Innovations Deserving
Exploratory Analysis Programs

NCHRP HIGHWAY

New IDEAS for Highway Systems

Annual Progress Report

JANUARY 2005

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OF THE NATIONAL ACADEMIES

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NEW IDEAS FOR HIGHWAY SYSTEMS

An Annual Progress Report of the NCHRP IDEA Program

2005

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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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 four 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;
- Safety-IDEA, which focuses on innovative technologies to improve transportation safety, with emphasis on commercial motor vehicles; and
- High-Speed Rail-IDEA, which focuses on advanced technologies for high-speed rail operations in support of the Federal Railroad Administration's Next Generation High-Speed Rail Program.

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

The IDEA program is open to all individuals, including entrepreneurs, small and large businesses, and institutions. The program provides an opportunity to investigate new and unproven concepts or to evaluate novel applications of technologies that have been tried, tested, or used for highway, 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 2003 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 2003 program year; several projects in this section are in the initial stages of inves-

tigation. 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; e-mail: ijawed@nas.edu.

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SECTION 1
COMPLETED IDEA PROJECTS

This section presents brief summaries of NCHRP-IDEA projects completed before the 2004 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% and an accuracy (relative to standard sieving) better than 4% 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 IDEA product is ready for field operational testing and marketing. The final report is available from the National Technical Information Service (NTIS # PB97-141642).

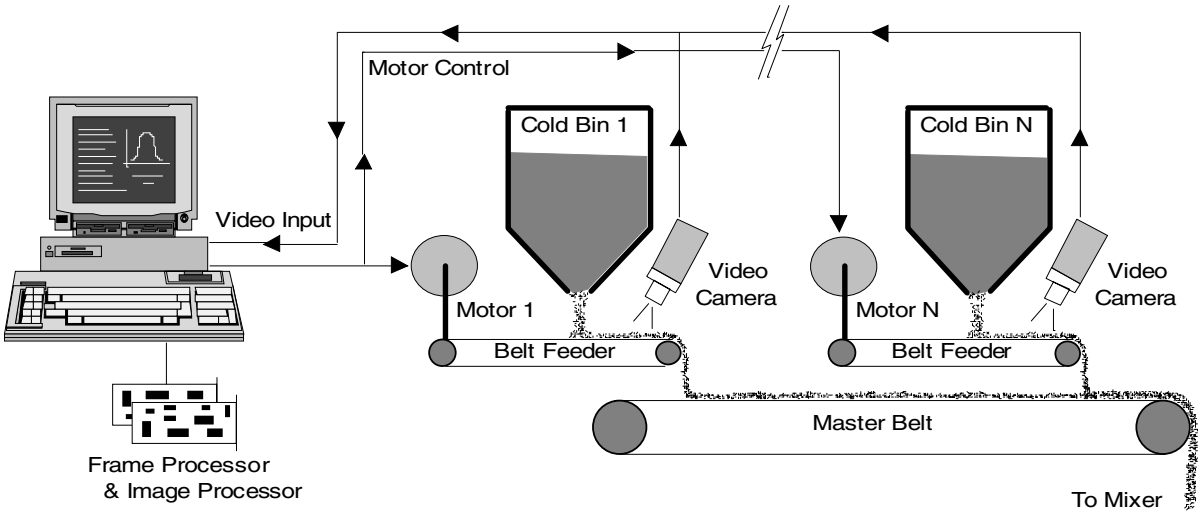


Figure 1

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).

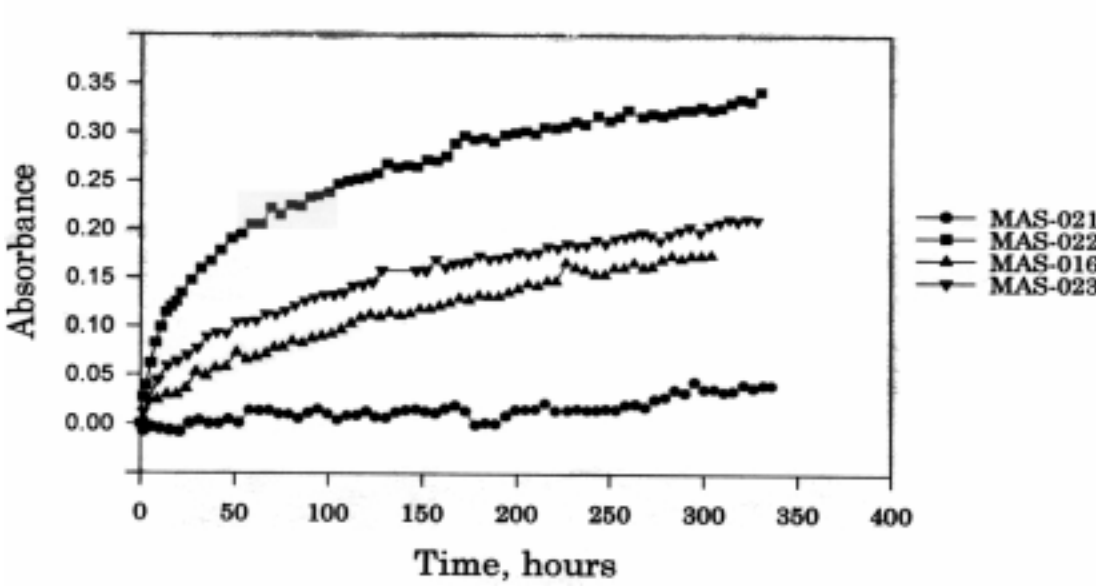


Figure 1

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. The product is undergoing large-scale field trials by the Florida DOT. 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).

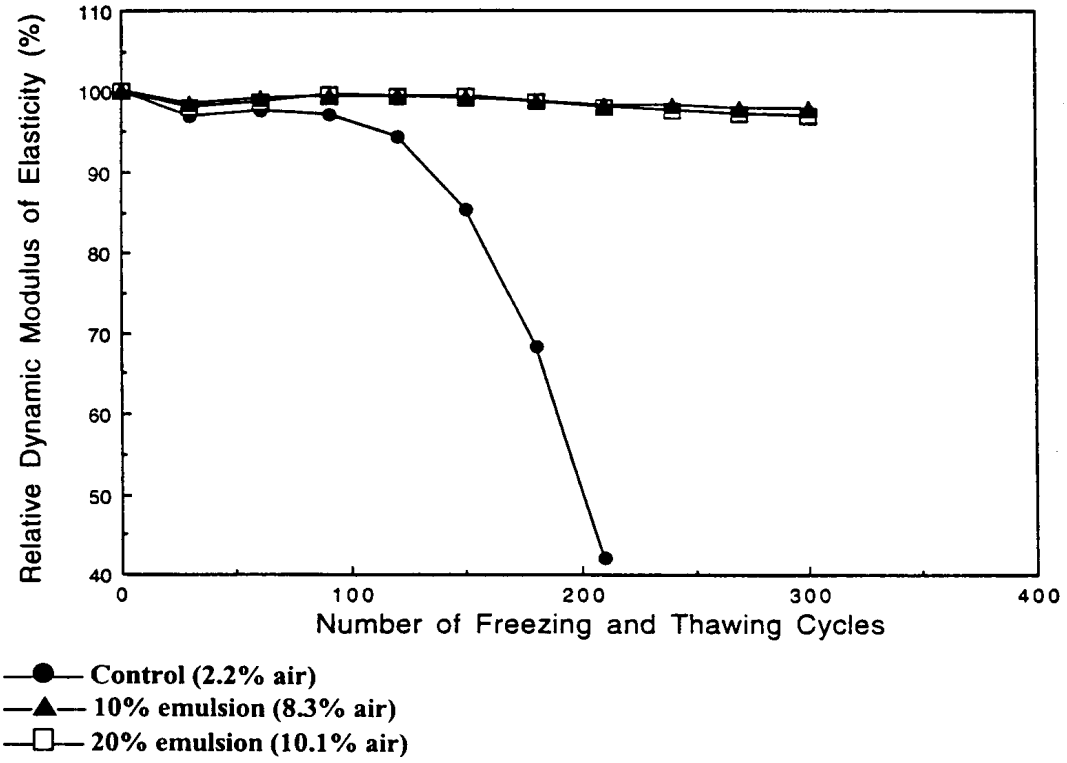


Figure 1

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).

