity requirement, there are potential savings on the pavement repainting budget. Typically, a road has a fixed repainting schedule based on many factors such as traffic load, prevailing weather conditions, and type of pavement markings. Some roads may have bi-annual paint schedules, while others may see years between repainting. The fixed schedule is based on worst case scenarios to guarantee compliance, thereby eliminating the ability to delay painting based on an evaluation of actual needs. With real time retroreflectivity data, those roads below the minimum requirement could be queued up for painting based on a priority schedule. Roads measured and shown to be in compliance with the required safety standards could be delayed in the repainting schedule. Such an arrangement will result in a safer environment and a more cost-effective and predictable repainting budget.

Product Transfer

With the success on the prototype development, more engineering and financial resources are being employed toward the commercialization of 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 research team expects to introduce the final product to the marketplace in the near future.

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

Paul Bradford, Watson Bowman Acme, Amherst, New York

Emily McCarthy, Rice University, Houston, Texas

IDEA Concept and Product

This NCHRP IDEA project will design, analyze, and test an innovative bridge expansion joint aimed at mitigating damage often seen after a seismic event in modular bridge expansion joints (MBEJ). Bridge joint enhancement is expected to benefit the dynamic performance to accommodate demands that are observed in such events as earthquakes, thereby improving the post-event functionality of the bridge. The proposed SMART expansion joint will integrate NiTiNOL shape memory alloys (SMA) as a means of modifying a current, commonly specified bridge joint. These joints can take advantage of the unique mechanical characteristics of SMAs that include recentering and energy dissipating characteristics, which improve seismic behavior, and corrosion resistance, which alleviates maintenance costs associated with bridge joints. Through this project, performance-based guidelines for expansion joints will be elaborated on and the new SMART joint will be designed and assessed for achieving such goals as minimizing post-event repair requirements, maximizing joint reliability, and reducing life-cycle costs. Upon project completion, a full-scale enhanced bridge joint will be developed and tested. Analytical and life-cycle cost models proposed will support cost-benefit analyses of SMART joints for different bridge types and locations.

Project Results/Planned Investigation

Stages one and two of IDEA project 147 have been completed. During these stages, performance goals for an enhanced modular bridge expansion joint were developed, which led to the establishment of set criteria against which an enhanced MBEJ could be judged. These criteria encompassed qualitative and quantitative performance goals given a bridge importance level as described by the AASHTO Seismic Design Specifications.

Component testing of devices in the existing modular bridge expansion joint provide foundational information from which reasonable analytical models can be developed. The key components driving the behavior of the expansion joint were determined to be the polymer equidistant devices and the friction components. Researchers in previous studies (Mokha 1993) established the friction behavior between Polytetrafluoroethylene (PTFE) and stainless steel, the two materials governing the coulomb friction response within the modular bridge expansion joint being assessed. The polymer equidistant devices were experimentally tested specifically for this work to map out their behavior. Focused service joints utilize 5.125 in.-long polymer devices of proprietary material composition and cross section. Those joints modified to accommodate seismic displacements currently use 6.75 in. polymer devices of the same material and cross section as the standard devices. In Figure 1 the standard polymer behavior and elongated polymer behavior are compared.

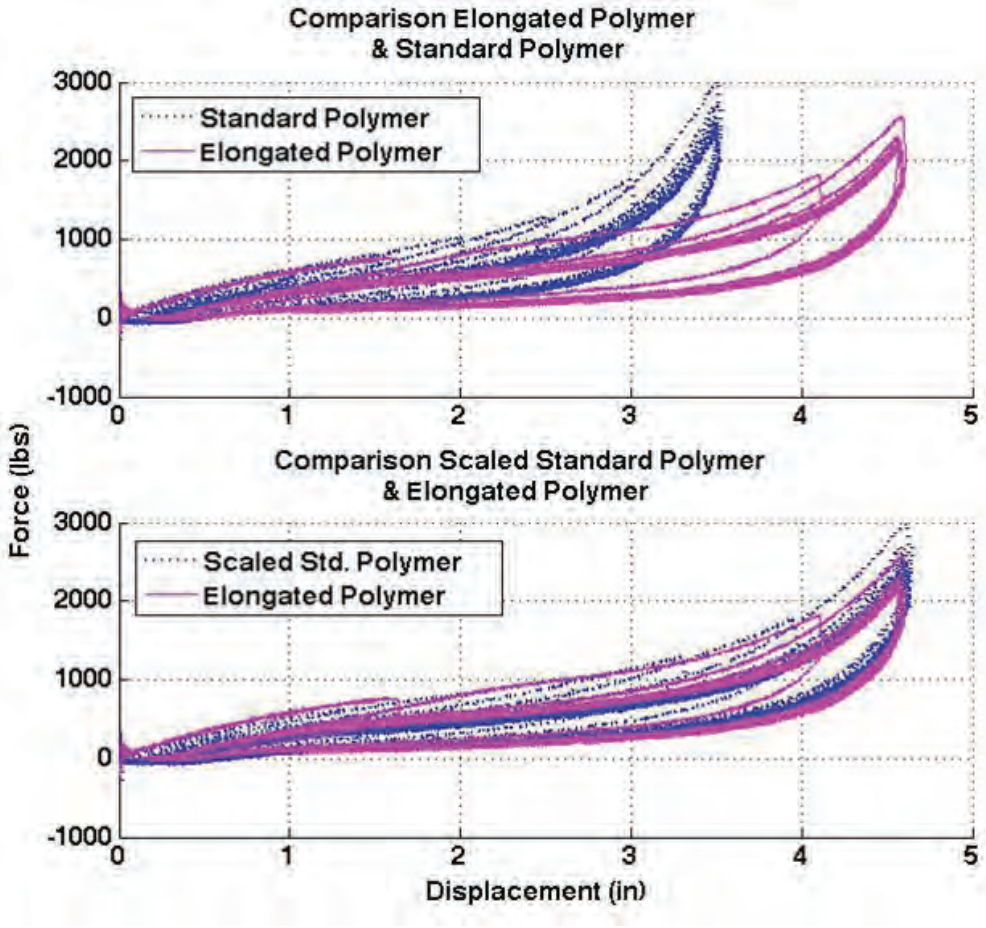


Figure 1

Comparison between mechanical response of a standard length and modified length polymer equidistant device

In Figure 1, the top plot shows the experimental force deformation characteristics of each device while the bottom is a comparison considering scaling of the standard polymer. Since the only aspects between these two devices that change are the length and the means of elongation, it is expected that the forces achieved within the devices would be similar in reference to the percent of compression in the device. This is indeed observed to be an accurate assumption through the majority of the compression. It differs after approximately 61% compression. This can be attributed to the fact that the elongated polymer is not a uniform specimen but, in fact, a composite of short and standard polymers. When the elongated polymer compresses beyond 60% compression, the buckling of the device forces the two meeting cross sections to no longer provide uniform support at which point the forces are allowed to remain lower in the composite device than in the standard device due to slippage. This revelation into the behavior of the equidistant devices will aid joint design efforts by enabling accurate representation of loading behavior within the joint.

A library of potential SMA components for joint enhancement was created through finite element and experimental testing. The finite element modeling utilized a self-defined material

in the ABAQUS platform, an in-house program, and the ADINA program in conjunction with SolidWorks. Given the increased control allowed in specifying analytical algorithms for the accurate description of material behavior, initial analysis used the in-house program to investigate the benefits of potential SMA configurations prior to experimental testing. Ongoing FEM analysis was performed in the ADINA program and focused on assessing multiple iterations of a spring configuration. Based on an in-series polymer and SMA composite device, limitations on the geometry of an SMA spring controlled the range of iterations. The in-built Shape Memory Alloy material definition in ADINA enabled both global and elemental assessment of the behavior of the device. Global force deformation characteristics determined compliance with project goals. Specifically, if the displacement range anticipated for seismic movements were achievable with the in-series configuration while reducing forces transferred through the joint compared to the current industry configuration, then successful attainment would be predicted through FEM analysis. Delving into the strain characteristics of the material at the elemental level reveled elongations of 8.5% strain for those iterations that most closely resembled ideal characteristics. This strain level is within theoretical and experimental recoverable limits given tensile test data. Figure 2 illustrates the force deformation characteristics for a single spring iteration with Figure 3 showing the resulting force deformation behavior of the full joint when analyzed with an in series equidistant device using the global spring behavior as input in the OPENSEES SMA model. Maintenance of service behavior up to 6 inches of opening displacement assures conformance to current industry joint behavior, while reduction of forces through 12 inches of movement indicates improved seismic joint behavior.

To date a full-scale modular bridge expansion joint has been tested through a displacement sine wave loading protocol run at approximately 2.18 inches per second. This speed represented the upper limit of equipment capabilities. The test aimed at recording global joint force displacement characteristics in order to provide a baseline against which an enhanced joint could be gauged. The locations of the LVDTs allows for approximation of center beam spac-

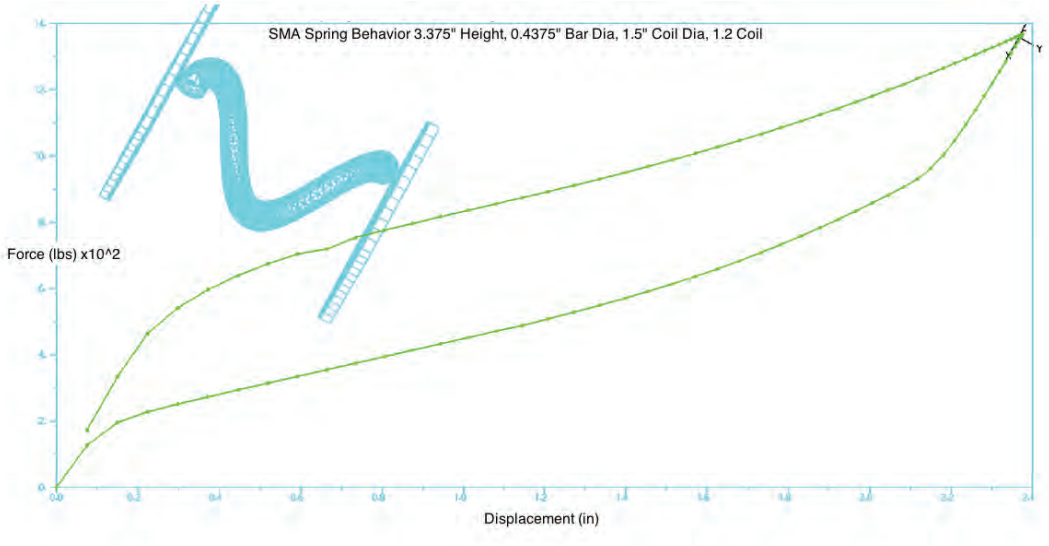


Figure 2

SMA spring ADINA predicted global mechanical behavior (3.375 in. height, 0.4375 in. bar diameter, 1.5 in. coil diameter, 1 full coil).

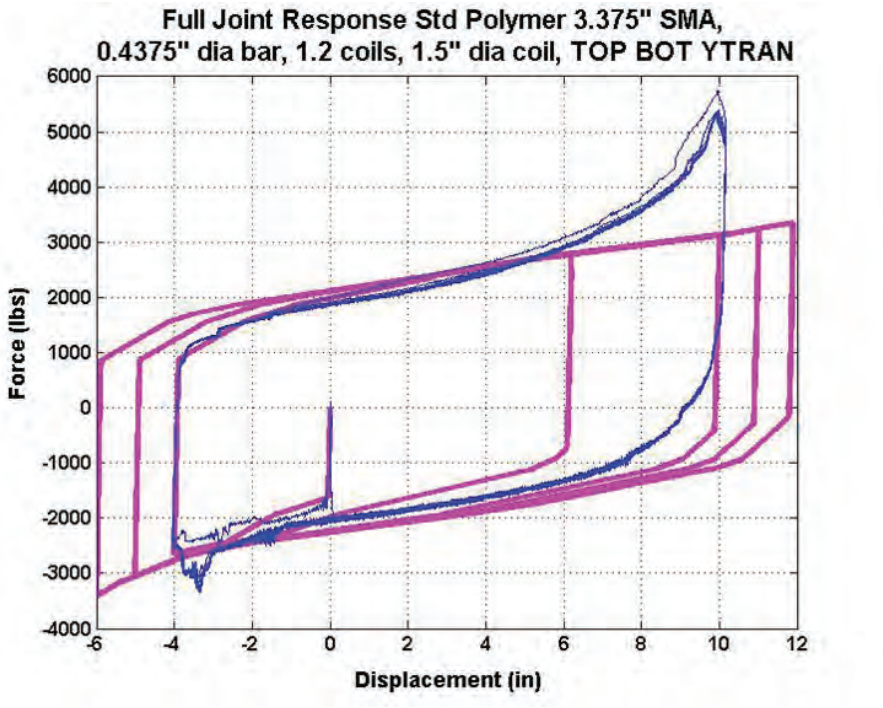


Figure 3

Full joint behavior incorporating in series polymer SMA configuration.

ing during dynamic opening and closing of the MBEJ, which facilitates accurate calibration of the developed analytical joint model. Two consecutive tests were run. Figure 4 shows the test setup, while in Figure 3 the experimental global force displacement behavior of the same joint is shown overlaid with the analytical response of the enhanced joint. During laboratory testing, the MBEJ was situated such that the components of interest were easily visible throughout the test so as to witness any failure modes. It was noted that after repeated cycles, dowel dislodgement at the equidistant springs was possible; and although no structural members failed, it was observed that the z-bars housing the polymers visibly deformed due to the stiffening of equidistant springs at larger joint openings. As the displacements reached were not maximum design displacements, these z-bar deformations and their potential failure was seen as undesirable. MBEJ enhancement will aim to reduce the loads transferred to these components while enhancing the design joint displacement capacity through the introduction of SMAs.

The current full joint model has been included in a simplified bridge model and excited by 10 synthetic ground motions to determine seismic behavior. The analytical results demonstrated the ability of the proposed configuration, utilizing ideal SMA characteristics, to accommodate seismic displacements and reduce forces transferred through the joint. Figure 5 shows the comparison for a simplified bridge, which uses either a joint with SMA enhancement or an as-built joint that employs elongated polymers to accommodate additional seismic displacements.

The simplified bridge represented here is excited by a 0.475 PGA 2% in 50-year synthetic ground motion developed by Wen and Wu (Wen 2001). The as-built joint is seen to transfer large forces through the joint at time 13 sec while the SMA enhanced joint limits this transfer-

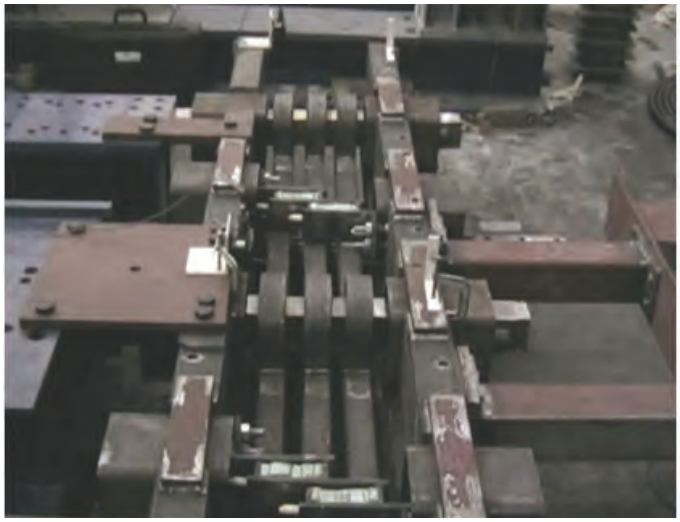


Figure 4

Full scale MBEJ joint test setup.

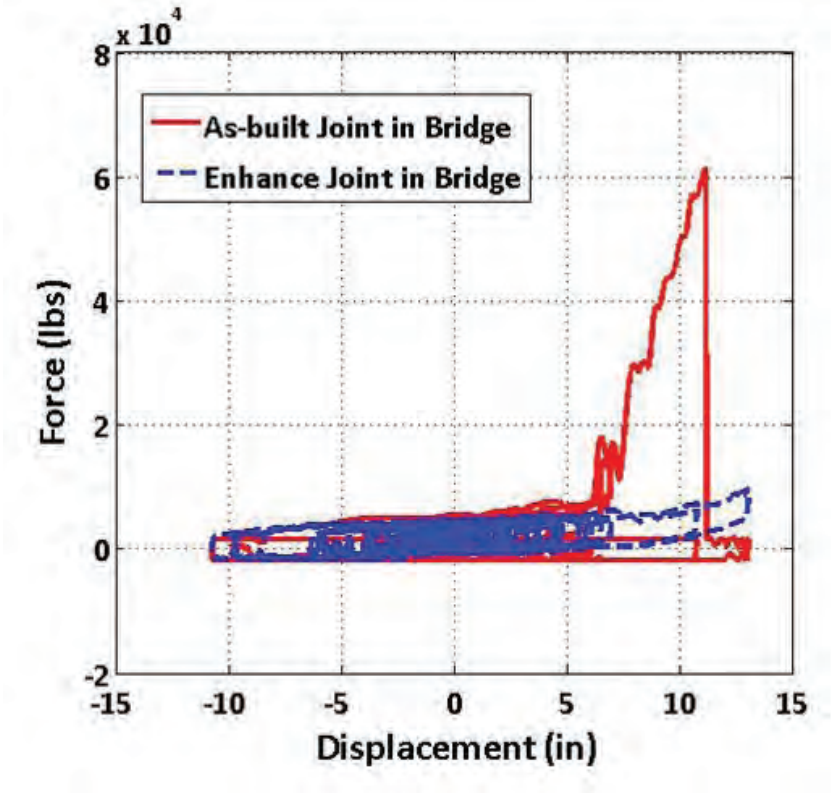


Figure 5

Analytical comparison between seismic joint behavior.

ence of force. The large forces in the as-built joint were seen to trigger failure in certain components in the joint, which translated into damage that would limit immediate bridge access without a degree of repair. These analytical results encourage further research in this area of joint modification.