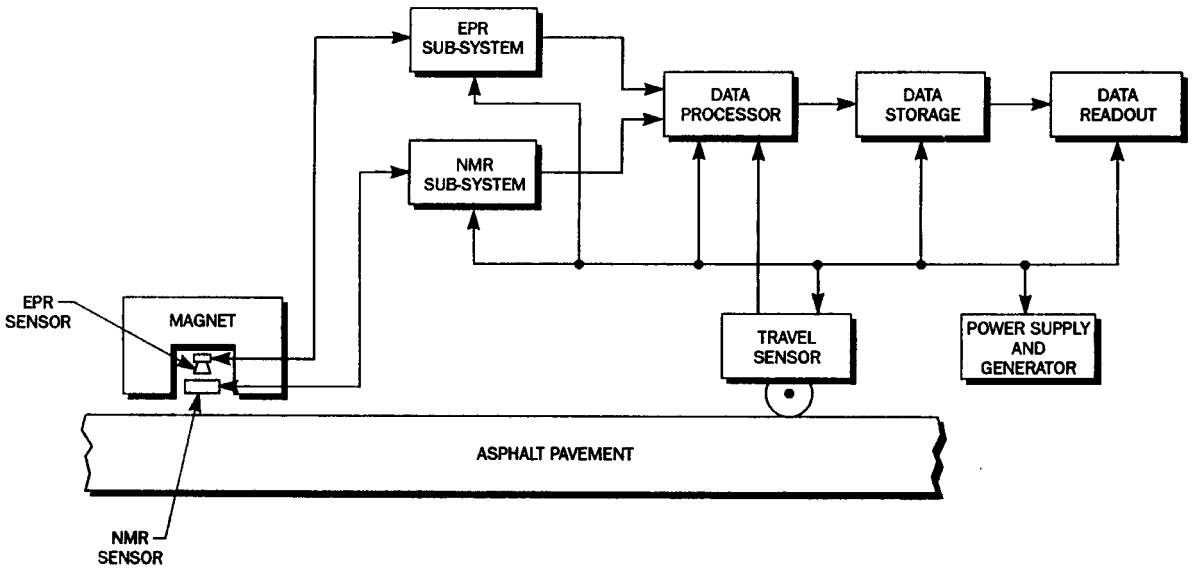


Figure 1

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 investigating team is working with the Illinois Department of Transportation to identify pavement sites during the 1996 construction season. Potential projects for testing include major highway or airport systems, low-volume roads, thin pavement overlays, and railroad track systems. After field verification experiments, a cost-benefit analysis is planned by the investigator to establish the efficiency of ECM pavement layers. The final report is available from the National Technical Information Service (NTIS # PB96-154414).

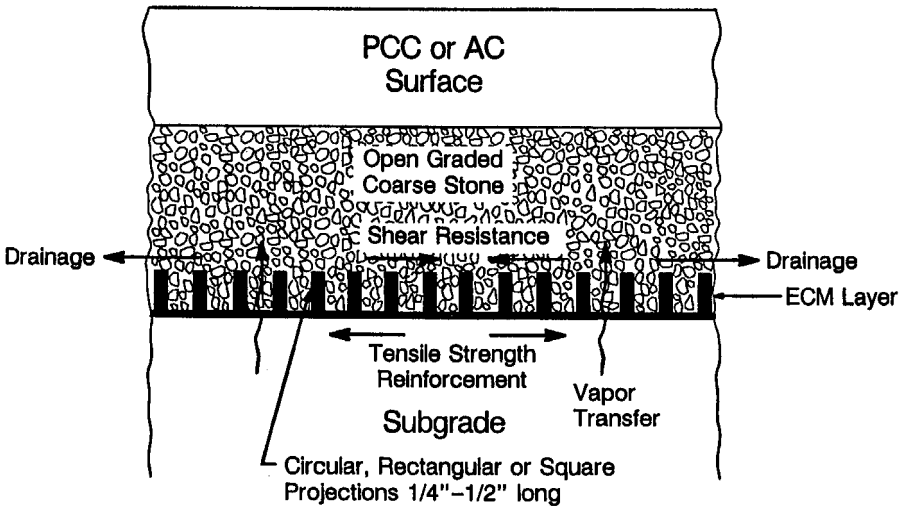


Figure 1

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 non-volatile 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.

A series of factorially designed laboratory tests was 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.

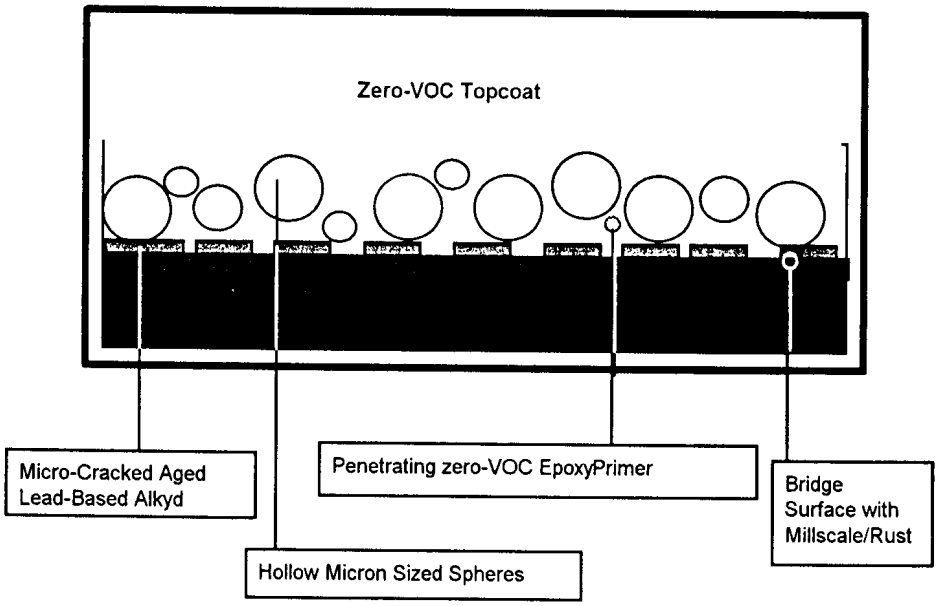


Figure 1

Product applied to bridge use.

The implementation of this new painting process on highway steel bridge structures will require extensive testing in collaboration with state highway agencies. No additional project action is planned by NCHRP-IDEA. 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% 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 results will be presented to ASTM Subcommittee A01.05 on Steel Reinforcement for consideration of specifications similar to ASTM A 615. The final report is available from the National Technical Information Service (NTIS # PB96-147988).