Future work will include manufacturing the optimized SMA components, installing them in the full-scale MBEJ, and testing the joint under the same loading protocol as the base joint. After the acquired data is used to refine the enhanced joint model, the analytical joint will be incorporated into a theoretical bridge representative of those typically specifying MBEJs for the purpose of simulating data for fragility analysis. This information will be used to analyze the life-cycle costs for the proposed enhanced joint. The resulting fragility curves and life-cycle cost models used for cost-benefit analysis will aid municipalities and DOTs in selecting and detailing bridge expansion joints for enhanced performance.

Product Pay-Off Potential

The proposed SMART expansion joint is expected to improve joint and bridge performance under both service and extreme hazard conditions and to reduce the need for repair with loss of functionality. The use of SMAs in modular expansion joints exploits materials that have superior corrosion resistance and fatigue properties, compared to traditional structural materials, and they simultaneously offer recentering and damping to effectively sustain extreme event loading and improve joint reliability. The integrated framework to consider risk-based life-cycle performance in joint selection could further provide the bridge community with an effective decision-making tool when considering high-performance expansion joints.

Product Transfer

Upon completion of this project, a fully functioning enhanced modular bridge joint will be developed through the collaborative efforts of Rice University, Georgia Institute of Technology, and industry partner Watson Bowman Acme. The joint design is targeted to augment current expansion joints to incorporate new SMA-based components with advanced performance and functionality, without changing the field construction requirements in order to provide easy transfer of the technology into practice. Performance and design guidelines along with analysis tools will be readily available and distributed for industry use at project completion.

References

Mokha A S, Constantinou M C, Reinhorn A M. 1993. Verification of Friction Model of Teflon Bearings under Triaxial Load. *Journal of Structural Engineering*. **119**:240-261.

Wen YK, and Wu CL. 2001. Uniform Hazard Ground Motions for Mid-America Cities. *Earthquake Spectra*. **17**: 2: 359–384.

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

NCHRP-IDEA Project 149

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

IDEA Concept and Product

It is well known that existing W-beam guardrails cannot meet current safety performance criteria when the posts are restricted from rotating in the soil, as with frozen ground, paved shoulders or mow strips, and bedrock. Half of the energy dissipated by the guardrail is due to rotation of the posts in soil. Thus, when post rotation is restricted, the W-beam rail element will have to absorb the excess energy, which is shown to be beyond its capacity in full-scale crash tests, as illustrated in the sequential photographs in Figure 1. There is currently no solution to this problem and little research has been conducted to date. The objective of this study is to develop a cost-effective solution to this problem.

The basic concept is to develop breakaway posts with energy absorbing capability so that the W-beam rail element does not have to dissipate any additional energy. If the study is successful, the new guardrail post would significantly improve the safety of guardrails during winter months and for situations in which rotation of the posts is restricted. Furthermore, it is believed that the guardrail post would actually reduce the cost of installing, maintaining, and repairing guardrail systems installed in pavement or rock.

Project Results and Planned Investigation

A number of conceptual designs for energy-absorbing breakaway posts were developed, analyzed, and evaluated. The two most promising candidate designs (welded tab and bent plate) were then selected for further testing and evaluation.

Two initial bogie tests were conducted, one on each of the two selected designs. The bogie tests

Figure 1

Sequential photographs from full-scale crash test showing failure of W-beam guardrail system in rigid soil.

involved a bogie vehicle weighing 1,744 lbs. impacting the posts at a nominal speed of 20 mph. Similar bogie tests had been conducted with standard line posts and breakaway posts, thus providing baseline data for comparison purposes. The welded tab design failed prematurely without exhibiting the desired failure mechanism. On the other hand, the bent plate design has the desired failure mechanism, even though the force level was too low. Thus, the bent plate design was selected for further development. Figure 2 shows a schematic of the bent plate design and Figure 3 illustrates how the failure mechanism functions.

The force level is primarily controlled by the thickness of the bent plate. As may be expected,

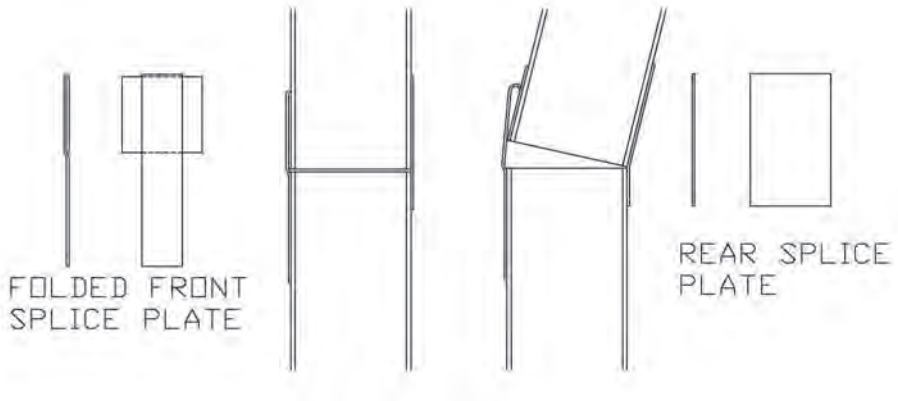


Figure 2

Schematic of bent plate design.

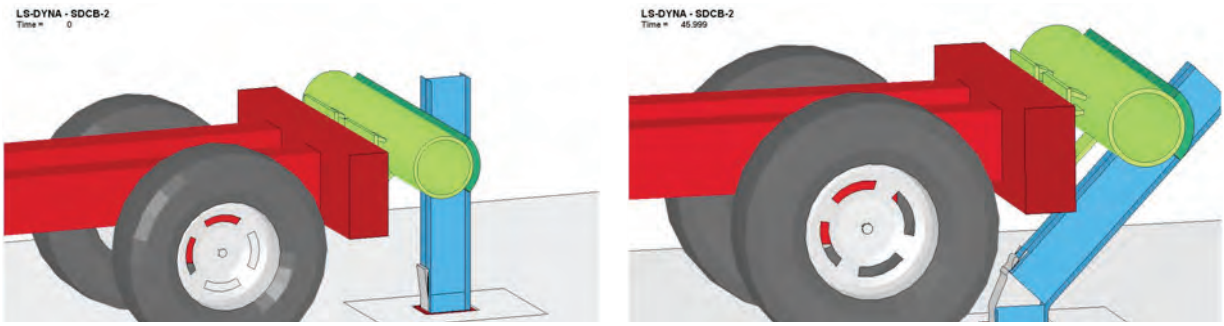


Figure 3

Illustration of failure mechanism for bent plate design.

when the bent plate is thicker, the force level and energy absorption capability of the breakaway posts are higher. On the other hand, excessively thick plates pose problems in the manufacturing process, resulting in higher costs. The LS-DYNA finite element simulation model was used to optimize the thickness of the bent plate to attain the desired force level. Based on results of the simulation and consultation with the manufacturer, a thickness of 3/16 in. was selected as the best compromise between force and energy absorption level and manufacturability. The posts were fabricated from standard W6x9 line posts, 72 in. long with an embedment depth of 40 in.

Two additional bogie tests were then conducted on the optimized posts. Results of the bogie tests indicated that the failure mechanisms of the optimized posts are performing as intended. The force levels are slightly lower than those of a standard line post, but still within the acceptable range. Further increase in the bent plate thickness would be counter-productive due to manufacturing concerns and only marginal increase in the force and energy levels.

To ensure that the energy absorbing breakaway posts would function properly with the W-beam guardrail system, the LS-DYNA finite element model was used to simulate a full-scale crash test. Results of the simulation indicate that the energy absorbing breakaway posts would improve the impact performance of the W-beam guardrail system under frozen or rigid soil conditions. Figure 4 shows the simulation results of an impact of a W-beam guardrail system

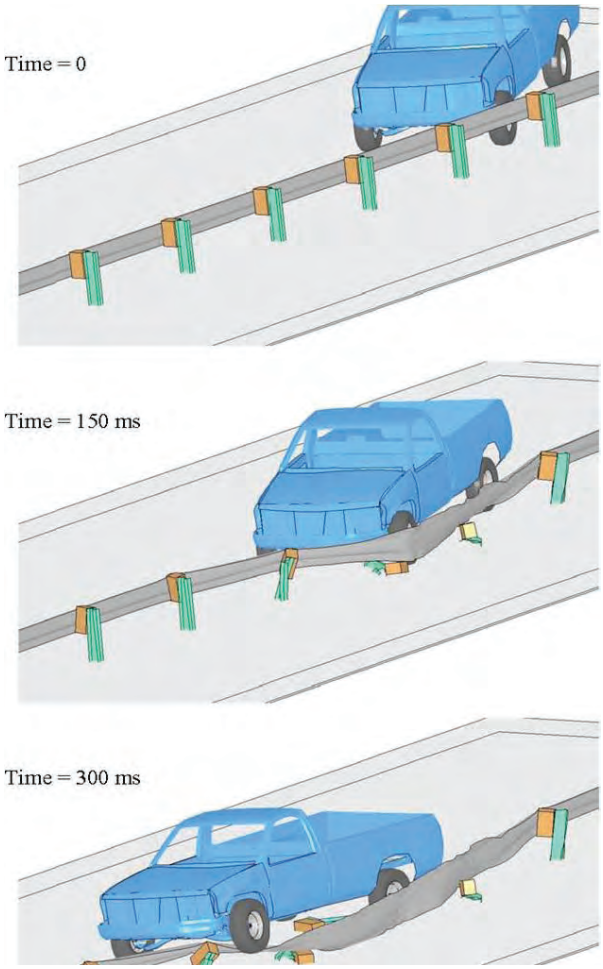


Figure 4

Simulation of crash test of W-beam guardrail system with standard line posts.

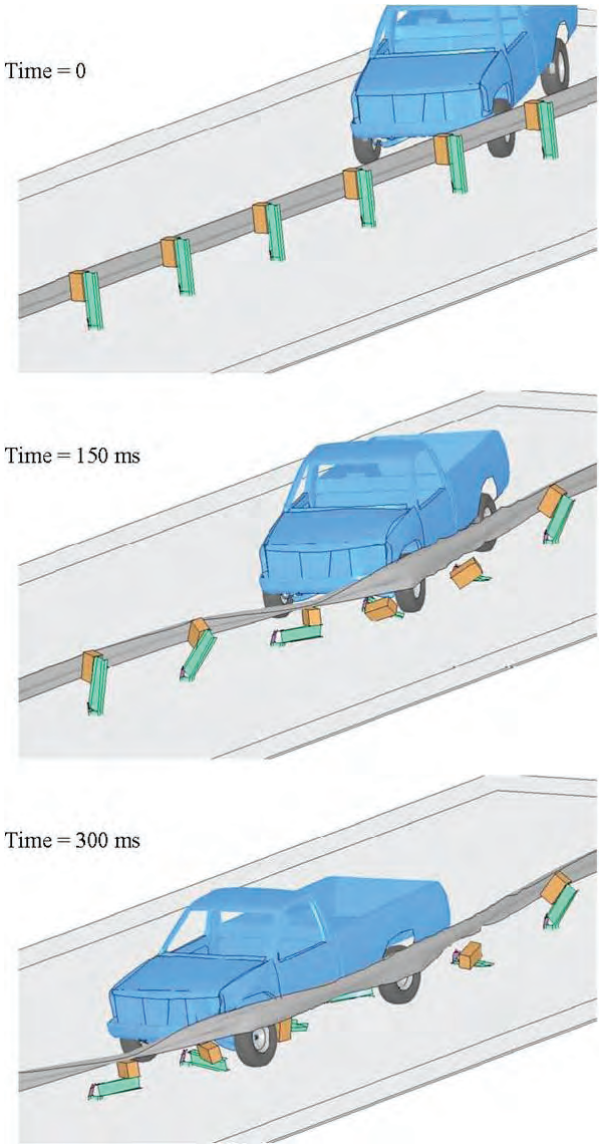


Figure 5

Simulation of crash test of W-beam guardrail system with energy absorbing breakaway posts.

with standard line posts. The simulation results closely duplicate the kinematics of the failed full-scale crash test (shown in Figure 1), in which the vehicle vaulted over the rail.

Figure 5 shows the simulation results of an identical crash test for a W-beam guardrail system with the energy absorbing breakaway posts. The vehicle was successfully contained and redirected, indicating satisfactory impact performance.

This completes all work planned under stage 1 of the project. The stage 1 report, summarizing the work conducted under stage 1 and the associated results as well as the proposed plan for work to be accomplished under stage 2, was prepared and submitted to the NCHRP Panel for review and approval. Following approval by the panel, a full-scale crash will be conducted in stage 2. Arrangements have been made with the manufacturer to fund and provide the materials for the test. This test, if successful, will qualify the system for use on the National Highway system following approval by the Federal Highway Administration. Also, field tests will be

conducted in Nebraska and Wisconsin to identify any potential installation and maintenance problems, evaluate its field performance, and demonstrate its economic viability in both frozen soil and mow strip applications.

Product Pay-Off Potential

This new concept of using energy absorbing breakaway posts should, for the first time, provide acceptable impact performance for W-beam guardrail where rotation of the posts in soil is restricted. Implementation of this new guardrail post could potentially reduce the severity of such guardrail crashes and the associated serious and fatal injuries.

The increase in the cost associated with the new guardrail posts should be relatively small compared to the potential benefit of improved guardrail performance in frozen ground. Note that the use of welded breakaway mechanisms helps to limit the cost increase, both by minimizing fabrication cost through mass production and by facilitating driving the post into hard soils and through asphalt. The ability to drive the post through asphalt and eliminate the need for pavement cutouts would produce large construction cost savings for the roughly 25 percent of new guardrail installations that are placed on paved surfaces. Elimination of the need for guardrail repair crews to replace low strength paving materials in the cut-outs is another significant cost saving. It is quite possible that the savings associated with guardrail placement in pavement can completely offset the cost of implementing the new post for all other applications.

Product Transfer

The new posts will be fabricated and marketed by Road Systems, Inc., (RSI) the industrial partner on the project. RSI is the second leading manufacturer of guardrail terminals and breakaway steel guardrail posts. The company maintains a nationwide marketing program that includes its own marketing personnel as well as the marketing departments of its nationwide network of distributors. RSI has brought more than a dozen products to the market and has one or more products approved for use by every state in the nation.

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

IDEA Concept and Product

This project was designed to assess the use of a laser-spectrographic sensor technology to identify the type and quality of aggregate materials used in pavement construction. The technology, referred to as laser-induced breakdown spectroscopy (LIBS), is a rapid method laser-scanning technique in which a very short-duration pulse of energy from a high-power laser is optically focused to a point, instantaneously heating the target sample to cause vaporization and atomization of 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.

Project Results

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 New York, Kansas, and Texas Departments of Transportation (DOTs), respectively.

In all cases, multivariate discriminate models were developed that were capable of identifying with a high degree of accuracy the quality of the test aggregate. For example, using the known acid-insoluble residue (AIR) content of a series of carbonates from New York, it was possible to establish a highly accurate calibration model for estimating the AIR content of New York carbonate aggregates and to use the model to predict the AIR content of test samples. It was possible to determine the compositional blend of noncarbonate rock in a noncarbonate-limestone blend. It was possible to model 16 beds from three Kansas quarries, to identify the specific source bed of an unknown aggregate, and to model aggregates that pass or fail KSDOT tests for D-cracking aggregates. The analysis of alkali-silica reactive cherts received from TXDOT yielded similar positive results. It was possible to differentiate between four types of chert, classify cherts as more or less reactive, and develop a calibration curve to identify and quantify the percentage of reactive chert in quartz-chert mixtures.

The conclusions from these findings are as follows:

- Laser-induced spectra are unique to the specific mineral aggregate tested and contain significant information about the fundamental properties of aggregate material;
- Such spectra can be modeled using multivariate models;
- Such models provide a means to effectively identify the specific spectral pattern associated with the target material and correlate those spectra with engineering properties; and
- LIBS has the potential to rapidly analyze mineral aggregates with promising use as a quality control tool in aggregate processing systems.

The results are presented in detail in the final Highway IDEA Project Report. The final report is available from the National Technical Information Service (NTIS Report # PB2012-111107).

Product Pay-Off Potential

Commercialization of the subject technology could provide state DOTs and material suppliers with a real-time, nearly instantaneous aggregate characterization and quality control tool.

Product Transfer

The authors of this study have initiated the development of a patent-pending, automated real-time monitoring system that can be used to capture the data generated by a continuous firing laser system. This developmental process involves transitioning the LIBS process from an individual particle-to-particle-focusing-and-targeting system to a bulk-material-sampling-and-laser-targeting system. The research team believes that the development of a viable field system will be successful. Plans have been initiated to demonstrate the technology in quarry applications, and a pooled study (KSDOT being the lead agency) is presently being explored.