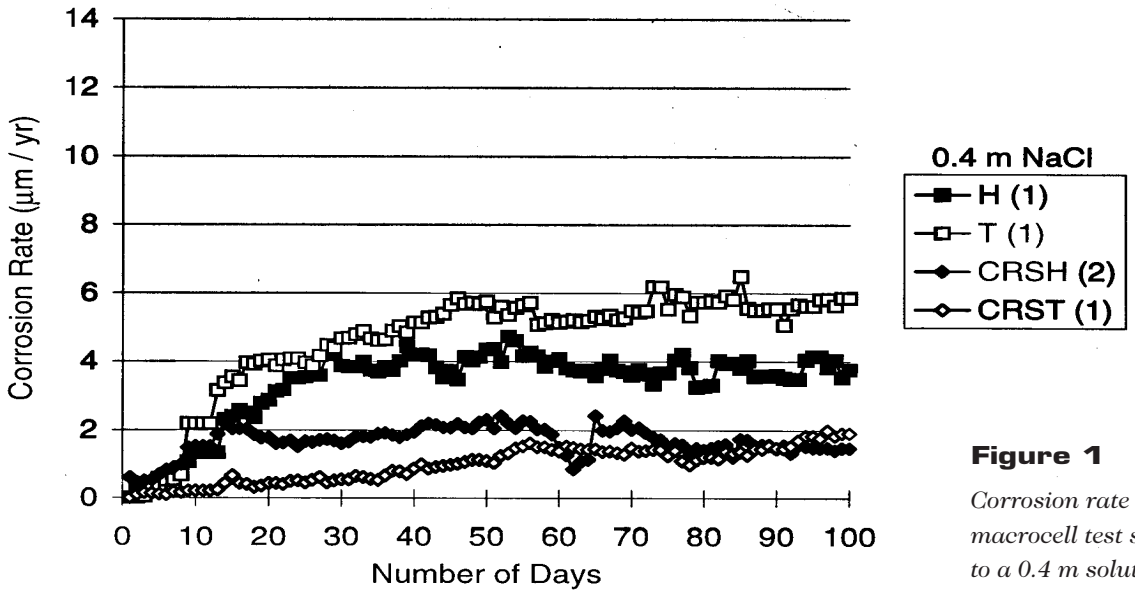


Figure 1

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 investigators are working closely with an industrial rebar coater, Western Coating of Oregon. Based on user input, conditions similar to those expected to be found in industrial production are being simulated. A broad user demonstration of the method is also planned by the investigator. The final report is available from the National Technical Information Service (NTIS # PB96-148002).

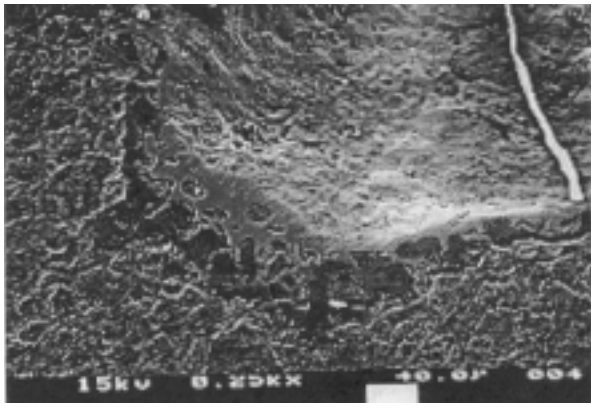


Figure 1

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% 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 failure mode of concern is that due to 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. This is planned in a follow-up NCHRP-IDEA project in collaboration with the Delaware Department of Transportation. The final report is available from the National Technical Information Service (NTIS # PB97-141964).

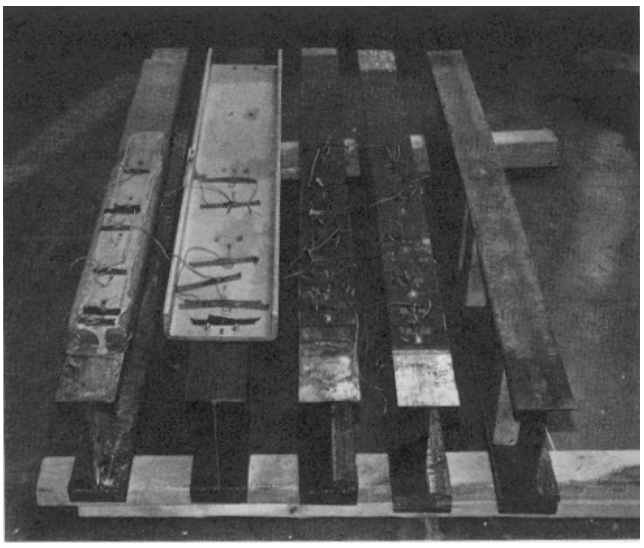


Figure 1

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%, 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 has 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. State agencies and private consulting companies have shown interest in using the system in the field.

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 its 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 their effectiveness in preventing access of chloride salt solution to 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. No additional action is planned by NCHRP-IDEA. The final report is available from the National Technical Information Service (NTIS # PB96-147970).

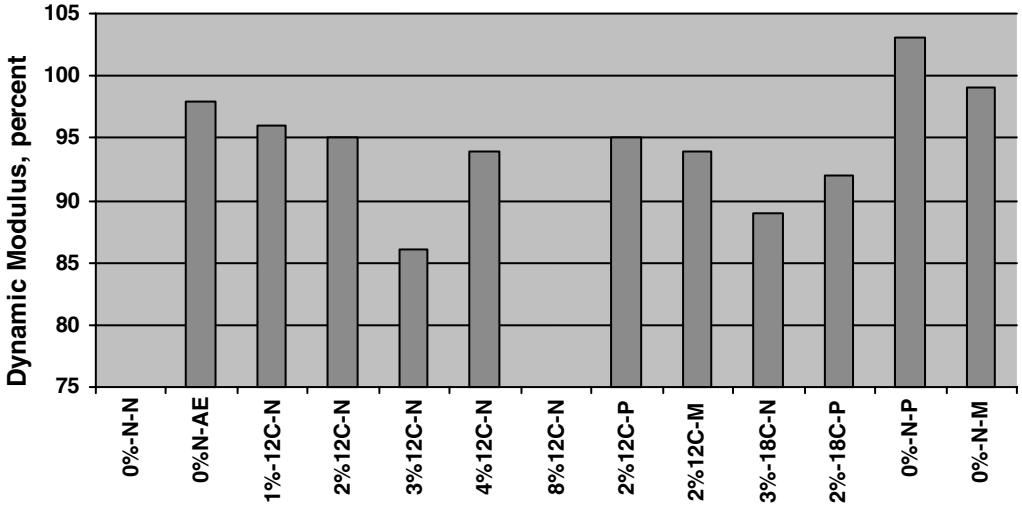


Figure 1

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% 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% 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).

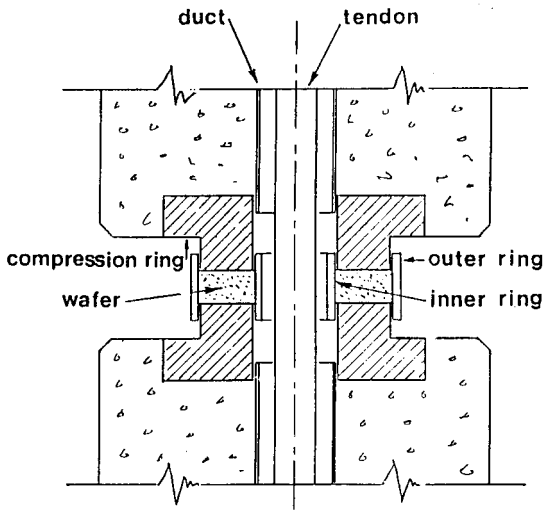


Figure 1

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).

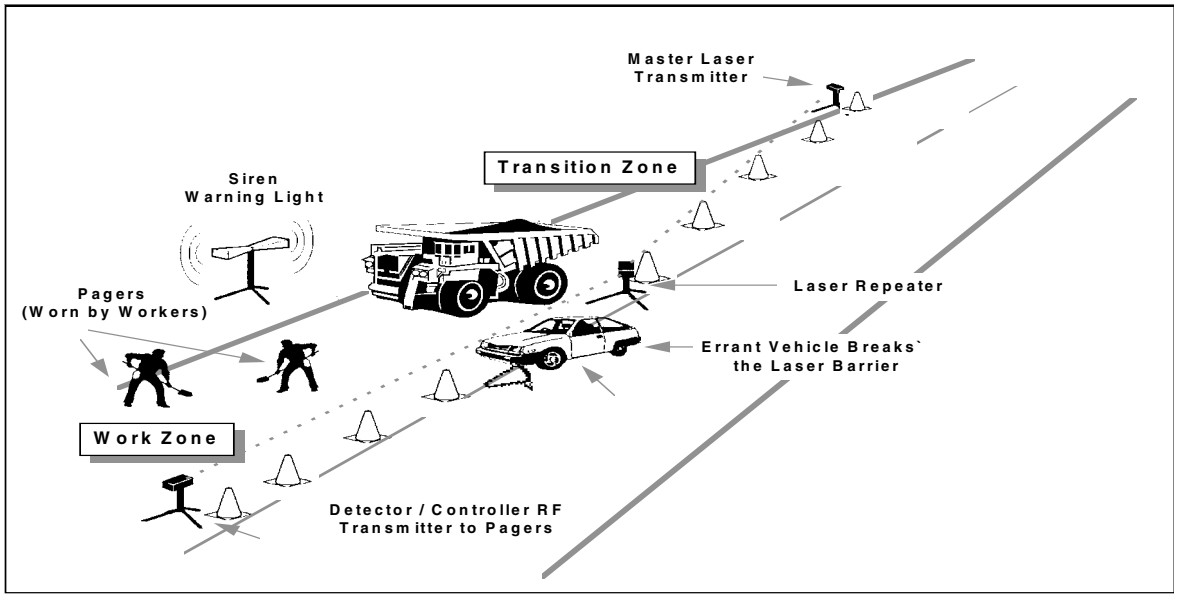


Figure 1

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.