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

NCHRP-IDEA Project 151

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

IDEA Concept and Product

In a recent IDEA project (NCHRP-133), a simple bending creep test on thin beams of asphalt mixtures (Figure 1) was developed along with a draft American Association of State Highway and Transportation Officials (AASHTO) specification. However, mixture creep compliance represents one of the two parameters required to predict low temperature performance; strength is the other critical parameter needed in the AASHTO pavement design guide low temperature algorithm. This follow-up research focuses on the development of a strength test for asphalt mixtures using the same bending beam rheometer (BBR) device. The product will be a BBR that can run low temperature creep and strength tests for both asphalt binder and mixture specimens along with draft AASHTO specifications.

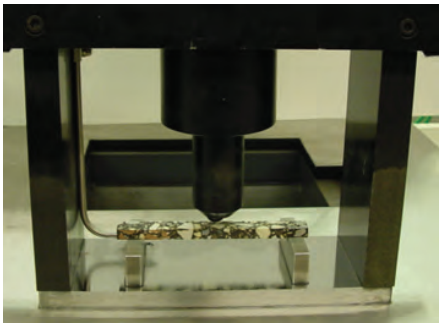


Figure 1

Bending beam rheometer (BBR) with thin beam of asphalt mixture.

Planned Investigation

The work proposed consists of four tasks. In the first task, a test method that includes the calibration, test protocol, and data analysis was developed to obtain the strength of asphalt mixtures and binders using a new BBR device provided by Canon Instruments. The new loading system offers a much more complex control of the pressure in the air-bearing system and is capable of providing a loading pattern that can be used to perform strength tests. This work was performed on a large number of replicates for typical asphalt mixtures and asphalt binders used in Minnesota. Based on a review of fracture mechanics concepts, it was decided to use a coupled energetic statistical approach to analyze strength and strength-size effect in order to keep the experimental part simple.

In the second task, the modified BBR device and the test method developed in task 1 were used

to perform strength tests on asphalt mixtures and binders. Results were compared with the current test methods: direct tension test (DTT) for binders, and indirect tensile test (IDT) for mixtures. The significant difference between BBR and DTT binder strength results prompted an investigation of the effect of commonly-used cooling media (ethanol, potassium acetate, and air) on the experimental results. It was found that ethanol significantly reduced the strength values, most likely due to environmental stress cracking. Weakest link model (WLM) and size effect theory showed that binder strength values obtained with DTT and BBR using potassium acetate and air, respectively, were similar. Simple statistical comparison of mixture BBR and IDT strength results indicated that higher strength values were obtained in BBR tests.

The IDT test does not have a predictable size effect due to the test geometry, making material strength extrapolation to larger structures practically impossible. In the third task, the issue of size effect for asphalt mixture strength was investigated by testing beams of different sizes. Probabilistic theory and WLM were applied to determine the failure probability of the representative volume element (RVE) of asphalt mixture. A set of closed-form equations was derived to calculate the characteristics parameters of the mean strength-size effect curve (energetic statistical size effect law). Mean strength model prediction was verified by the energetic statistical size effect law showing that asphalt mixtures present a quasi-brittle failure behavior at low temperature. The size effect analysis also indicated that the failure strengths in "tension" and in "bending" were similar.

In the last task, the effect of cooling medium on mixtures BBR strength was further investigated. It was concluded that testing in air represents the best option for mixture testing, for which the results are less sensitive to small temperature fluctuations. Given the smaller

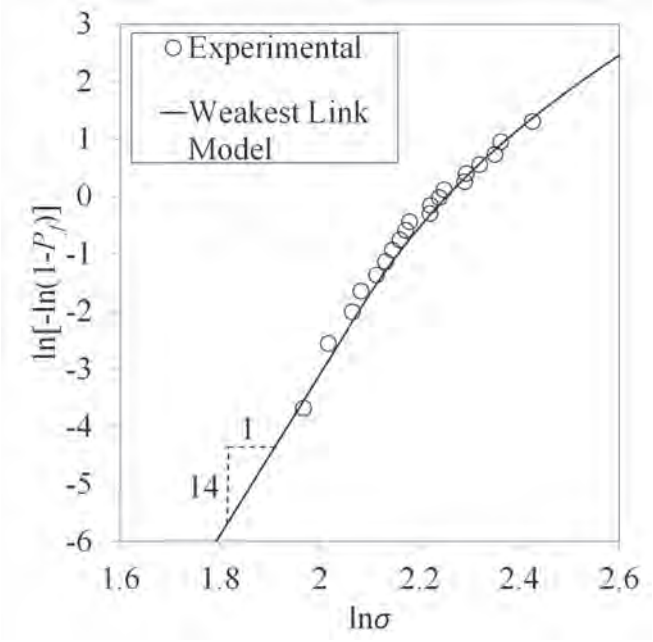


Figure 2

BBR strength histograms and weakest link model prediction for asphalt mixture.

dimension of the BBR beam compared to the RVE size of asphalt mixture, a mathematical model for reconstructing the material RVE was proposed. This approach is based on BBR data and an assembly of bundled and chain statistical models. The RVE model is validated through histogram testing on larger specimens. The good agreement between the predicted strength obtained from the RVE model and the experimental results indicates that BBR may provide a simple alternative to asphalt mixture strength testing.

Product Payoff Potential

This research effort will 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 the structure of real pavements. The smaller size of the test specimen also allows investigating the properties of thin and ultra thin layers made with premium materials, a technology that has seen considerable growth in recent years.

The payoff for transportation agencies can be significant. Currently, many agencies are struggling to maintain their pavement networks at acceptable conditions, and therefore new methods must be developed to increase pavement service life with the existing resources. The proposed method has the potential to improve the selection and design of asphalt materials and to lead to construction practices that will improve the durability and performance of pavements.

Product Transfer

The principal investigator has already worked closely with state departments of transportation and the Federal Highway Administration as part of a recent IDEA project. He will continue to work closely with Minnesota Department of Transportation, Utah Department of Transportation, and the Asphalt Mixture and Asphalt Binder Expert Task Groups to address any issues related to the practicality and applicability of this test. Once the method is perfected, the principal investigator will promote the method at various professional meetings and, based on feedback, will deliver a provisional version of an AASHTO test method for approval.

BRIDGE CABLE INSPECTION WITH LONG-RANGE ULTRASOUND

NCHRP-IDEA Project 152

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

IDEA Concept and Product

The developed technology can be used to rapidly and affordably screen bridge suspender ropes and main cables for corrosion, wire breaks, and other structural flaws. The technology can fill some of the inspection gaps from other inspection products available on the market. These areas include cables hidden by gatherers, separators, collars, and sockets. These are areas where corrosion may be accelerated to due fretting and moisture penetration. Stress concentrations may also initiate fatigue cracking overtime at these zones. The research undertaken during this NCHRP-IDEA project has demonstrated that the concept and product are sensitive to cable flaws at these critical areas. The concept is illustrated in Figure 1.

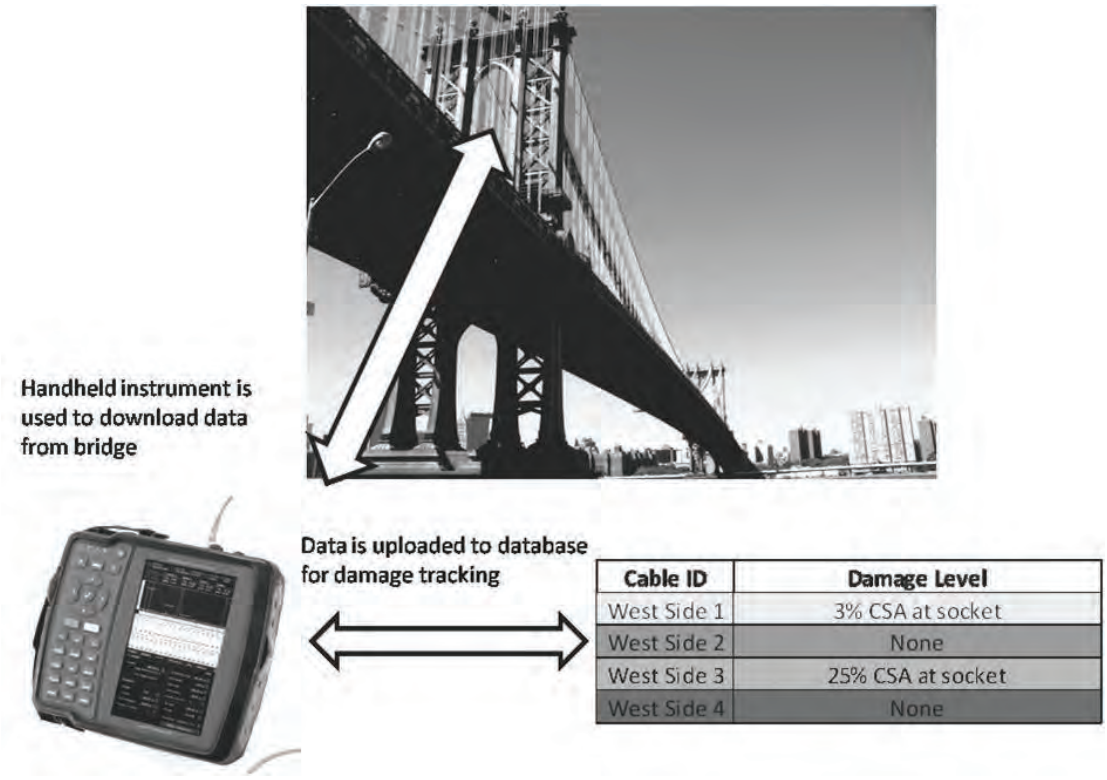


Figure 1

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

Project Results

Cable inspection was performed in a controlled setting in a test laboratory environment at Lehigh University. During these tests, artificial flaws were inserted at a suspender rope–cable socket interface. Data was then acquired from the interface to study if the long-range ultrasound was sensitive to small defects in the zone. The results showed that the technology is sensitive to these flaws and that the change in data relative to baseline data on a structurally sound cable may be used to track damage at this interface.

Cable inspection was also performed in the field on the suspender ropes on the Manhattan Bridge. Of the five ropes tested, all contained cross-sectional area (CSA) changes that were identified using guided wave ultrasound. On three of the ropes, it was possible to visually confirm the presence and location of each cross-sectional area change detected. On two of the ropes, it was impossible to visually confirm the presence of the cross-sectional area reduction due to access problems. The Manhattan Bridge suspender ropes were taken out of service and inspected visually to confirm the presence of cable defects.

The feasibility of inspecting the main cable of a cable stay bridge was studied for the first time. From one sensor position, the technology scanned approximately 120 feet. Ultrasonic data were acquired at four different locations. A total of four collar reflections were observed every 20 feet. Between the collars, no significant reductions in cross-sectional area due to wire breaks or corrosion were observed. The study showed, for the first time, that main cables may also be inspected with the proposed technology. The final report is available from the National Technical Information Service (NTIS Report # PB2012-110783).

Product Pay-Off Potential

The technology has numerous benefits that could reduce the total cost of ownership of cable-system bridges. The potential benefits include the following:

- The time spent visually inspecting bridges could be significantly reduced. Visual inspection would be performed only on cables that exceed the allowed tolerance on ultrasonic data. Significantly less bridge inspector time would be required to evaluate the bridge cables over the lifetime of the bridge cable system.
- Less traffic control would be required for bridge cable inspection: Ultrasonic inspections are most commonly performed on walkways where the sensor is installed. Very rarely is traffic control required to assist with the inspection. The same logic applies to reduction of rope access and aerial lift device equipment and personnel costs to support bridge cable inspection.
- Subjective and inspector-dependent visual inspection results could be eliminated. The technology would provide high-quality engineering data over the entire bridge cable system remotely.
- Less cable- and suspender-rope access would be required. Due to security concerns and surface coatings, cables systems are becoming increasingly difficult to inspect visually. The ultrasonic technology is an excellent inspection solution for the future bridge cable systems.

Product Transfer

The technology may be used to prompt visual inspection based on cable condition instead of the regulatory periodic visual inspection. In this scenario, the technology could be retrofitted onto an entire bridge cable system or cables with advanced corrosion or wire breaks. A technician would install the sensor(s) and acquire baseline data. Moving forward, data would be acquired on a weekly, monthly, or annual basis to determine if cable damage has been initiated or if it has advanced by comparing it to the baseline data. Beyond a certain damage tolerance, a follow-up visual inspection would be required. There are numerous benefits to the technology that would contribute to reducing the total cost of owning cable system bridges. These benefits include the following:

- **Transitioning from time-based to condition-based visual inspection:** Visual inspection would be performed only on cables that exceed the allowance tolerance on ultrasonic data. Significantly less bridge inspector time would be required to evaluate the bridge cables over the lifetime of the bridge cable system.
- **Reducing traffic control required for bridge cable inspection:** Ultrasonic inspections would most commonly be performed at walkways where the sensor is installed. Very rarely would traffic control be required to assist with the inspection. The same logic would apply to reduction of rope access and aerial lift device equipment and personnel costs to support bridge cable inspection.
- **Eliminating subjective and inspector-dependent visual inspection results:** The technology would provide high-quality engineering data over the entire bridge cable system remotely.
- **Reducing the need to access cables and suspender ropes:** Due to security concerns and surface coatings, cables systems are becoming increasingly difficult to inspect visually. The ultrasonic technology is an excellent inspection solution for future bridge cable systems.

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

IDEA Concept and Product

This project is using laser metrology instrumentation to aid in the bridge retrofit process. The complete system makes measurements that are difficult or impossible to make with manual string-line or tape measurements. A noncontact laser system measures sections of a bridge structure involved in a retrofit process. These laser measurements will 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. The system can measure the exact dimensions and spatial location of bridge details. The system saves time and improves measurement quality by eliminating currently used manual measurements with string lines and conventional survey equipment.

Project Results

Work has been performed with retrofit fabricators and state departments of transportation to determine measurement requirements and application areas. A number of field measurements have been made. This includes measurements on a bridge struck by an over-height load (Figure 1). Measurements can be made quickly and efficiently on multiple lanes in traffic without

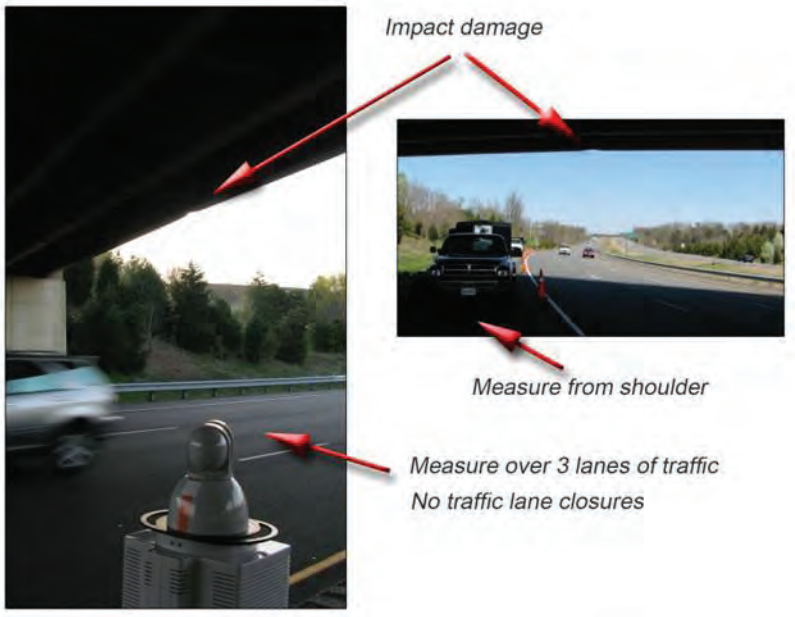


Figure 1

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

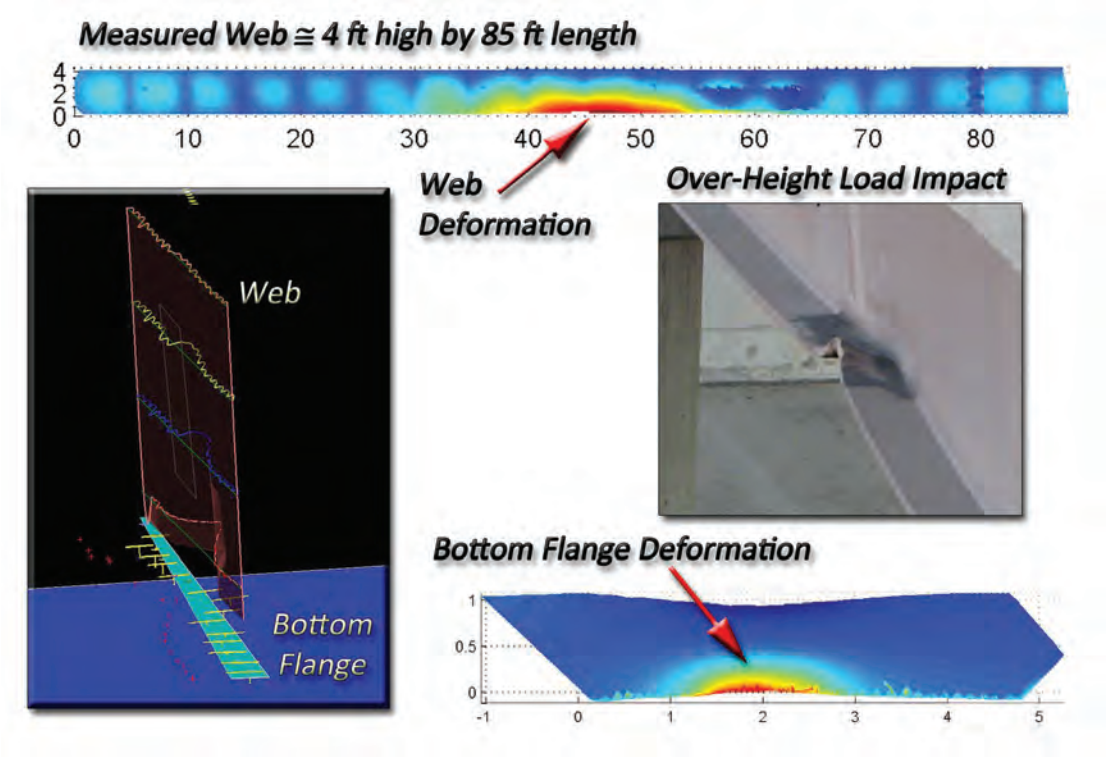


Figure 2

Data from impact damage on a steel bridge girder

lane closures. The system can make very accurate measurements of localized damaged and can also measure global change in an entire girder (Figure 2). The system has been used to evaluate steel truss bridges to measure vertical and diagonal members and localized damage in gusset plates. The system has been designed to allow reliable and efficient measurements in the field.