Demonstrations of the prototype mobile unit on highway or parking lot markings or both are planned for the departments of transportation of nearby states, starting with Nevada. It will also be demonstrated to companies that deal in highway markings. If these demonstrations create sufficient interest, then commercially viable field units will be designed and implemented for removal of highway markings. 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) has been 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).

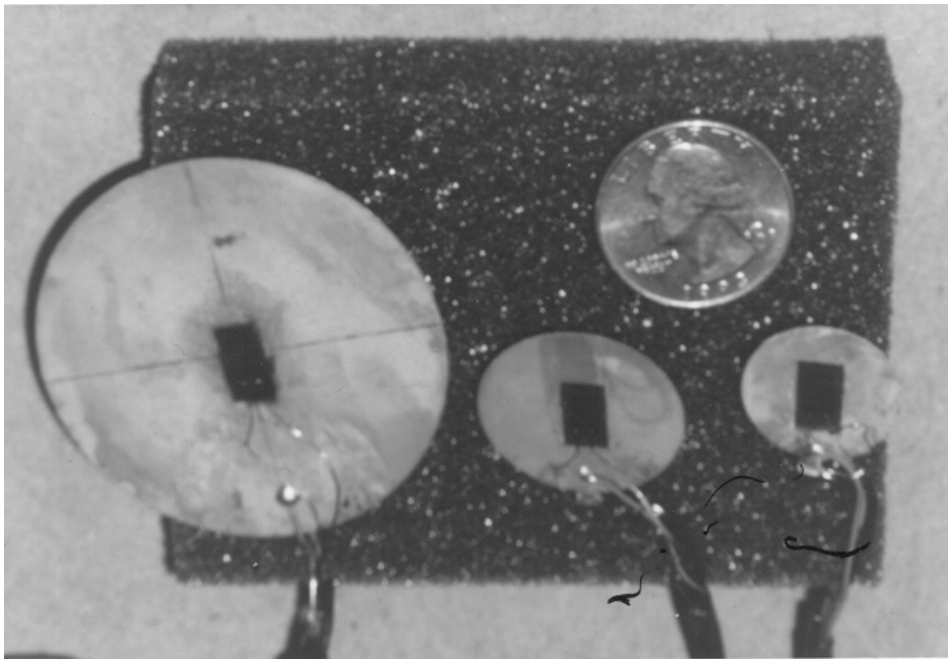


Figure 1

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.

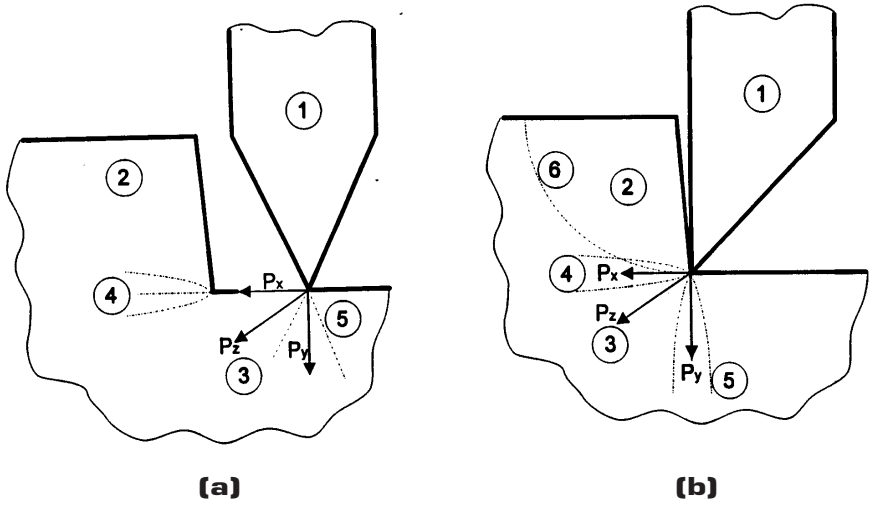


Figure 1

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).

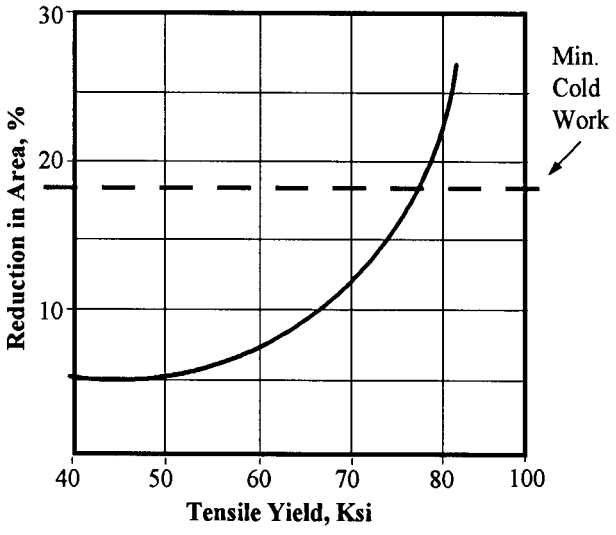


Figure 1

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

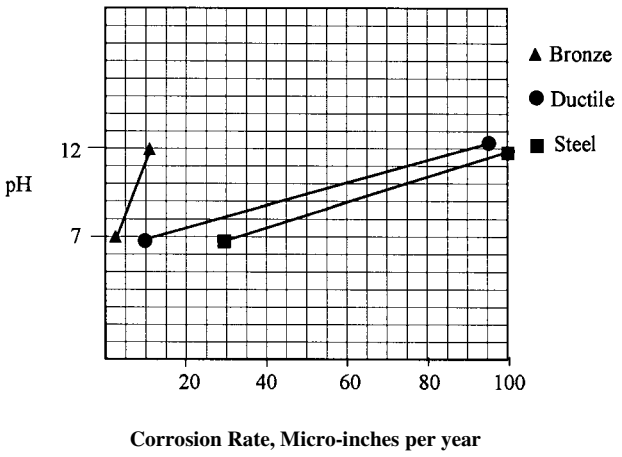


Figure 2

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 gun-like 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.

Tomco is working with the Georgia Department of Transportation to develop a CO_2 cleaning system to clean at least at a speed of 5 miles per hour. To do this, the feed mechanism and nozzle needs to be improved. Further field testing is also needed in order to develop a commercially feasible system.