Product Pay-Off Potential

The proposed system has the potential to significantly reduce the time between the initial identification of a problem on a bridge and the repair and resumption of service of the structure. The system saves time and money by allowing measurements to be made more rapidly and with potentially more information and better data than is currently available. Minimizing the time that a bridge is out of service, or a lane closure is required, can save state departments of transportation substantial amounts of money and is in the best interest of the traveling public. The proposed system can make measurements with minimal impact at the bridge site. Measurements can typically be made without altering traffic under the structures.

Product Transfer

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. Work is being done in coordination with multiple bridge fabricators specializing in retrofit work. Work is also being done in coordination with multiple state departments of transportation.

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

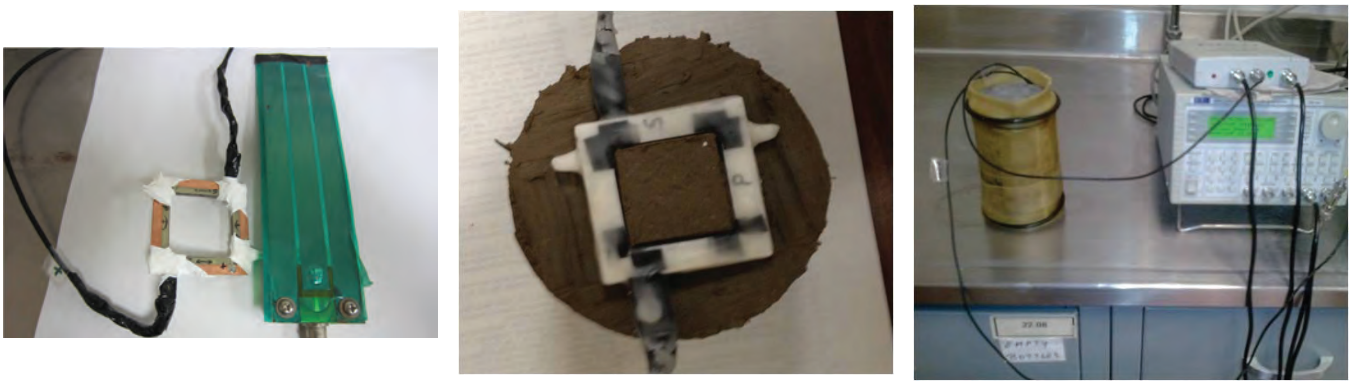
IDEA Concept and Product

The concept of this project is to develop an integrated sensor that uses both time domain reflectometry and bender element technologies. This sensor can provide quick assessment of sulfate heaving problems in chemically treated sulfate soils. This sensor can provide continuous measurements of water content, shear wave, and compression wave velocities in a soil sample. The shear wave measurements will be used to develop algorithms that will aid in the assessments of sulfate-induced heaving in a chemically treated soil in rapid time. Conventional procedures for swell testing in laboratory tests take several weeks to assess this type of heaving. Figure 1 shows the sensor and the testing process of the ongoing research work.

Project Results

The research project is being conducted in two phases involving both laboratory and field tests. The laboratory phase, which was already initiated, has focused on engineering characterization of three clayey soils with different amounts of sulfates. Currently laboratory stabilizer design was completed and the swelling strains of treated soil specimens were measured. This swelling was attributed to Ettringite formation and their subsequent growth and hydration processes that result in heaving of the treated soils. Additive treatments that cause excess sulfate heaving in a treated soil will eventually damage or distress pavements.

Current testing with the new sensor embedded in the lime and cement treated soils was continued for several days (Figure 1c). Test results, including shear wave velocity and moduli calculations, and their variation with time was plotted; these changes will be compared and related to sulfate induced heaving in the soils.



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

Figure 1

(a) Present sensor; (b) embedment in a treated soil specimen; and (c) stiffness measurement at full saturation condition.

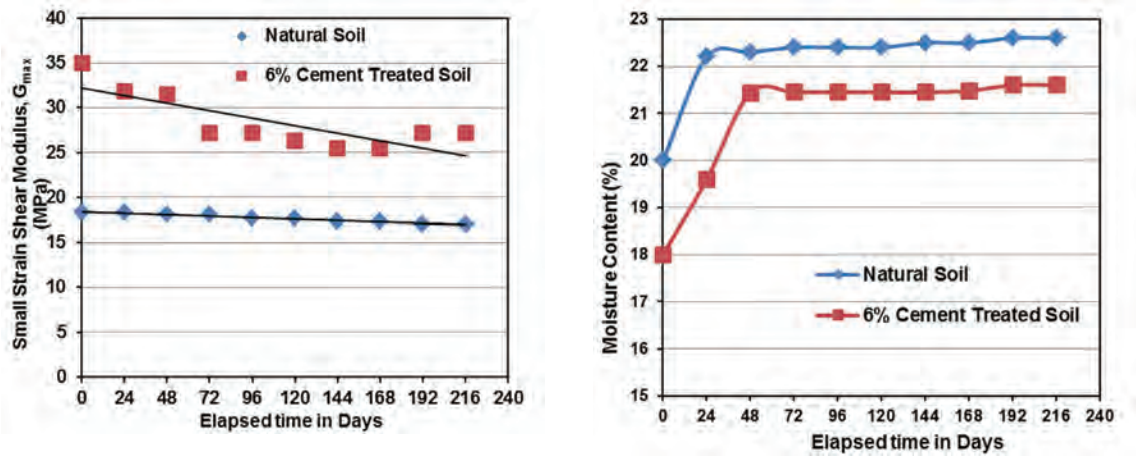


Figure 2

Shear modulus and moisture content variation with elapsed time period of Oklahoma soil specimens (sulfate content of 15,200 ppm).

Overall, the development of this sensor and rapid assessment of sulfate heaving are considered to be effective tools in the screening of chemical stabilizers for inducing less or no sulfate heaving in field conditions. Laboratory testing will be completed during the latter part of 2012 and these results will be analyzed to explain the onset of sulfate heaving. Figure 2 presents shear moduli and moisture content results of untreated and soaked cement treated samples in the laboratory conditions.

Product Pay-Off Potential

This project can result in three beneficial outcomes. First, this research will be helpful in developing a sensor that will provide rapid and better design of alternative stabilization methods for sulfate soils, thereby mitigating the heaving caused by sulfate and chemical stabilizer reactions. This implies significant cost savings due to lower repair costs and shorter construction times for pavement projects built in a sulfate-soil environment. In addition, the application of this innovative sensor can provide stiffness properties that can be used for characterizing pavement layers as per AASHTO pavement design methods. Third, this tool can also be used for compaction quality assessments in the field as modulus-based compactions are currently being studied by departments of transportation for potential implementation in real practice.

Product Transfer

In the second and final phase, researchers will work with Texas Department of Transportation to install the sensor in a pavement construction project in a high-sulfate-soil environment. A site near Dallas/Fort Worth International Airport is currently considered for the evaluation of the sensor in the field condition. This sensor will be embedded in a treated subsoil section rich with sulfates, and the sensor readings will be monitored and analyzed to address any onset of sulfate heaving. This field application and demonstration will provide valuable data that can revise the laboratory-based algorithm development. Ultimately both laboratory and field testing phases with the proposed innovative sensor will lead to widespread use of the proposed sensor in pavement construction projects on stabilized pavement layers.

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

NCHRP-IDEA Project 155

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

IDEA Concept and Product

This project will develop and demonstrate a proof-of-concept approach for in-situ reclamation of corroded structural material in load-bearing infrastructures (specifically bridges), which will also impart robust corrosion protection. The basis of this strategy is to use advanced high-velocity thermal spray deposition technology to engineer a metallic reclamation layer directly onto a distressed area within the structure (Figure 1). The deposit will not only serve as a filler material but will impart compressive residual stresses into the structure via the high-velocity impact of fine particles enhancing structural robustness. Subsequently, a galvanically active overlay coating will be applied, also via thermal spray technology, to prevent further degradation (corrosion) of the material and thus impart longer life.

Project Results

IIn order to investigate strength recovery using high-velocity oxy-fuel (HVOF) spraying, steel dog-bone specimens were machined with reduced cross sections in the gauge length. The HVOF thermal spray process was used to build up the reduced cross sections to original thickness. During deposition, the tensile specimens were fixed to a rotating stage and the torch was horizontally traversed as shown in Figure 2a. A JP-5000 torch (Praxair) with liquid fuel was used in order to achieve very high particle velocities for good bonding with the substrate and compressive residual stress state. Nickel was used as the filler material due to its corrosion resistance and low oxidation under the HVOF spray condition.

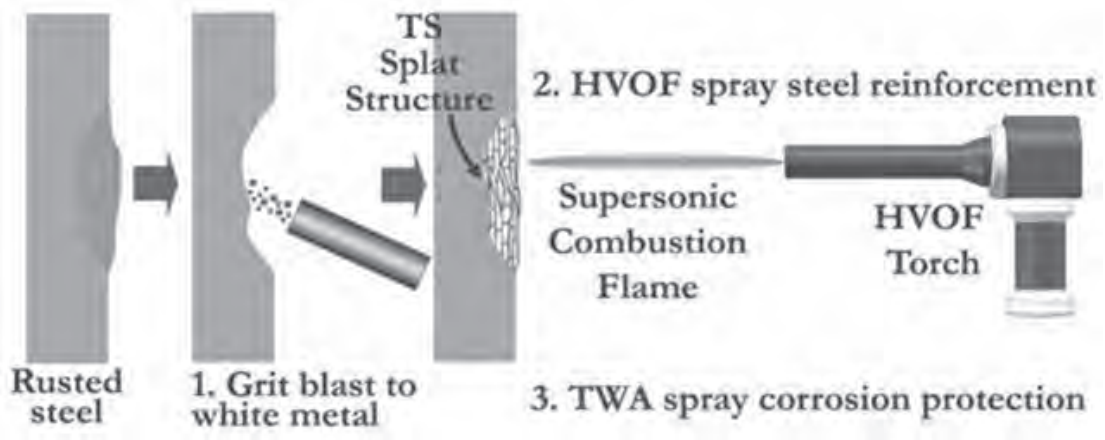


Figure 1

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

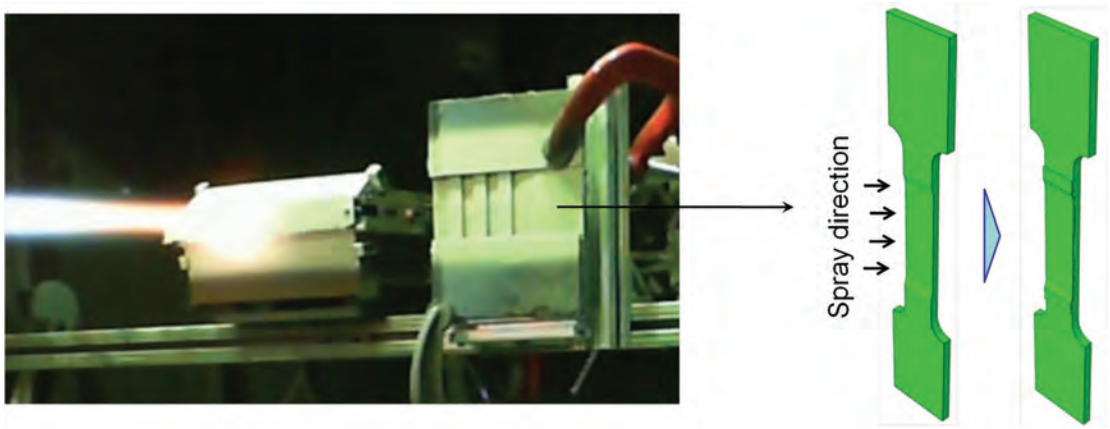


Figure 2

Photograph of the test sample preparation and illustrative schematic of tensile testing strategy. The image on the left is the thermal spray plume impacting the in-situ-coating-property sensor, which allows for determination of residual stresses and coating properties through beam curvature measurements. The image on the right displays grooved or ungrooved dog bones that were used to conduct testing of simulated reclamation process.

The strategy to assess the efficacy of the reclamation was through tensile testing of virgin and coated dog-bone specimens. A variety of processing variables were assessed as part of this study and described in the subsequent sections.

Figure 2 provides an illustrative and photographic schematic of test specimen fabrication. The samples were first preheated by two passes of the torch without powder and then coated. The final thickness of the coating was at least enough to fill the groove but no more than 0.030 in. over the virgin sample thickness. In subsequent developmental efforts, it was deemed that simply spraying coating over the dog bone was sufficient to examine the efficacy of the reclamation process. Figure 3 shows the tensile testing results.

The data from these experiments support initial evidence that thermal spray coatings can bear a significant load, even past a substrates yielding point. These experiments have shown the potential for thermal spray reclamation; and as the project continues, process optimization will be used to increase the overall strength of the base material while also imparting corrosion resistance. New specimens have been prepared with improved process conditions, and they are also being evaluated.

Concurrent to the mechanical analysis, corrosions studies were also conducted on the reclaimed composite. A cyclic polarization test was used with 5% NaCl solution with the coated surface being directly exposed to the polarization cell. These results are shown in Figure 4.

Figure 4 clearly demonstrates that the proposed approach can significantly benefit from a corrosion point of view. The Ni coating is more noble than the Fe coating and, as such, shows much lower corrosion potential. The overall response is also significantly improved compared to bare steel or those reclaimed with thermal sprayed steel.

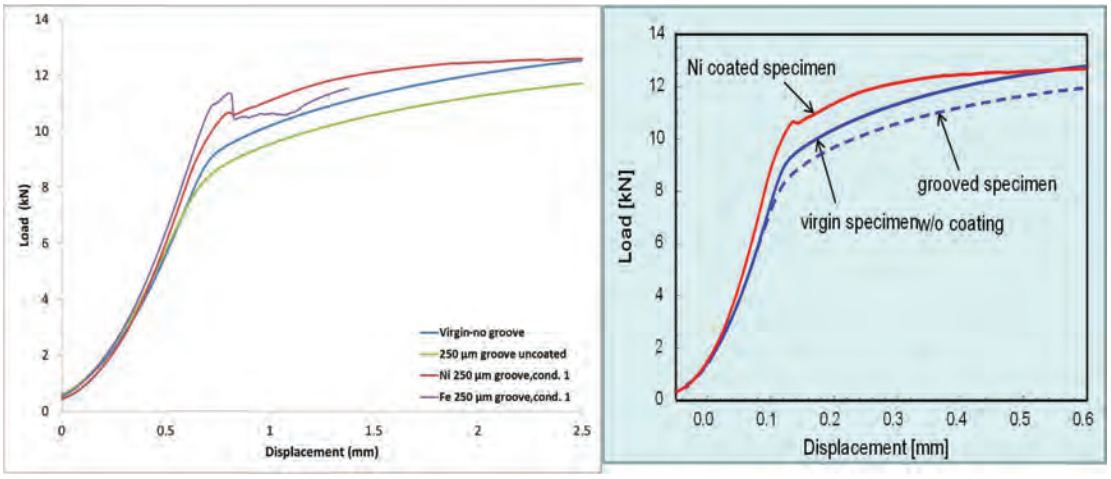


Figure 3

Tensile stress-strain data of virgin and thermal spray reclaimed samples. Two types of sprays were explored: nickel (Ni) and iron (Fe) with groove depth of 250 micron on a 3-mm thick tensile dog bone. The application of coating showed an increase in yield load. These results, when converted to stress, also showed enhanced mechanical behavior. The figure on the right shows details of the yield region. Both grit-blasted and coated samples showed a drop in the strain to failure. The exact reason for this is unclear at this point.

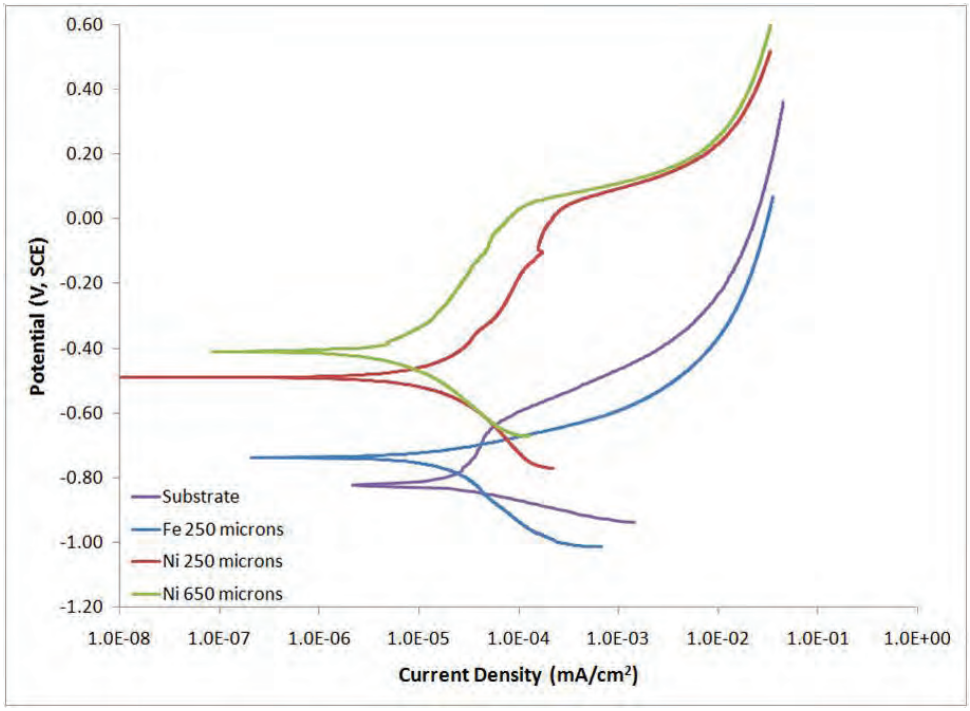


Figure 4

Cyclic polarization response of virgin steel and thermal spray reclaimed materials with 250 micron Fe and Ni and 600 micron Ni deposited via HVOF process.

Product Pay-Off Potential

The proposed strategy, if successfully demonstrated, has a number of benefits. It could allow in-situ repair of structures with little or no thermal loading to the parent structures. It could be applied on site with use of portable equipment and trained operators. It could be completed quickly and cost-effectively as only local modification is required (i.e., eliminating the need for large repair); the HVOF coated structure could also enhance corrosion resistance for sustainable performance.

Product Transfer

The team has established effective communication with the New York Department of Transportation bridge maintenance group. They visited, discussed the project, and offered a number of ideas and even opportunities for collaboration. Following optimization of the approach, there will be a follow-on effort during the second half of the project to attempt testing the device on a large-scale structure. The Center for Thermal Spray Research has also engaged its industrial consortium members to enable transitioning of the idea into commercial solutions for the benefit of departments of transportation. Finally, Professor Sampath had the opportunity to present the results to the Executive Committee of the Transportation Research Board during a meeting in Woods Hole, Massachusetts. A technical paper is now under development.

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

NCHRP IDEA Project 156

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

IDEA Concept and Product

The concept of this study is to develop an innovative coating technology with improved corrosion and mechanical performance as compared to existing commercially available coatings used for reinforcing steels with the overall purpose of extending the service life of steel and concrete structures, while reducing maintenance costs and improving the reliability and safety of highway structures. Diamond-like carbon (DLC) coatings are attractive for use as protective overcoats due to their excellent mechanical and tribological properties. However, DLC coatings are traditionally prepared by vacuum deposition processes that have various limitations, including high costs and slow film production rates. To overcome these limitations, this research project is investigating an inexpensive atmospheric solution-based processing technology by which DLC coatings can be deposited on carbon steel for reinforced steel concrete applications. Specifically, the process involves a scalable and affordable method for chemical synthesis of a soluble hydrocarbon polymer precursor that can be thermally converted to DLC. This study will further evaluate the electrochemical and mechanical properties of the resultant solution-based DLC (s-DLC) coatings. It is expected that this project would provide a cost-effective DLC coating with improved corrosion mitigation and mechanical enhancement performance that can be applied to steels used in reinforced concrete and steel structures.

Project Results

This research project has proceeded into two main stages. Stage 1 comprises the development and optimization of the s-DLC coating deposition methodology and mechanical testing of coated steels. Stage 2 will comprise the electrochemical testing of coated steels in simulated concrete pore solutions and the after-exposure mechanical testing.

In Stage 1, initial formulations of the proposed s-DLC coating were successfully fabricated on steel coupon substrates and steel rebar sections, and their chemical and mechanical properties were characterized (Figure 1). A scalable and affordable method was established to reproducibly synthesize hydrocarbon polymers possessing a diamond-like structure by the reduction of α-α-α-trichlorotoluene at room temperature and normal atmospheric conditions. A post-synthesis purification procedure was developed to further refine the raw polymer products. The polymer precursors are soluble in a variety of organic solvents. Following synthesis, polymer solutions were prepared and deposited as films on steel substrates using a spray-coating technique. The coated substrates were subsequently heated to temperature lower than 600°C to convert the films into s-DLC. The chemical composition and microstructure of the resultant s-DLC films were examined with scanning electron microscopy (SEM), FTIR, Raman spectroscopy, and water contact angle measurements. Additionally, the mechanical properties of the coatings including microhardness, Young's modulus, wear, and adhesion were investigated. The s-DLC coatings exhibited properties akin to those of traditional vacuum-based

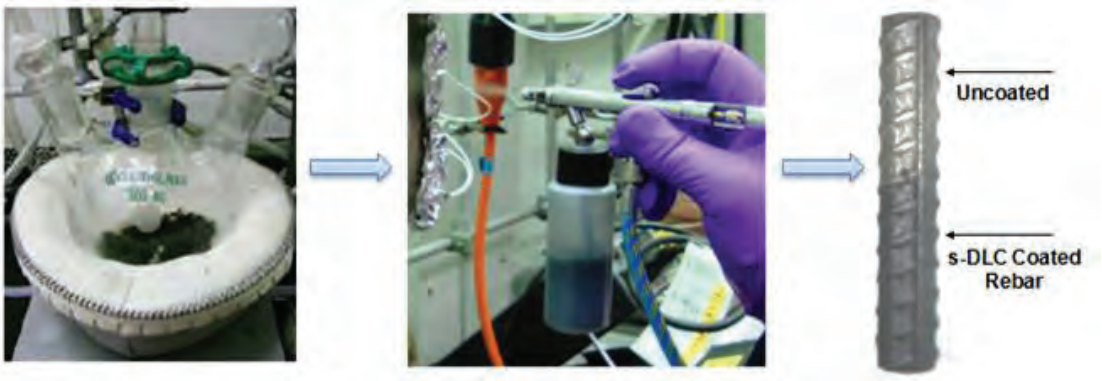


Figure 1

Developed atmospheric solution-based processing technology by which DLC coatings can be deposited on carbon steel coupons and rebar samples. Process steps involve chemical synthesis of DLC polymer precursors, spray-coating polymer precursor solutions onto steel substrates, and subsequent heat treatment to convert films to s-DLC.

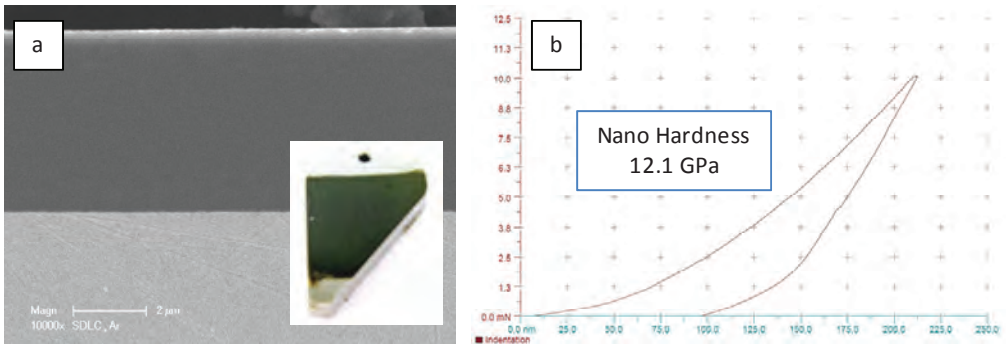


Figure 2

(a) Cross-section SEM image and photograph (inset) of machined edge on s-DLC coated steel substrate; (b) Nanoindentation analysis of s-DLC coated steel substrate.

DLC. The s-DLC coated substrates can be cut and machined with close tolerances (Figure 2a). Nanoindentation analysis on s-DLC film revealed high hardness of 12.1±1.1 MPa (Figure 2b). The next phase of the project will involve continued s-DLC formulation development of the s-DLC coating along with further comprehensive mechanical and electrochemical testing towards coating performance optimization.

Product Pay-Off Potential

Several coating technologies (such as epoxy, galvanized, or stainless steel cladding), acting either as a physical barrier or as a sacrificial protector to reinforcing steels, have been developed. However, the performance to cost benefit of such coatings is not meeting expectations,

especially when exposed to aggressive environments. This research effort will address the current coating problems by developing a cost-effective coating that will exhibit improved corrosion and mechanical performance and is expected to surpass those of commercially available coatings.

Product Transfer

Southwest Research Institute (SwRI) will formalize teaming arrangements through negotiated business agreements to support technology integration and transition. SwRI has already engaged in discussions with small businesses regarding scale-up synthesis from the pilot synthesis to larger production (500–2,000 gallons). Additional potential technical transfer teaming partners include large chemical and coatings companies. Steel manufacturers currently providing products to state departments of transportation will be also contacted for technology transfer.

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

NCHRP-IDEA Project 158

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

IDEA Concept and Product

This project uses nonlinear acoustoelastic theory to identify dead load stress—which can be used to determine whether or not structurally critical components are over stressed, to verify finite element models, and to verify uncertainties of structural connection models. In the proposed approach, a stress perturbation is introduced into the measurement region; this stress is estimated by measuring the change in ultrasound behavior due to the perturbation and stress. This project also performed a wide study of surface wave propagation in structural steel to understand the effects of thickness, surface roughness, paint, and bolt holes. Figure 1 shows the measurement tools: the hand-held ultrasonic device, the ultrasonic sensors, the wedges, and the Plexiglas® holder, which keeps the distance between two sensors constant and prevents ultrasonic leakage.

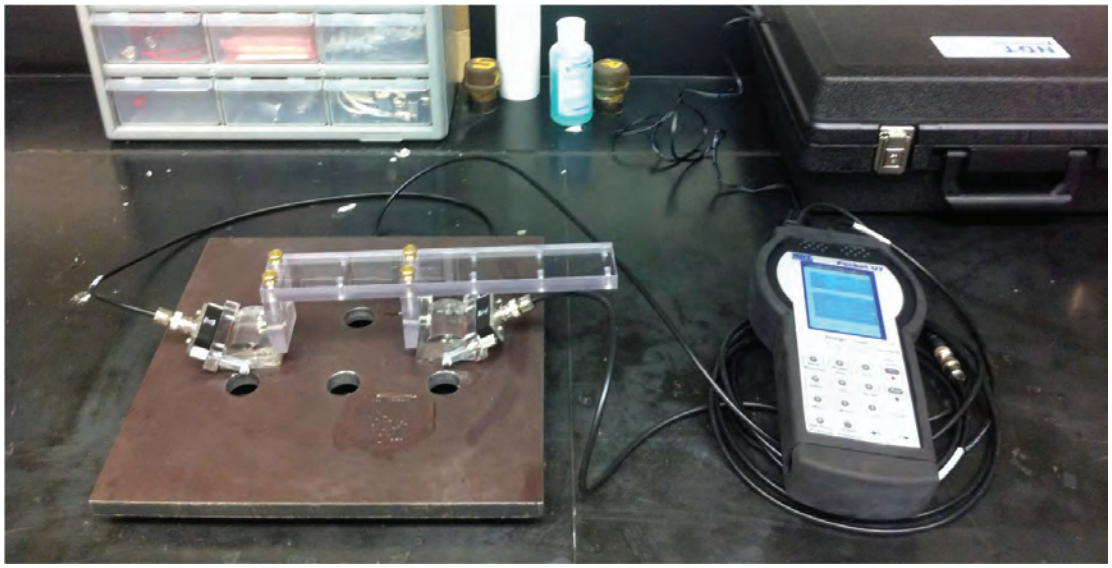


Figure 1

Fixture designed for ultrasonic wave transmitter and receiver with variable angle and distance.

Project Results

In the first phase of the project, the approach was demonstrated in laboratory scale tests. The required wedge angle and the ultrasonic frequency were identified using numerical time-dependent models and experiments. The effects of the presence of bolts, the plate thickness, surface roughness, and the paint on the received ultrasonic signal were identified. The designed measurement fixture (Figure 1) is unique in how it measures stress. In theory, ultrasonic

waves are modified with stress; however, ultrasonic waves can also be modified if sensor distances vary, which occurs when sensors are permanently attached and the structural element is loaded. The designed measurement fixture keeps the distance between the transmitter and the receiver constant, which eliminates the latter variation.

The numerical and experimental studies show that the Rayleigh wave arrival is not influenced when the plate thickness is greater than 0.5 in. and the excitation frequency is greater than 700 kHz. The presence of bolt holes causes 0.03 μsec difference in arrival, which is considered an error range in the stress measurement. As the sensors are not continuously attached to the structural elements, recoupling repeatability is crucial. Surface roughness becomes influential for high-frequency measurements. After many repeated experiments, cleaning the surface with an ultrasonic couplant before measuring was identified as a good methodology to reduce the recoupling error significantly.

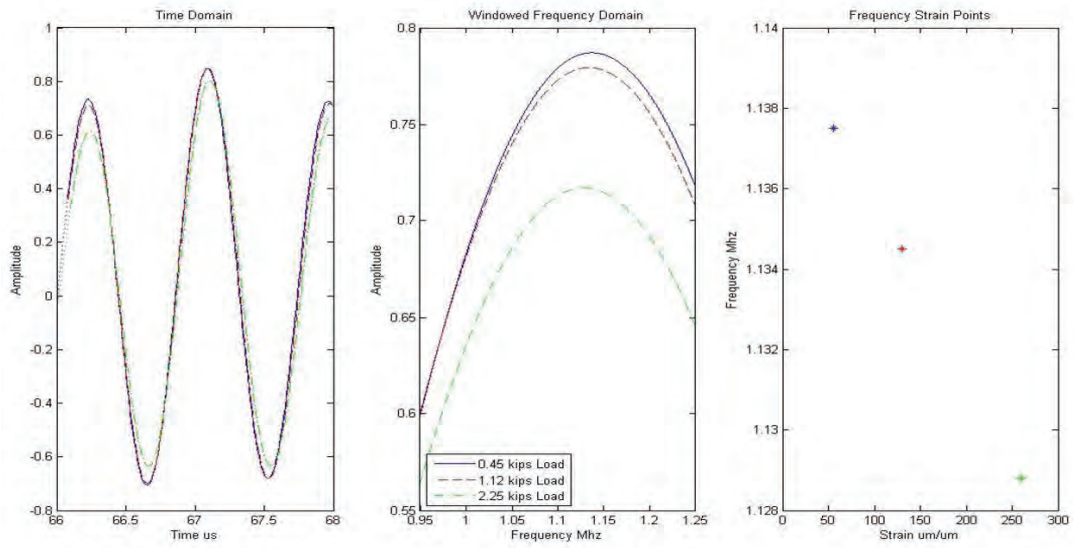
Paint causes a significant problem for 1 MHz ultrasonic excitation. The peak frequency for a painted sample was 0.66 MHz while a similar unpainted sample was measured as 0.89 MHz. The experiments were repeated with 500 kHz transducers. The peak frequency for a painted sample was 0.554 MHz while a similar unpainted sample was measured as 0.548 MHz. The sensitivity of 500 kHz to the paint presence is less than 1 MHz excitation, as expected. However, the Rayleigh wave penetration for 500 kHz is higher, which may require different stress-frequency correlation curve for thin plates with thickness less than 0.375 in.

Figure 2 shows the measurement of ultrasonic signature under three different stress levels using 1 MHz transducers. The completed tests are uniaxial loading of an L-shaped hot-rolled profile using 1 MHz and 500 kHz transducers and biaxial loading on a Grade50 steel plate using 1 MHz transducers.

The next phase of this project includes testing plates under higher compression-tension loading and repeating the biaxial loading to show the measurement reliability and field validation at selected bridges in Illinois and Virginia.

Product Pay-Off Potential

Currently, there is no rapid, cost-effective method for measuring actual loading on structural elements due to the dead load of existing structures. Increasing transportation demand as well as fatigue and corrosion may lead to critical bridge components reaching an over-stressed state. These conditions can be identified by measuring the state of stress. Additionally, determining the reliability of finite element models with suitable boundary conditions is an important step in understanding the remaining life of structurally critical components. The project approach can improve finite element models by measuring dead load stress and combining field measurement with numerical models, and it can detect over-stressed condition due to structural variations. In summary, the proposed approach can serve as a rapid inspection method for bridge inspectors to obtain the stress level of critical bridge components.