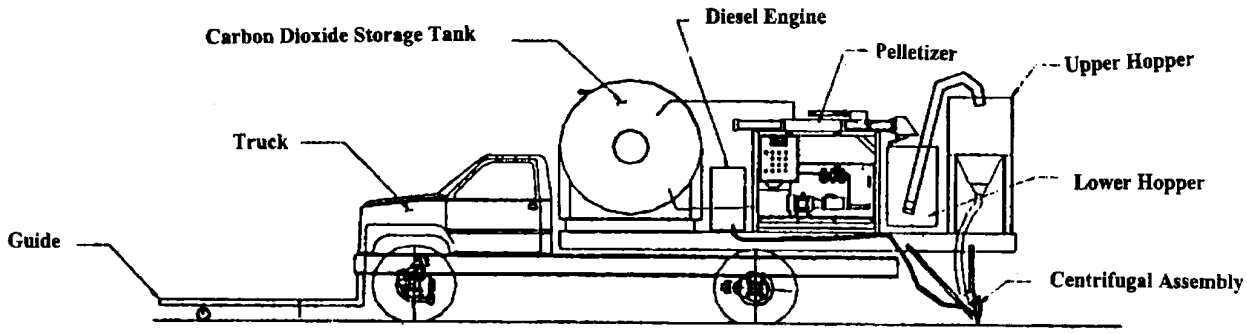


Figure 1

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

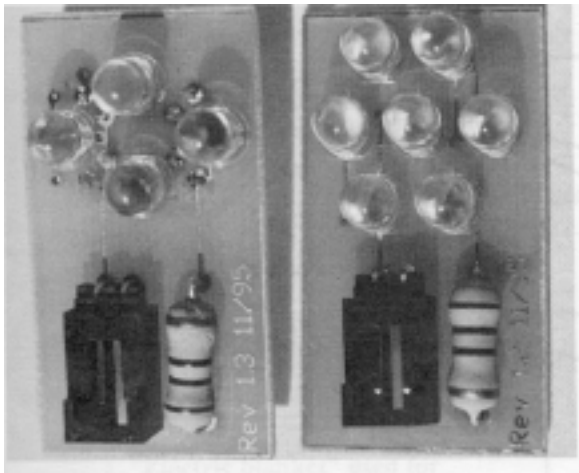


Figure 1

High- and low-intensity LED devices.

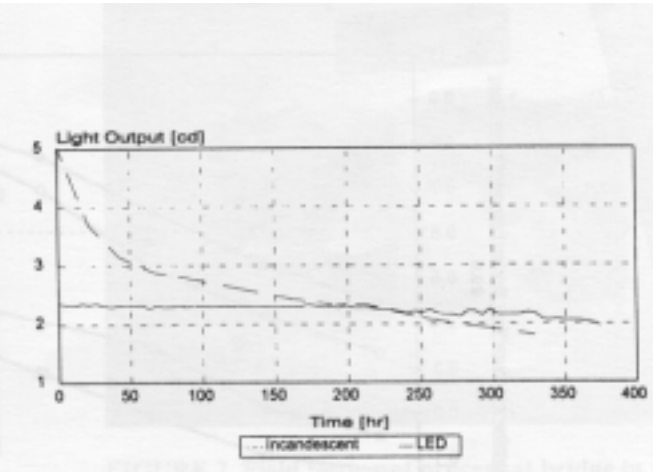


Figure 2

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 stored and released 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).

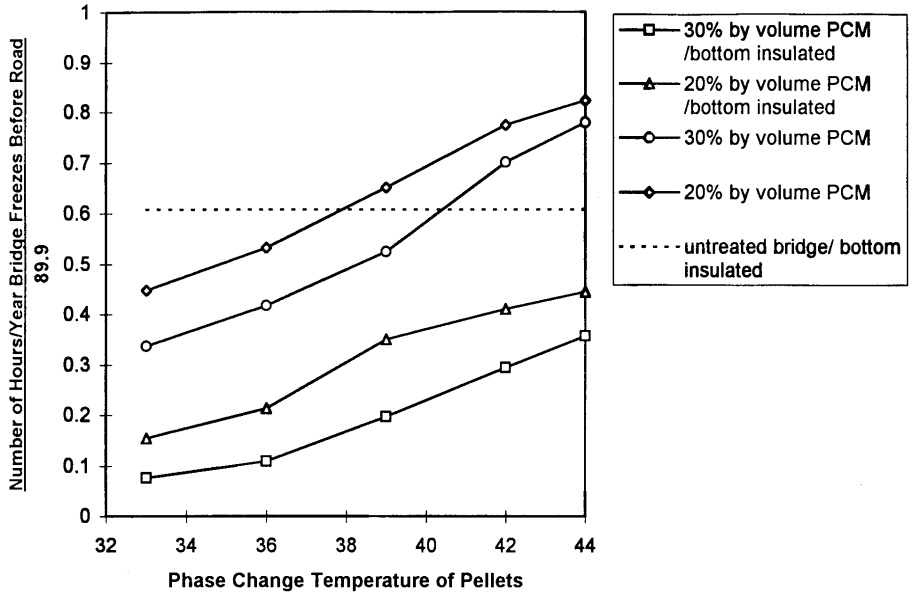


Figure 1

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 optimize process parameters. The process effectively debonded and removed paint from steel surfaces in 1 to 2 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 shows 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).

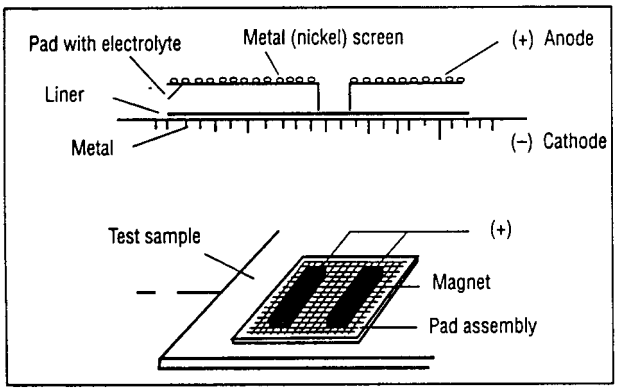


Figure 1

"Electric blanket" used for electrochemically assisted paint removal.

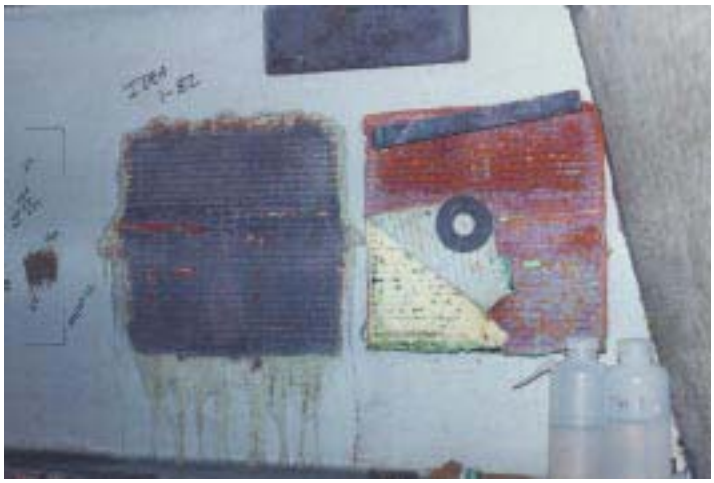


Figure 2

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 converting it 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. Because of the limitations of the current OTDR system in achieving accurate measurements and the limitations of the type of optical fiber used in the concrete environment, no field demonstrations were conducted. The final report is available from the National Technical Information Service (NTIS #PB 98-139074).

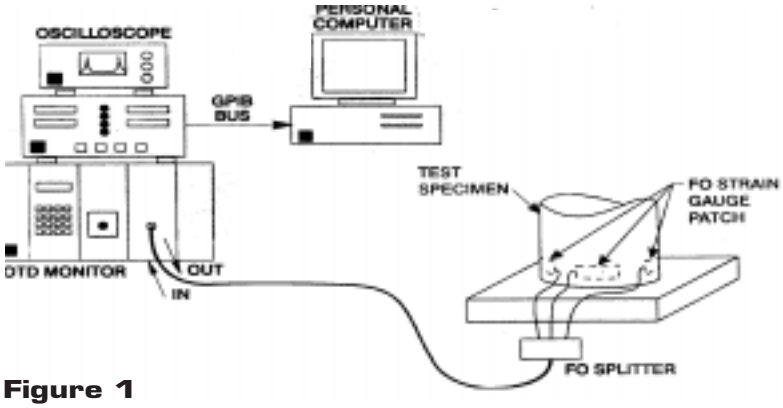


Figure 1

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% to 90% 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 is being 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).

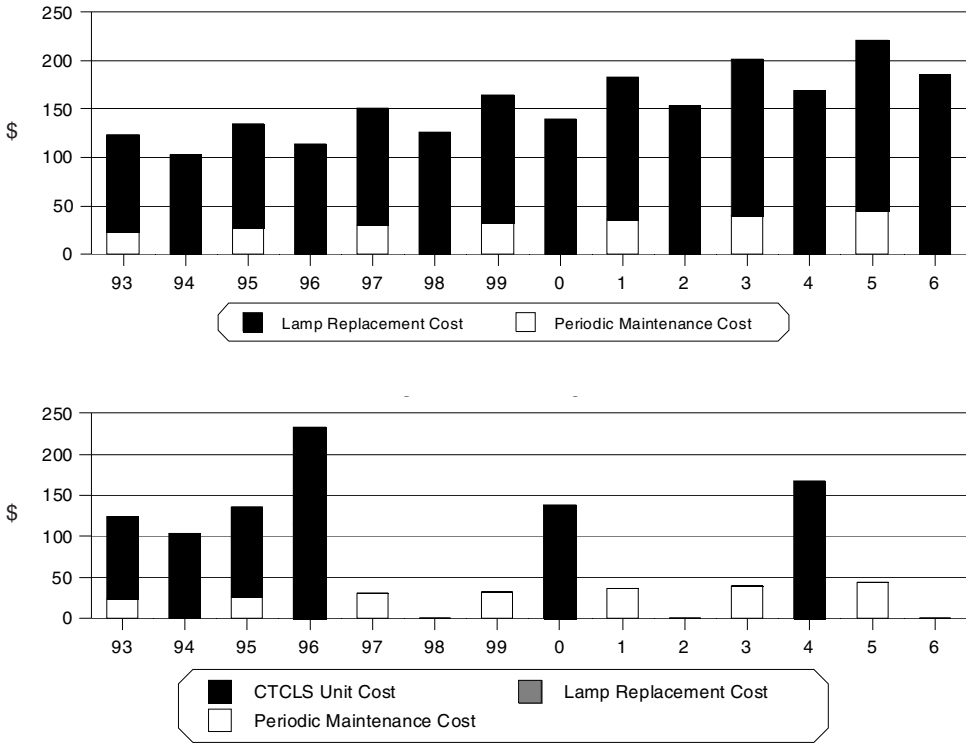


Figure 1

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 have shown interest in using the system for road applications. The final report is available from the National Technical Information Service (NTIS # PB99-130718).

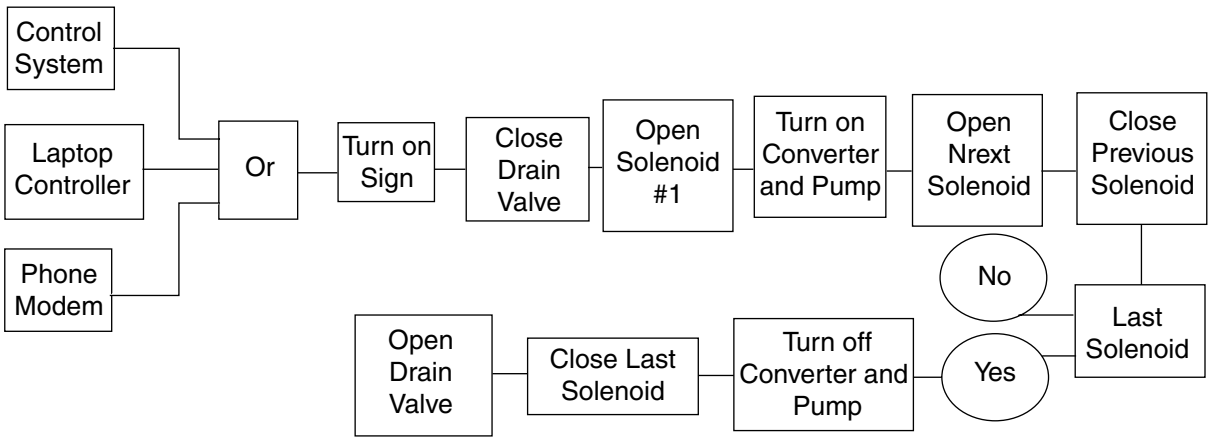


Figure 1

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% 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 is negotiating with Nucor Steel, a steel manufacturer, for production of a 50-ton heat of DFM steel. Since Nucor Steel does not have an on-line quenching, the steels must be heat treated following rolling. Bars from Nucor will be tested for mechanical and conversion properties. The final report is available from National Technical Information Service (NTIS #PB-139060).

Figure 1

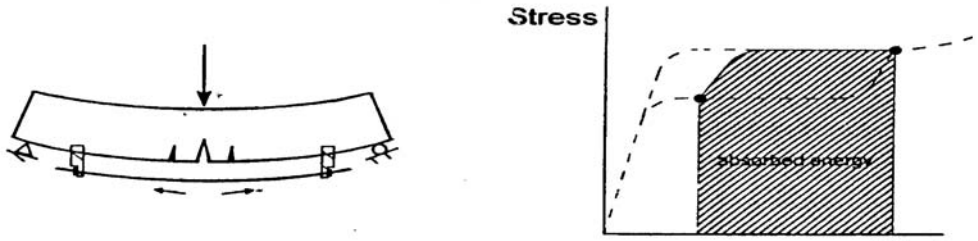
ASTM A615 and DFM steels after ex situ imposed polarization testing.

SUPERELASTICITY-BASED MATERIALS FOR BRIDGE REHABILITATION

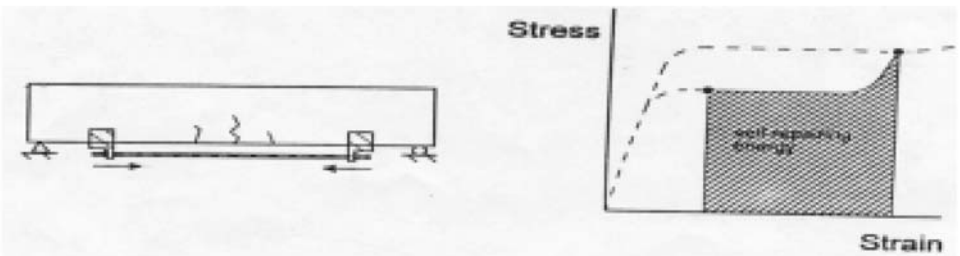
NCHRP-IDEA Project 29

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% 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 is being 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 6 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) has been made for preparing specifications and guidelines for installing the composite bridge and 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% accuracy in detecting ice, snow, wet and dry road conditions. The classifier's accuracy was improved to over 95% by using a neural network technique. Several configuration modifications were made to the system to improve its performance. Field test of the system were 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 has received media attention through regional newspaper articles, TV and radio segments, and also has been 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).

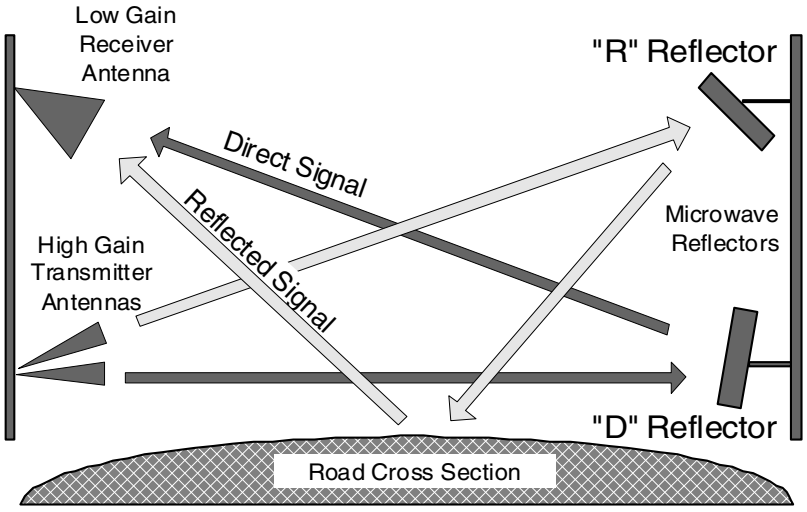


Figure 1

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 5 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 are being monitored for durability and bond integrity. Results to-date show 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 5 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 principal investigator, with Duke University's Office of Science and Technology, is processing a patent on this product and is looking for potential product developers who would be granted a license to manufacture and commercialize the product. The final report is available from the National Technical Information Service (NTIS #PB 98-139058).