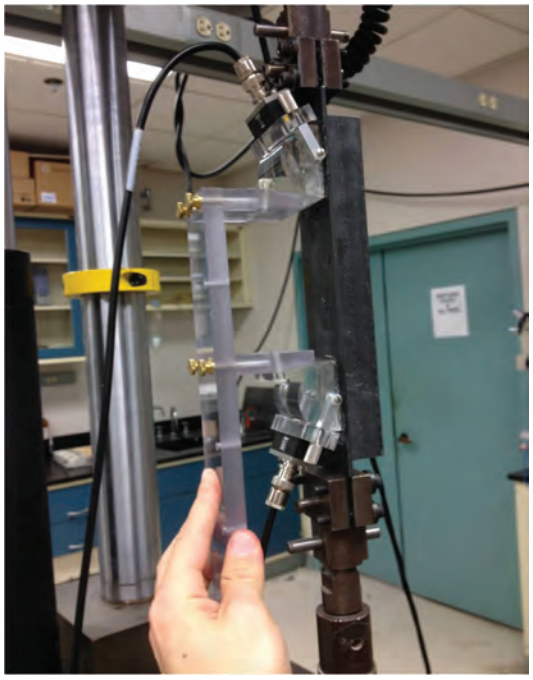


Figure 2

Stress effect on ultrasonic measurement in time domain and frequency domain (top) with a photograph of experiment (right).

Product Transfer

This project aims to produce a hand-held measurement system with automated analysis software. The customer base for this tool includes owners of infrastructure, such as departments of transportation (DOTs), and contractors. An ultrasonic device manufacturer, an academic expert on ultrasonic waves, and two DOTs are specifically guiding the project team on implementation issues. The approach will be demonstrated on two bridges in Illinois and Virginia, which is a critical step in proving the readiness of this technology.

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

NCHRP-IDEA Project 159

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

IDEA Concept and Product

The objective of this project is to develop an electric heat lance (Figure 1, left) and a vacuum attachment (Figure 1, right) for the crack cleaning device (CCD), which was developed in NCHRP-IDEA Project 148. Moisture should not be present in the crack at the time a sealant is applied. To prevent this, an electric heat lance was developed and attached to the CCD. The heat lance is capable of drying out the crack that is cleaned by the wire brush and dries an area approximately 3 in. wide to allow the sealant to have the proper amount of overlap onto pavement.

The CCD is powered by a pneumatic motor rather than a compressed flammable gas source. When a flammable gas is used, extreme caution must be taken to ensure the pavement is not overheated, which can result in the asphalt binder becoming brittle and leading to premature failure. Care should also be taken to never allow for direct flame methods to be used, as the charring affect can lead to a soot residue and cause poor initial bonding. Furthermore, propane regulators are often frozen in cold weather, which delays the sealing process. The electrically powered heat lance eliminates the need to address these issues.

When the cleaning process is taking place, the dust and debris being removed from the crack may need to be contained due to air quality, workers' health, and the safety of motorists. For these reasons, this project developed a vacuum attachment that can be installed on the CCD to contain the dust and debris created from the crack cleaning process.

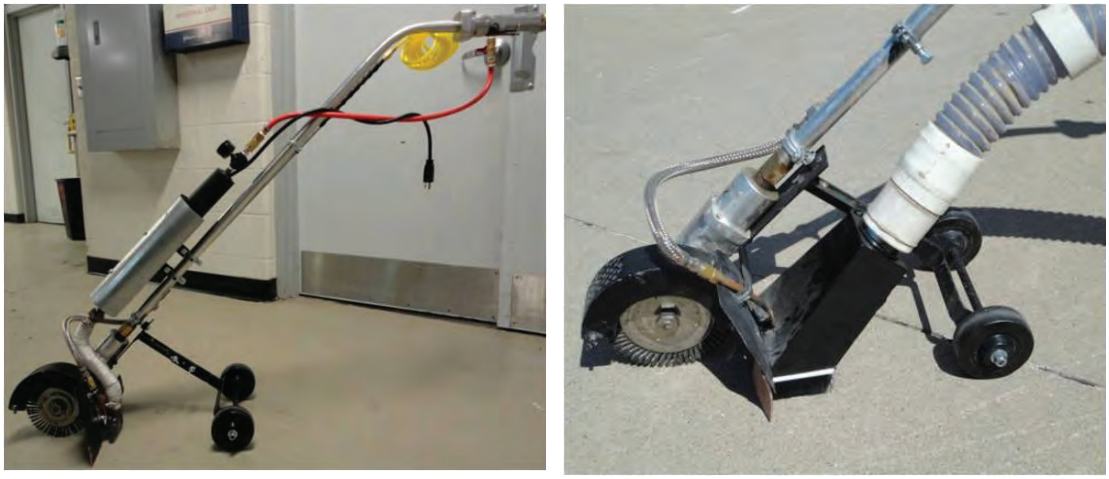


Figure 1

Heat lance configuration (left) and vacuum configuration (right).

Figure 2

Field tests with NDOR crews.

Project Results/Planned Investigation

The CCD is powered by a pneumatic motor with an aluminum shaft. The wheel assembly is adjustable so the height of the shaft can be adjusted to accommodate different users. This unit was built to be easily modified.

Attachments were constructed that can be installed as a modular component, so the time to change from one application to another is minimal. The prototype has been tested by the Nebraska Department of Roads (NDOR) and the City of Omaha. Based on their feedback, modifications were made (Figure 2).

The heat lance pictured in Figure 2 is the second generation, which uses multiple heating elements as the heating source. This heat lance is capable of temperatures to 370° C (approximately 700° F). The third-generation heat lance is currently being developed to get even higher temperatures, which will help the CCD work more efficiently.

The vacuum attachment pictured in Figure 1 is the first generation. To collect larger debris more effectively, the second generation of vacuum attachment is under development.

Product Pay-Off Potential

From the city level up to the national level, maintaining infrastructure is very important. Performing this maintenance as efficiently as possible can lead to roads that last longer. It is expected that the CCD will be used on a higher percentage of cracks, yielding an increase in preventive maintenance and a decrease in new construction costs by formulating a more efficient way of cleaning joints and cracks, including deicing chemicals. These cost savings translate into tangible budget factors that could funnel state-allocated money to other needed projects. Furthermore, using versatile effective means of crack and joint preparation will undoubtedly lead to an increase in overall quality. This upgrade in quality will promote an increase in the useful life of pavements, and postpone the allocation of valuable tax revenue towards the rehabilitation or new construction of existing roadways.

Product Transfer

The University of Nebraska—Lincoln is ideally suited to take this project from prototype through the various stages of research and development, and onto industry acceptance. There has been a long-standing relationship with NDOR on the testing of this product. This testing process will ensure that a quality product is developed both from economic and efficiency standpoints. Demonstrations and workshops also have been performed with the manufacturers of pavement maintenance equipment for industry acceptance and commercialization.

SUPER-WEATHERING STEEL FOR INFRASTRUCTURE APPLICATIONS

NCHRP-IDEA PROJECT 160

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

IDEA Concept and Product

There is an urgent need to develop and adopt new weathering steels that are significantly more corrosion-resistant than those that are in use today. Phosphorus (P) is the most potent element to enhance the corrosion resistance of steels; however, P also embrittles steels. The approach of this project is to add a comparatively high amount of phosphorus to steel and to introduce just the correct amount of titanium (Ti) binding to P in order to prevent the grain boundary segregation of P that causes embrittlement in the first place. Other elements that enhance weathering of steels will be added, too. It is expected that a new class of "super-weathering" (or SW) steels with superior mechanical and low-temperature fracture properties, ease of manufacturing, and competitive cost will be developed for the nation's civil infrastructure, including highways, bridges, and buildings.

Project Results

The reference steel is A710 Grade B, which is used as the starting point for the design of new SW steels. A710 Grade B steel was developed at Northwestern University. Its yield strength is 70 ksi. This copper-precipitation-strengthened steel has excellent fracture properties at low temperatures, and its corrosion loss is approximately 40% less than that of bridge A588 and A709 HPS70W steels used for bridges, as measured at Bethlehem Steel Co (now ArcelorMittal) in accordance with the automotive accelerated test protocol SAE J2334.

The chemical composition of all steels is summarized in Table 1. To date three experimental steels (SW1, SW2, and SW3) were designed, produced in 100-lb heats, and had their

Table 1

Chemical Composition, wt. %.

Steel	C	Mn	Si	Cu	Ni	Cr	Mo	Nb	S	P	Ti	CI*
A710B**	0.05	0.50	0.50	1.30	0.80	NA	NA	0.07	<0.005	<0.005	NA	7.3
SW1	0.04	0.49	0.45	1.25	0.55	NA	NA	0.07	<0.005	0.11	0.68	8.1
SW2	0.07	1.29	0.59	0.71	0.37	0.53	0.10	0.05	<0.005	0.08	0.45	8.1
SW3	0.05	1.16	0.51	1.15	0.86	0.51	0.11	0.08	<0.005	0.08	0.53	8.6
SW4***	0.05	1.20	1.00	1.30	0.80	1.00	0.10	0.06	<0.005	0.10	0.50	9.0

* ASTM G101 Corrosion Index

** Typical A710B composition

*** Target composition of SW4 to reach CI of 9.0

mechanical properties tested. Concentration of P in SW steels is significantly higher than in ordinary steels for infrastructure; it varies from 0.08 to 0.11%. Ti is added to steels in the 0.45 to 0.68% range. In SW2, chromium (Cr) is added, but copper (Cu) and nickel (Ni) concentration is reduced. In SW3, the Cu and Ni concentration is increased to strengthen the steel. All steels were hot rolled and then air cooled. No thermomechanical-controlled rolling or post-rolling heat treatment (both required for production of A709 HPS steel) was used during the steel production. Compositions and ASTM G101 corrosion indices (CI) are given in Table 1. The higher the index, the more weatherable the steel is. For reference, the corrosion index for high-performance bridge steel A709HPS70W steel is 6.6 and for CorTen A steel, which is brittle, 5.9. The table also contains the target composition for SW4 to reach the goal of CI 9.0. A laboratory 100-lb heat of this steel has already been ordered from Sophisticated Alloys, Inc.

Table 2 summarizes the mechanical properties of all the steels produced to date. It is evident that chemical composition is a significant factor that determines the strength of the steels. In spite of the addition of P, all three SW steels maintain excellent ductility (20–27 %).

Table 2

Mechanical Properties.

Steel	Yield Strength, MPa (ksi)	UTS, MPa (ksi)	Elongation to failure, %
A710B	496 (72)	586 (85)	30
SW1	393 (57)	538 (78)	27
SW2	316 (36)	548 (79)	22
SW3	521 (75)	668 (96)	20

Figure 1 summarizes results of Charpy fracture tests for SW1, SW2, and SW3 performed down to –100°F. All steels significantly exceed the toughness requirement of ASTM A709 standard for bridge steels, Charpy values of 35 ft-lbs at –10°F for fracture-critical components. SW2 and SW3 exceed this requirement down to at least –100°F.

So far, in 2000 hours accelerated weathering test performed at the Kentucky Transportation Center, only SW1 together with A710B steel was investigated. Addition of P and Ti to SW1 resulted in about 40% reduction in corrosion loss.

The next phase of the project will involve the following:

(1) Production and mechanical testing of SW4;
(2) Accelerated weathering testing of SW1 to SW4 and weatherable A606 steel (as control) at Kentucky Transportation Center; and
(3) Welding studies of the best weathering steel based on (2).

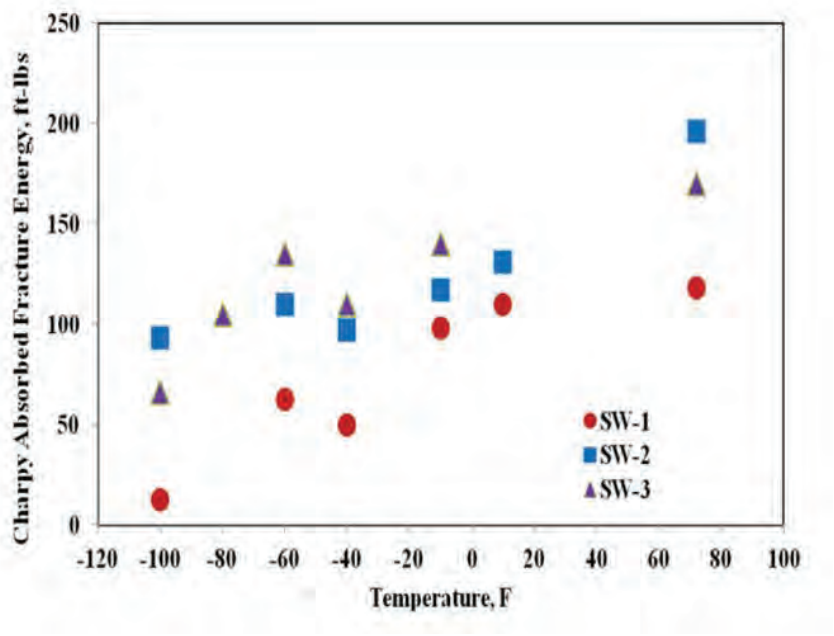


Figure 1

Charpy absorbed fracture energy of experimental super-weathering steels.

Product Pay-Off Potential

Weathering steels that are currently available do not have the corrosion performance to withstand salting and marine environments. Therefore, they must be painted under these conditions, but the painted surface has unavoidable defects that lead to accelerated rusting at these locations. The use of unpainted super-weathering steels as proposed here will result in significant upfront and long-term savings.

Product Transfer

The immediate application of the steel to bridge construction is not part of the scope. The steel has to undergo rigorous testing and has to be included into appropriate standards for infrastructure application. The infrastructure community will be alerted to existence of super-weathering steel through publications and conference presentations.

TOOLS FOR DETERMINING YIELD STRESS OF IN-SERVICE GUSSET PLATES

NCHRP-IDEA Project 161

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

IDEA Concept and Product

Nondestructive testing methods that can verify or identify the as-built material properties of steel plates used in bridges are needed. This has become an important consideration for performing connection evaluations after the collapse of I-35W in Minneapolis, Minnesota. This research will develop a new device and testing techniques that can establish the yield strength of gusset plates. The device will be able to perform three major roles for connection evaluations:

1. Establish the material properties for bridges that do not have construction documentation of the steel plates,
2. Establish the minimum yield stress of the plate to allow a connection to achieve a specific rating, and
3. Establish the actual yield stress of the plate to extract the most capacity from the connection.

The proposed device is a self-reacting instrument that produces a small patch load at the edge of the gusset plate, as shown in Figure 1. Using small-deflection thin plate theory, the applied load and corresponding plate deflection can be used to establish the yield stress of the plate. The instrument is hand portable and can be deployed and operated by a single person in the field.

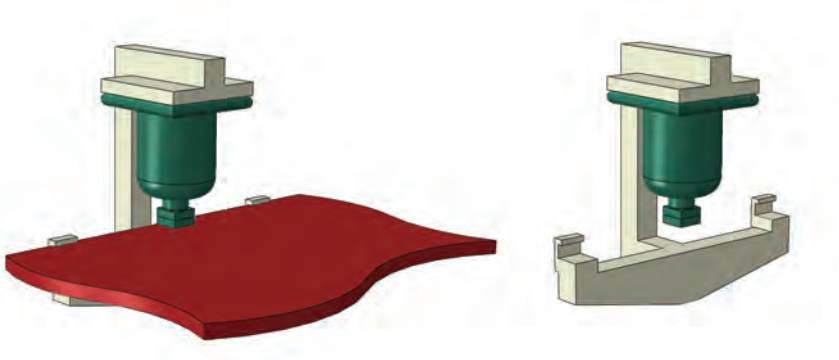


Figure 1

Illustration of the proposed nondestructive instrument to establish the yield stress of an existing gusset plate. Device is clamped onto the gusset plate free edge (shown with and without plate).

Project Results

The proposed technique was demonstrated with nonlinear finite element analyses using Abaqus 6.8-2. In the demonstration, a 0.5 in.-thick gusset plate was used as an example that would be common in the field. The device was placed at the free edge and manually operated to apply a patch load to the plate. The analytically predicted device load versus plate edge deflection was computed and showed that an operator would be able to clearly determine the yield stress of the plate.

In the next phase of the research, the prototype device will be fabricated and then demonstrated over a wide range of practical plate parameters. The research will investigate different plate thicknesses, yield strengths, plate rolling directions, paint coatings, and the influence of inherent dead load stresses in the plate. The predicted material properties will be compared with material samples (coupons) tested according to ASTM E8. A full-size gusset plate with controlled service-level dead load stresses will be investigated to directly assess the role of attached truss members and dead load plate stress state on the device output. The laboratory setup is shown in Figure 2.

Figure 2

Full-size gusset plate connection test to investigate influence of dead load stresses.

Product Pay-Off Potential

Large numbers of steel truss bridges are in the national inventory (approximately 12,600) and require rating and evaluation. The costs of repairing or strengthening gusset plates are very high. The proposed device and technique will allow the bridge engineering community to establish gusset plate material properties for bridge ratings. This can payoff for practice in the following ways:

1. For bridges without documentation of the specified steel materials, the device will eliminate the need for costly material sampling and the damage caused by sampling.
2. By establishing the steel plate material properties, needless strengthening or posting may be avoided.
3. The proposed technique may be extended to other steel components such as flanges of rolled or plate girders to assess material properties for a broad range of steel bridges. This has the potential to offer even greater benefits to the bridge engineering community if the actual material properties can be used to provide improved ratings and extend service life.

Product Transfer

The research team is collaborating closely with the Oregon Department of Transportation (ODOT). The team will work with ODOT and several engineering consultants to establish and conduct field demonstrations of the techniques on in-service bridges. Research findings will be presented and reported at American Association of State Highway and Transportation Officials (AASHTO) technical committee meetings and national technical conferences.

FULL-SCALE PROTOTYPE TESTING AND MANUFACTURING AND INSTALLATION PLANS FOR NEW SCOUR-VORTEX-PREVENTION PRODUCTS

NCHRP-IDEA Project 162

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

IDEA Concept and Product:

Scour of the foundations of bridge piers and abutments is one of the most common causes of highway bridge failures. Current countermeasures are temporary and do not prevent the cause of scour. Figures 1 and 2 show the vortices that cause scour. The key to development of the new scAUR with VorGAUR products is understanding how to prevent flow separation and the formation of scouring vortices around the bottom of bridge piers and abutments with robust optimized shapes. Manufactured fairings with these shapes can be installed around existing and new bridge piers and abutments of any shape that *prevents* scour.

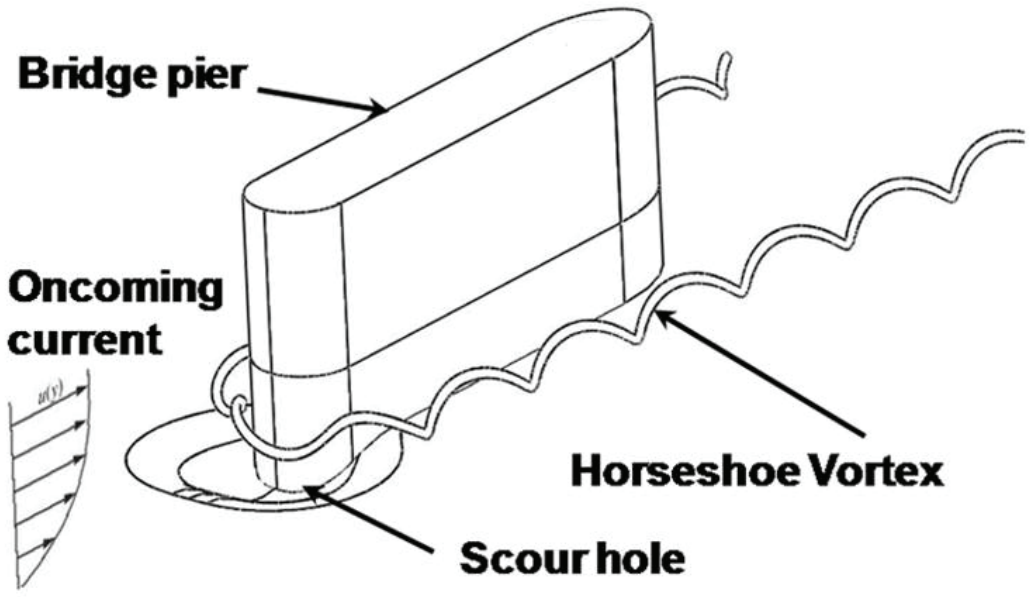


Figure 1

Horseshoe vortex around bridge pier.

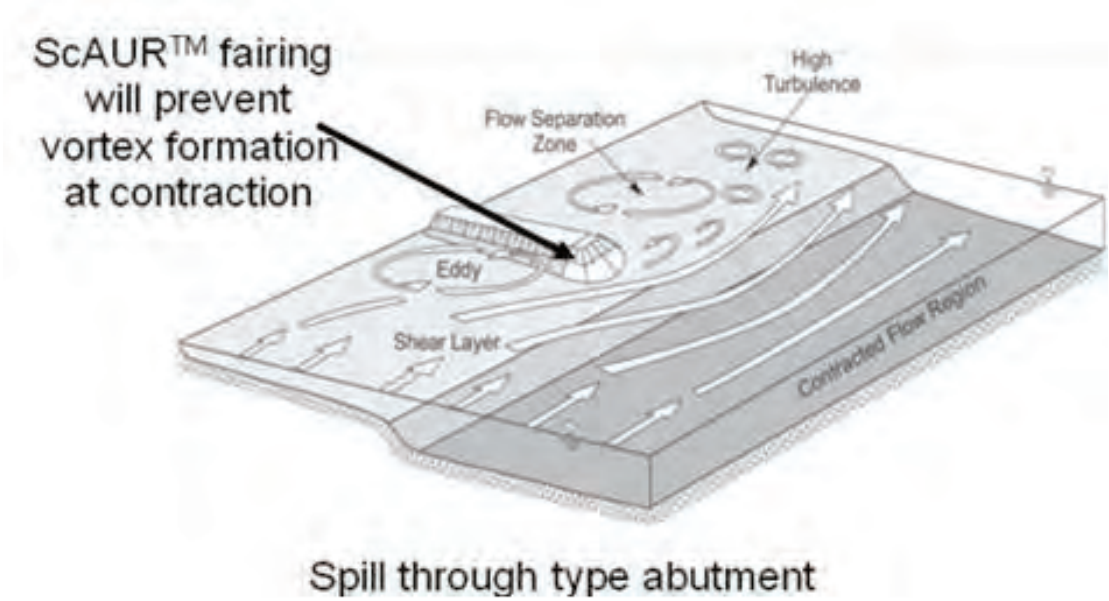


Figure 2

Vortices at abutment. (Barkdoll et al., NCHRP 587, 2007)

Project Results and Planned Investigations

Since computational fluid dynamics (CFD) and model-scale flume tests have shown that scAUR with VorGAUR products prevent the vortices that cause scour, as shown in Figure 3 (a and b), the next steps are to further test these products and develop plans to install a full-scale prototype on a scour-critical bridge to prove to future users that the entire installation process is practical, feasible, and cost effective.

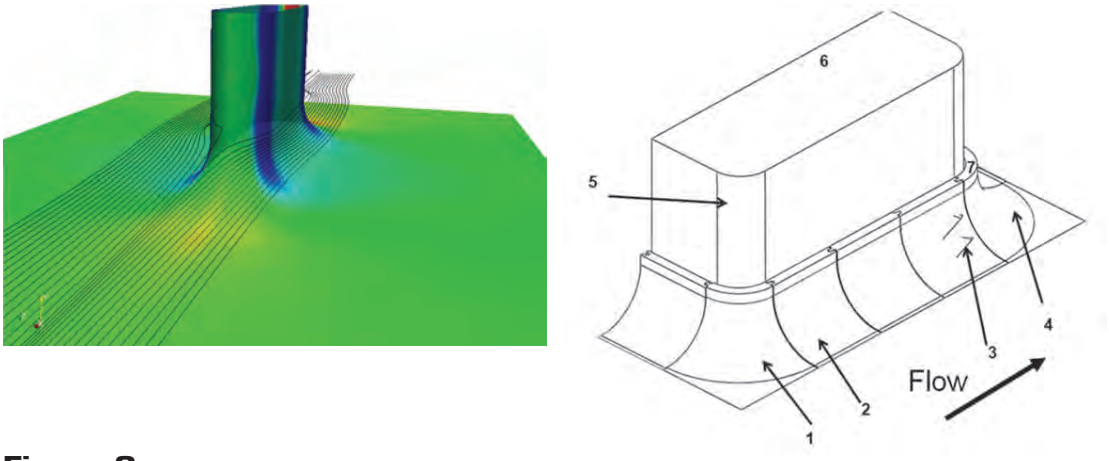


Figure 3

Left (a): Near wall streamline flow pattern at the downstream end of the scAUR fairing for the approach flow aligned with the pier; obtained via CFD simulation by AUR using in-house codes. Right (b): A wing-wall abutment with a scAUR fairing (1,2,4,5) with VorGAUR vortex generators (3) that prevent scouring vortices.

So far, full-scale Reynolds number and bridge pier and abutment size effects have been examined using computations, which show no scouring vortex formation. Scale-model flume tests of these products with several smaller size sediments also show no scour. The performance of scAUR and VorGAUR concepts for a larger class of abutments is currently being examined by model-scale flume tests. Model-scale spill-though and wing-wall abutment flume models, with and without scAUR with VorGAUR product features, have been designed and constructed and are being tested. All tests so far show no scour on these abutments with the scAUR with VorGAUR products. The effects of contraction scour, long-term degradation scour, settlement and differential settlement of footers, undermining of the concrete scAUR segments, and variable surrounding bed levels are also being addressed.

This project will test and develop full-scale installation plans for scAUR and VorGAUR products on a scour-critical bridge in Virginia to demonstrate their effectiveness in preventing scour-causing flow characteristics at piers and abutments. A full-scale scAUR with VorGAUR model will be developed for independent testing in a large flume. Manufacturing processes for scAUR and VorGAUR products will be refined.

Product Pay-Off Potential

A detailed economic analysis for scAUR and VorGAUR fitted bridges with conservative assumptions was conducted. The benefits to bridge owners and managers include actual cost reductions of +90% over the life of a bridge. Risks and liabilities due to a catastrophic failure *are avoided* with scAUR with VorGAUR, whereas catastrophe theory shows a finite probability of failure with current temporary measures. Even for bridges with little life left, current countermeasures are more expensive. The more frequent the occurrence of scouring floods, the more cost effective scAUR and VorGAUR are.

Product Transfer

Several state departments of transportation (DOTs) have endorsed this full-scale prototype work by Applied University Research (AUR). Virginia DOT plans to install full-scale versions upon the successful completion of this project. AUR has already done much work prior to this project in developing cost-effective precast concrete and corrosion resistant metal methods to be able to manufacture modular segmented components for installation on existing or new bridges that are cost effective, high quality, and have a long life. In addition to reporting this work, AUR plans to manufacture and provide these products in the future.

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

NCHRP-IDEA Project 163

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

IDEA Concept and Product

Pavement raveling increases pavement roughness, which results in poor ride quality, road/tire noise, and shortened pavement longevity. Loose stones may break windshield glass or contribute to hydroplaning, which causes safety concerns. To date, no reliable, cost-effective method has been developed to automatically detect pavement raveling. However, 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 study will develop an algorithm to automatically detect raveling using emerging 3-D line laser imaging technology, as shown in Figure 1.

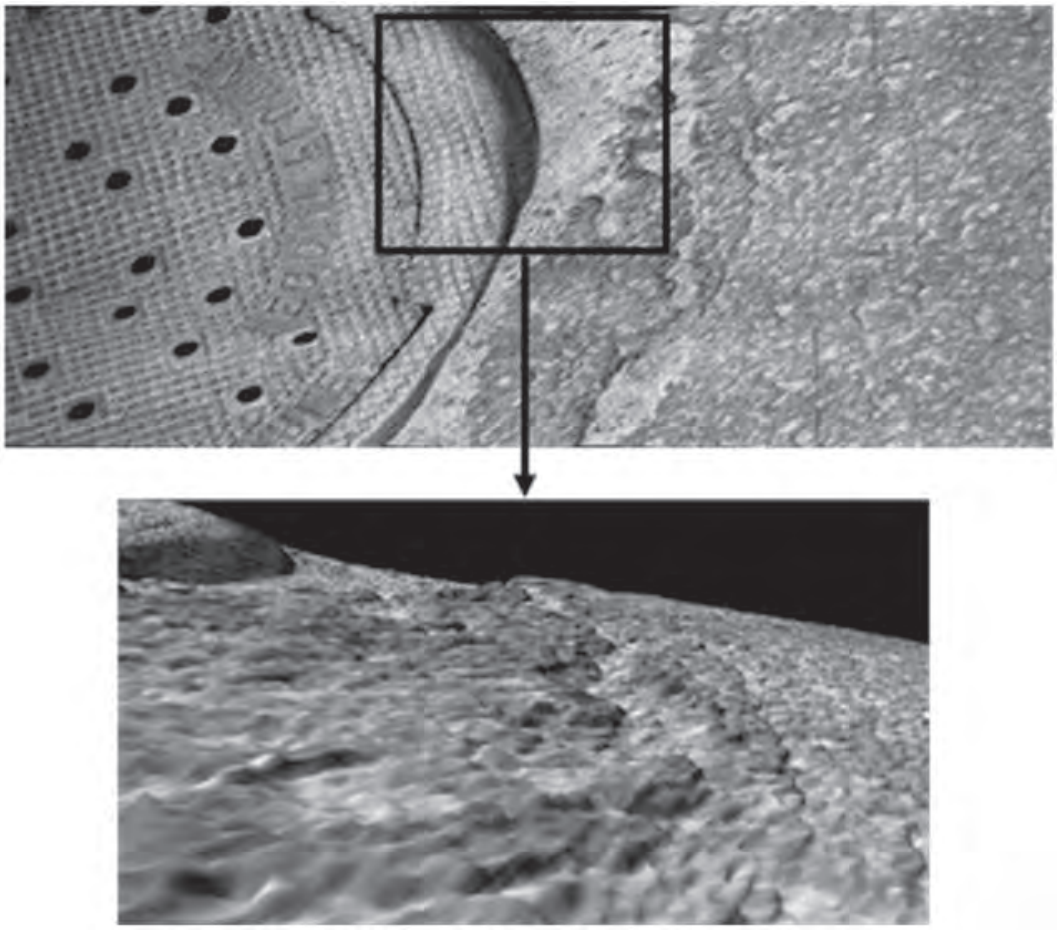


Figure 1

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

Project Results

The proposed pavement raveling detection algorithm consists of (a) preprocessing of 3-D pavement surface range data to remove signal noise; (b) filtering of nonraveling pavement features; (c) probabilistic, multiscale region- and grid-based raveling detection; and (d) spatial clustering of raveling areas. The research team at Georgia Tech worked with pavement experts to define raveling, including different levels of raveling. A literature review of existing methods for detecting raveling was also conducted. The preliminary algorithm was developed, which is described below. The preprocessing steps, involving denoising and drop-off detection, are completed. A parametric probabilistic regression model to detect the missing stones and the mean surface of the road was also developed. The next step is to collect the data for testing and refining the proposed algorithm.

Product Payoff Potential

The proposed algorithm will provide a cost-effective and reliable means to automatically extract pavement raveling data, which has not been achieved before. To reduce the time and money spent on field data collection, 3-D pavement surface-range data that have already been collected for rutting and crack detection in a previous study will be utilized in developing the raveling detection algorithm. It is expected that various pavement distresses can be extracted using the same device and same data set collected in one run in the field. Companies have already purchased this emerging 3-D laser technology. The outcomes of this research could reduce time and money spent on collecting pavement condition data.

Product Transfer

Departments of transportation (DOTs) from five states: Georgia, Florida, North Carolina, South Carolina, and Kansas; one city, Nashville, Tennessee; and one company, Fugro Roadware Inc., have committed to participate in this research project and to support this study by collecting and providing the necessary data. In addition, their personnel will work with the research team to validate the results obtained in this study. Once the algorithm has been developed and tested, the project team would like to develop software that will promote the use of this algorithm by transportation agencies and private companies.

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

NCHRP-IDEA Project 164

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

IDEA Concept and Product

The concept in this project is to develop a laser-spectrographic sensor technology that can map the corrosion process of steel structures, identify the types of coatings applied to the structure, and detect the presence of heavy metals associated with the coating. The primary objective of this proposed effort is to provide a field product that can rapidly determine the condition of steel structures to assist in judging whether and what type of maintenance is required.

The technology is based on the characterization of atomic emission spectra induced by the high irradiance that is associated with a laser system targeted onto a field sample, as shown in Figure 1. A typical field sample is conceptually illustrated in Figure 2. Continually targeting a laser at the same location on the protective cover can result in subsurface penetration (laser boring of a micron-sized hole), which has the potential to identify the nature of the coating and the underlying stratum.

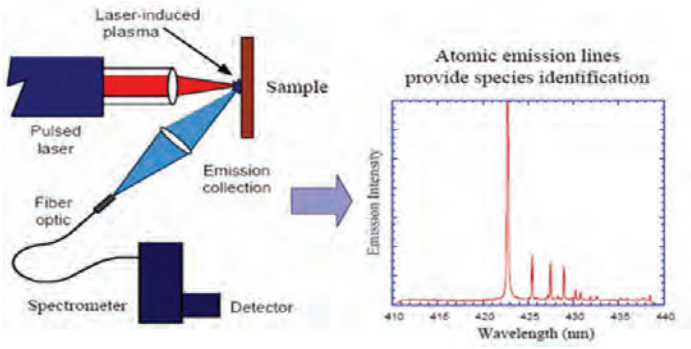


Figure 1

Example of laser-induced boring systems and resulting spectrum.

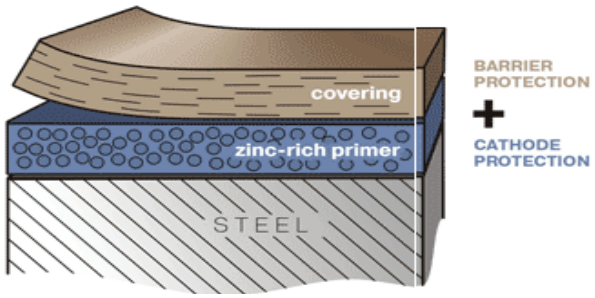


Figure 2

Typical protective cover profile for steel.