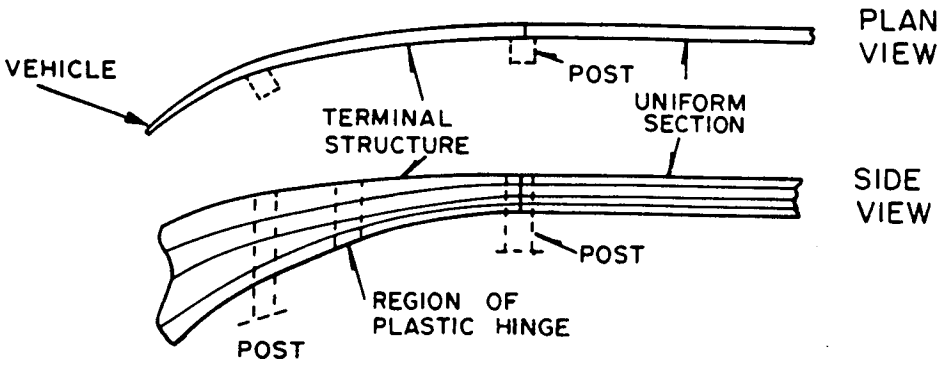


Figure 1

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.

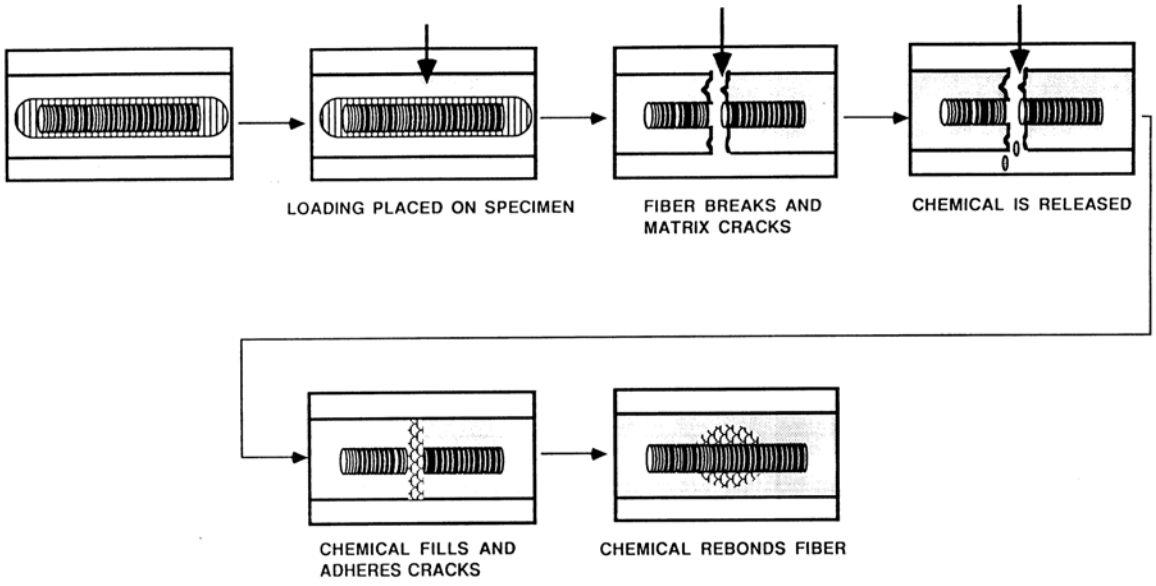


Figure 1

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).

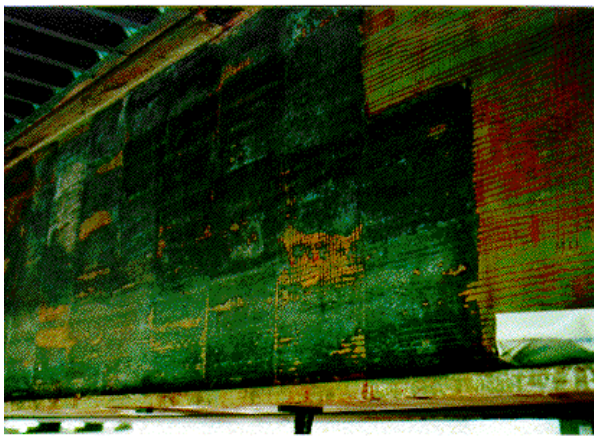


Figure 1

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 has generated interest from the industry, and an international consortium is exploring the possibility of adopting and implementing this technology. The final report is available from the National Technical Information Service (NTIS # PB2000-103400).

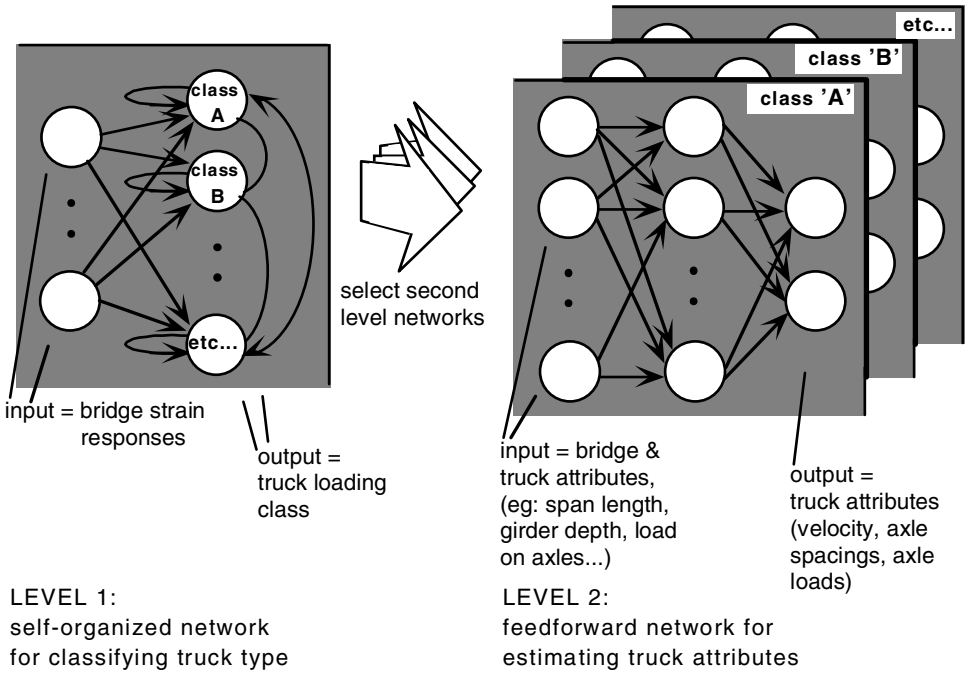


Figure 1

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 3-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. Contacts with equipment manufacturer to integrate the field unit are being pursued. Implementation of the system will require a commercial prototype and field trials.

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 using 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 show 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.