Planned Investigation

The work will focus on calibrating an initial set of samples (steel coupons) with commercially available coatings for detecting the presence of heavy metals and corrosion using laser-induced ablation technology to generate spectra for analysis. Sample coupons will be collected and/or prepared and characterized by conventional means. Multivariate (chemometric) calibration models will be developed by comparing laser fingerprints to the known properties of the collected samples. An assessment will be made of the effectiveness of the approach. Work will also be initiated on the development of a corrosion index for assessing the severity of the corrosion detected.

Preliminary results from early start-up testing have revealed that a laser spectral output can readily differentiate a corroded spot from a coated or fresh spot. The next phase of the project will focus on quantifying and establishing corrosion-related evaluation criteria, based on spectral data.

Product Pay-Off Potential

The system could reduce the labor effort required to inspect bridges, which could lead to reduced inspection costs, more rapid processing of data, and improved decision making for planning of bridge maintenance activities.

Product Transfer

A three-phase commercialization process is ultimately envisioned. Phase 1 includes the proof-of-concept stage and the development of the design basis for the fabrication and deployment of a commercial prototype. The prototype would be field tested in Phase 2. Phase 3 would involve marketing and sales of the developed system.

BATTERY-LESS WIRELESS WEIGH-IN-MOTION SENSOR

NCHRP-IDEA Project 165

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

IDEA Concept and Product

This project will develop a road weight restriction enforcement system based on the use of a wireless weigh-in-motion (WIM) sensor and a smart phone app that wirelessly receives and displays the weight and type of each passing vehicle. The WIM sensor will utilize a previously developed vibration energy harvesting system to create a battery-less wireless device embedded in the road. The WIM device embedded in the road will obtain all energy required for its operation from the vibrations of each passing vehicle. Building on previous work, this project will develop a new rigid sensor design, develop an all-metal casing for sensor operation, develop a smart phone app for wireless internet access to the sensor signals, and evaluate the performance of the new sensor over a range of year-round weather conditions. The developed secure smart phone app can be used by an enforcement officer to observe the weight of any passing vehicle within an accuracy of 10%. Due to the low cost of the sensor, easy installation, battery-less zero energy operation, and remote smart-phone access, the enforcement system can be widely deployed if its performance is evaluated to be satisfactory.

Planned Investigation

Figure 1 is a photograph of a previous generation of the weigh-in-motion sensor. The sensor consisted of a 6-foot long beam-like device with double-layered legs. The first layer has a non-linear load-strain response curve and is used for energy harvesting. The second layer has a linear load-strain response curve and is used for measuring vehicle axle weights.

Figure 1

Photograph of weigh-in-motion sensor.

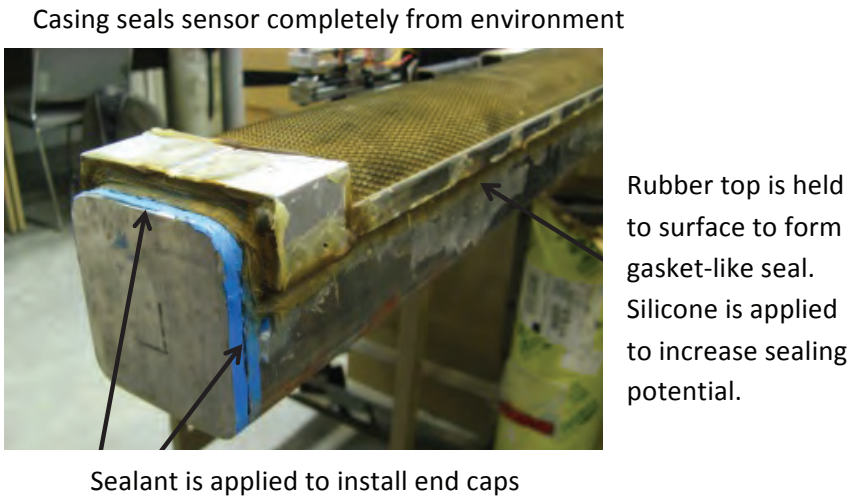


Figure 2

Photograph of casing for sensor.

Figure 2 shows a baler-belt rubber top casing for the previous generation sensor. The casing is designed to provide two functions:

1. Isolate the electronics and sensing mechanisms from dirt, moisture, and other debris from the road environment; and
2. Allow the load due to the weight of each axle to be fully transmitted to the sensor inside the casing.

The major activities to be undertaken in the proposed project are as follows:

1. Enhancement of sensor to a more rigid design with an all-metal enclosure and its evaluation in asphalt pavement for a full range of speeds;
2. Development of internet access to the WIM sensor through a secure wireless interface;
3. Development of a convenient smart phone app for easy access to the WIM sensor (The smart phone app will display vehicle axle weights, graphically display type of vehicle, and provide vehicle overweight alarm based on adjustable weight thresholds.);
4. Evaluation of life of new sensor and its ability to withstand a range of year-round weather conditions; and
5. Preparation of comprehensive project report.

Product Pay-Off Potential

Due to the low cost of the sensor, easy installation, battery-less zero energy operation, and internet-based smart phone access, the enforcement system can be widely deployed if its performance is evaluated to be satisfactory. The potential users of the developed weigh-in-motion system include state and federal departments of transportation, counties, ports, and other transportation agencies responsible for maintenance of roads and for enforcement of road weight restrictions.

Product Transfer

The University of Minnesota filed a provisional patent application for intellectual property protection of the proposed technology. Subsequently, the inventors have filed a full United States patent application. Funding from the NCHRP IDEA Program will enable the research team to complete the development of the sensor system, to pursue future large-scale field evaluation studies, and to commercialize the developed technology.

Once the research team fully evaluates the sensor under a range of real-world conditions and records long-term data on sensor performance, it can contact existing weigh-in-motion companies to demonstrate the developed technology and pursue its commercialization.

GUIDELINES FOR THE USE OF WASTE CONCRETE FINES

NCHRP-IDEA Project 166

Julie Vandenbossche [Tel.: (412) 624-9879, Fax: (412) 624-0135, Email: jmv7@pitt.edu] University of Pittsburgh, Pittsburgh, Pennsylvania
Donald Janssen [Tel.: (206) 543-9655, Fax: (206) 543-1543, Email: dnjan@msn.com] University of Washington, Seattle, Washington

IDEA Concept and Product

Portland cement concrete is a very versatile material that uses mostly local ingredients to produce energy-efficient pavements and structures. Unfortunately, a considerable amount of waste material in the form of water with high pH as well as dissolved/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, as can be seen in Figure 1. Disposal of this material can be costly, adding to the cost of infrastructure construction and rehabilitation.

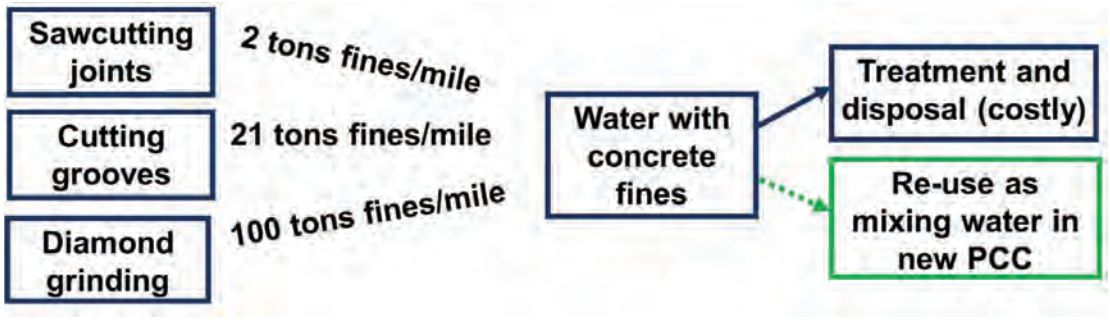


Figure 1

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

Fortunately, the wastewater and suspended/dissolved solids can be used in the production of new concrete. Guidelines for the use of these recycled fines in new concrete, however, are currently unavailable, though in some instances there are either limits to the maximum amount of suspended solids that can be included or the use of these recycled materials is prohibited entirely. This research will develop guidelines for the use of recycled concrete fines, and the associated wastewater, by first developing methods to rapidly characterize fines samples. The effects of various amounts of fines on a range of cementitious materials combinations will be determined, and a performance model will be developed that predicts the optimal amount for given fines source to add to a specific concrete mixture for improved concrete performance. The final stage of this research will be proof-of-concept testing to verify that the guidelines produce acceptable concrete mixtures using a variety of fines types/sources. An implementation plan will be prepared from these results, which will explain how a ready-mix concrete plant can implement the optimized fines recycling program. This work can result in reduced waste as well as reduced new water usage in concrete production, while improving the actual performance of the concrete.

Planned Investigation

The development of guidelines for the use of recycled concrete fines will be accomplished through the completion of three primary stages: (1) collection and preparation of recycled concrete fines, (2) experimental investigation, and (3) proof-of-concept testing and implementation plan. In Stage 1, both diamond grinding fines and truck cleanout fines will be collected. These fines will then be characterized in Stage 2, which includes measuring the index of refraction, conductivity, and pH. The fines are then used to prepare test mortar mixtures so that the set time and strengths can be established. Figure 2 shows the equipment used to assist in performing this work. The results from these tests will be used to develop statistical correlations using the optimal fines contents, mortar performance measurements at optimal fines, the fines characterizations at those fines contents, and the $Ca/(SiO_2+Al2O_3)$ of the cementitious material in order to develop a performance-prediction model for the different recycled fines materials. This model will then be used to produce guidelines for the use of recycled concrete fines in new concrete mixtures. Finally, under Stage 3, a laboratory-scale water recirculation system will be constructed. It will include inline sensors that provide continuous readings of the index of refraction, conductivity and pH. Waste fines will then be added to the recirculation system and concrete will be made using the optimum blend of water from the recirculation system (containing the waste concrete fines) and freshwater based on both the inline measurements and the desired concrete mixture characteristics. The experience gained is then used to develop an implementation plan for ready-mix concrete producers to use when upgrading their plants with inline sensors and instructions on how to apply the guidelines for using recycled fines developed from the experimental investigation.

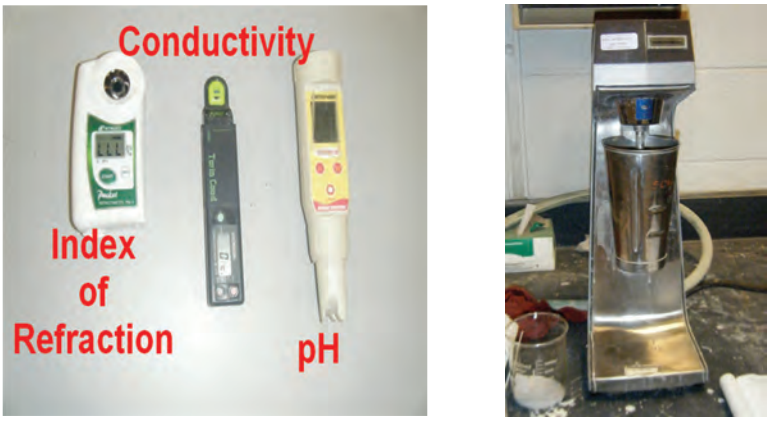


Figure 2

Equipment used for material characterization and mixing the recycled fines with water.

Product Pay-Off Potential

Concrete producers could use their recycled wash water more efficiently, assured that this use will have no negative impacts on properties of the concrete mixtures produced. In addition, they could accept fines from other sources, such as fines from diamond grinding of concrete pavements and fines from crushing operations associated with concrete recycling. They could characterize those fines, no matter what the source, and determine the optimal amount to use in a given concrete mixture.

Product Transfer

The final stage of this research will include a laboratory-scale wash water recirculation system. This system will have inline (continuous reading) sensors installed, and concrete mixtures will be prepared using amounts of fines determined from those sensors and based on the guidelines produced from this study. These results will be used to prepare an implementation plan for ready-mix concrete producers to use when upgrading their plants with the inline sensors. To ensure a sound implementable strategy is developed, this plan will be carefully crafted in cooperation with concrete producers.

SECTION 3
NSF/NRC-IDEA COOPERATIVE PROJECTS

The projects described in this section were funded jointly by the IDEA Program and the National Science Foundation (NSF) under a collaborative arrangement between NRC/TRB and NSF. The projects were funded in two separate yet interrelated parts. The basic science part (theoretical investigations and analytical verifications) was supported by an NSF grant, while the IDEA funds and contracts were used to develop and test the research product in a practical setting and to transfer results to highway applications.

CONTROL SYSTEM FOR HIGHWAY LOAD EFFECTS

NSF/NCHRP-IDEA Project 1

Andrzej S. Nowak [Tel.: (313) 764-8495, Fax: (313) 764-4292]
University of Michigan, Ann Arbor, Michigan

The project developed and field tested an integrated monitoring system for highway load effects control (Figure 1). The system includes a weigh-in-motion (WIM) truck weight measurement, fatigue load spectra measurement, and failure detection systems. The integrated system coupled with analytical procedures (development of load spectra, component-specific diagnostic test, prediction of remaining fatigue life) was applied for monitoring and providing bridge loading diagnostics. The system proved to be effective on truck parameters (weight, axle loads, speed, lane position, multiple presence) and load effects (girder moments and shears, component-specific strain and stress, fatigue load spectra) for estimating the health and remaining life of the bridge.

The system has the potential to serve as an efficient control measure to monitor highway loads for bridge diagnostics (evaluation of site-specific bridge condition) and management. The results of this project are on the way to implementation by the Michigan Department of Transportation (MDOT). The project team works closely with the technical staff of MDOT. The field work was carried out on bridges selected in coordination with MDOT. Some of the most efficient results that have already been implemented include WIM measurements and proof load testing. The developed procedures have been used by MDOT for evaluation of selected partially deteriorated bridges. The investigators are extending the project to focus on developing a remote-sensing device for measuring lane-specific truck parameters to arrive at practical procedures for active and passive control of truck load effects and to improve prediction of life expectancy and reliability of bridge structures based on WIM measurement.

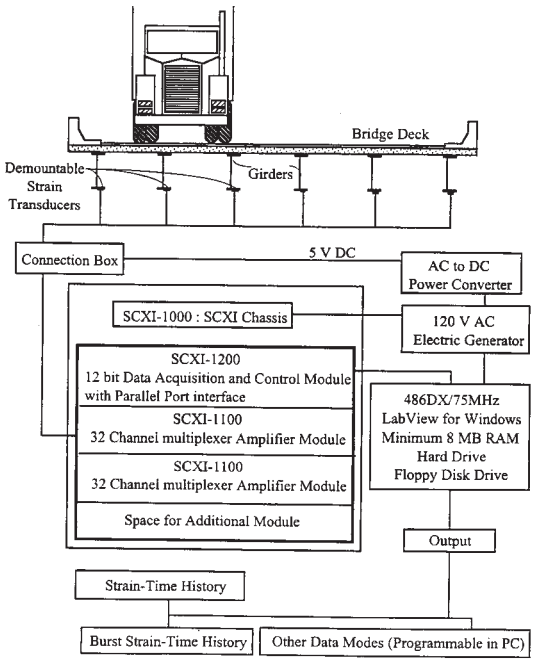


Figure 1

Data acquisition and control system.

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

NSF/NCHRP-IDEA Project 2

Hua Lee [Tel.: (805) 893-4480, Fax: (805) 893-3262], University of California,
Santa Barbara, California

The objective of this research is to develop pulse-echo tomographic imaging techniques for quantitative nondestructive evaluation (NDE) of civil structures and materials. Pulse-echo impulse radar provides a means of detecting voids, cracks, and the condition of concrete reinforcement bars. The ability to recognize and identify the constitution of detected objects is also useful for NDE of civil structures. Classification of the material type permits the confirmation of design specifications and a more accurate evaluation of unknown areas.

Pulse-echo radar transmits a pulse and performs time-delay estimation on the received echoes to form the time-delay profile. A Fourier transform is used to decompose the returns into their frequency components. The frequency components are individually back-propagated to create a wavefield of the area. The wavefields are then superimposed to reconstruct the image area. A singular value decomposition of the wavefield at a target is used to generate a signature vector that minimizes the sum of all distances from each wavefield to its projection onto the vector. Signatures of different materials are stored in a database for comparison to the signatures of unidentified targets. Matches are performed by computing the magnitude of the inner product with each signature in the database. Objects are identified by matching multiple signatures from the target and applying majority rule.

The investigators successfully developed and implemented the image reconstruction algorithm for the data acquisition system and operating configuration. The utilization of wavefield statistics for accurate image formation was optimized and pattern recognition techniques were evaluated. Matching and recognition experiments were performed to demonstrate the application of the technique to evaluate civil structures.

Five classes of materials were used to test the object recognition method. The five targets included an air void, air permeated concrete, a full water occlusion, the air portion of an air/water mix, and the water portion of the air/water mix. All targets were embedded in concrete. The results showed that the technique identified all targets correctly. In fact, the object recognition scheme was able to correctly identify all classes of test objects with as few as 5 test set vectors.

The technique is being used in industrial applications at the Special Technologies Laboratories of the University of California, Santa Barbara. The California Department of Transportation is planning to use the technology in conjunction with the Lawrence Livermore National Laboratory system for bridge inspection. Cooperation for implementing the technology will be available from the NSF University/Industry Research Center on High-Speed Image Processing.