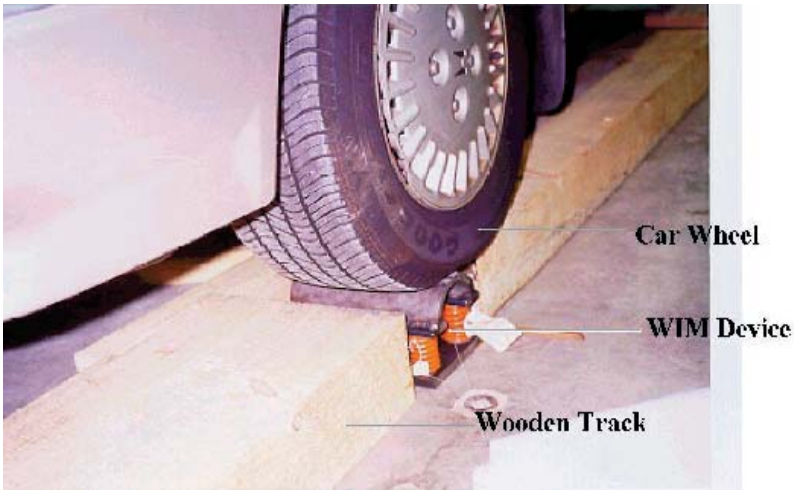


Figure 1

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 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.

The Kansas State University Research Foundation is pursuing patent protection for all aspects of this system. The Mid-America Commercialization Corporation is developing commercialization strategy for this technology. 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% 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. Discussions are under way with the Wisconsin Department of Commerce for support from its Technology Development Fund to explore the use of 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).

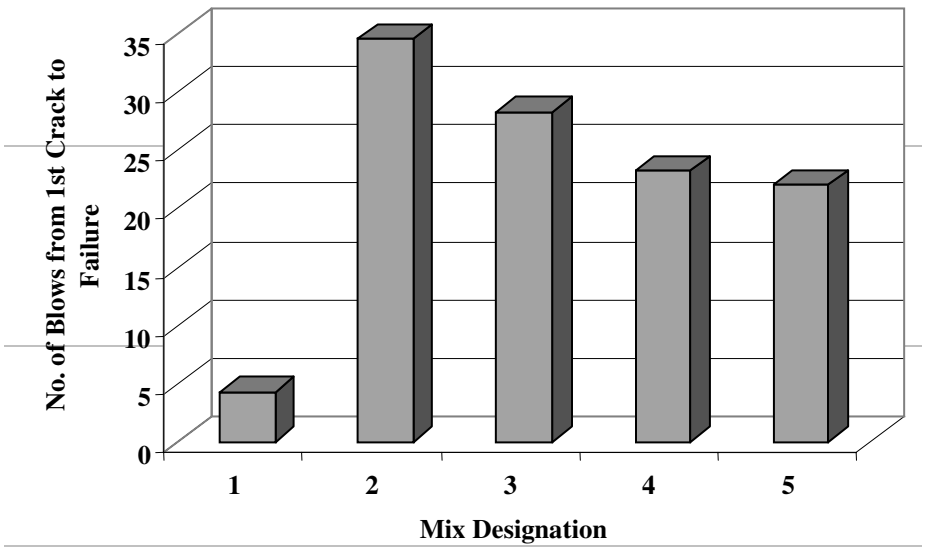


Figure 1

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 involves re-decking of 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 is approximately 25 kip and replaces an estimated 88 kip of existing roadbed — a 70% 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) has been set up to provide updated information on the project.

The technology developed through this project is currently being used for two bridge decks in Missouri and one in West Virginia. Technical discussions have been conducted with six other states that are interested in this technology. In 2001, at least 10 bridge decks will be installed on new or rehabilitated bridges. 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 those 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.

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 U.S. and abroad. The PQI system is currently being 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 # PB2000-105O60).

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. Two major equipment manufacturers have expressed interest in licensing the technology. Additional refinement and field testing are needed for a full implementation of this technology.

Figure 1

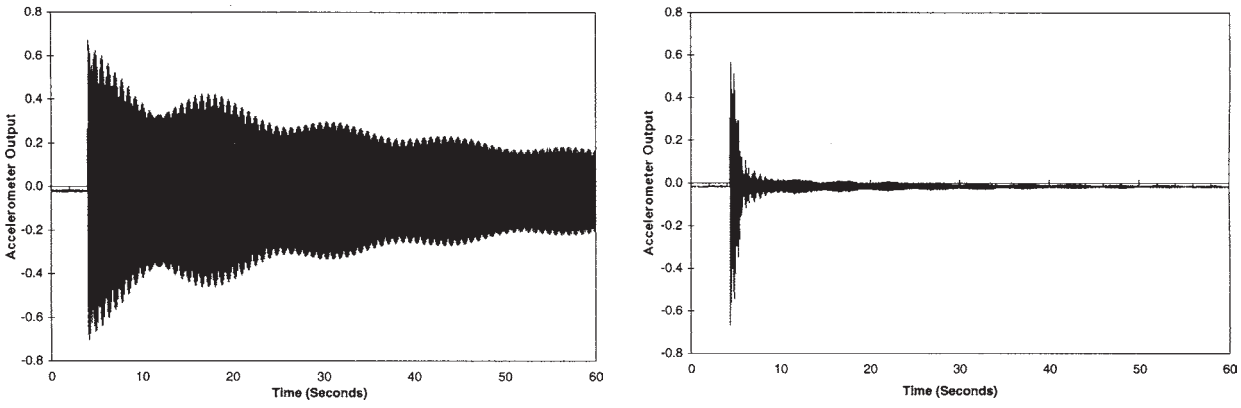
Truck-mounted RoadWriter™ prototype system in field operation.

DAMPER SYSTEMS FOR SUPPRESSION OF BRIDGE STAY CABLE VIBRATIONS

NCHRP-IDEA Project 50

Habib Tabatabai and Armin B. Mehrabi [Phone (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 has been 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.

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 non-toxic 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 have been under 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 will 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. Companies interested in licensing high performance, environmentally friendly coatings have been identified. Another option is the formation of a joint venture company to manufacture the coatings. A partner company for this approach has been identified. The regional manufacture of coated rebar will be done by licensing individual fabrication and coating companies.

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.

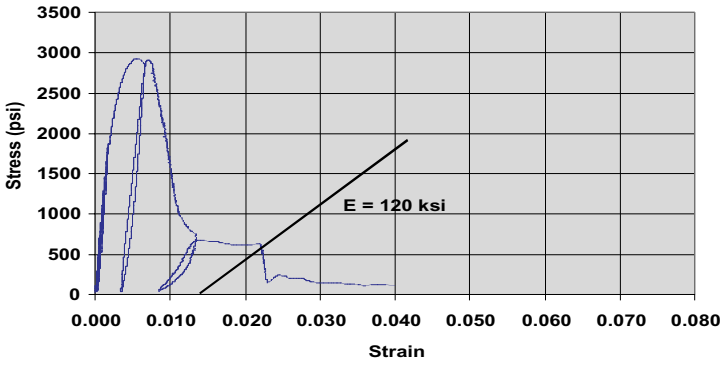


Figure 1. Stress Strain Response - Compression Test

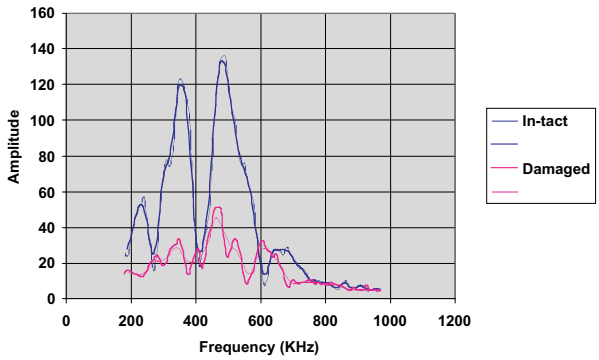


Figure 2. Voltage Amplitude vs Frequency : Incidence Angle 25 Deg

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,, and 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 U.S. and Canada.

Figure 1

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

The potential for a simple yet effective in-situ test device has already drawn significant interest from both government and private industry. In addition to IDEA Program funding, the Ontario Ministry of Transportation (MTO) and Regional Municipality of Ottawa-Carleton have committed financial and in-kind support for this investigation. Furthermore, a number of independent consultants have also expressed interest in the potential of the InSiSST™.

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. The principal investigator is pursuing a patent for this novel design. A new cellular decomposition suitable for motion planning of serpentine robots was developed. Work on path planning and control of serpentine robot has resulted in further improvements. Additional development and extensive laboratory and field 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.

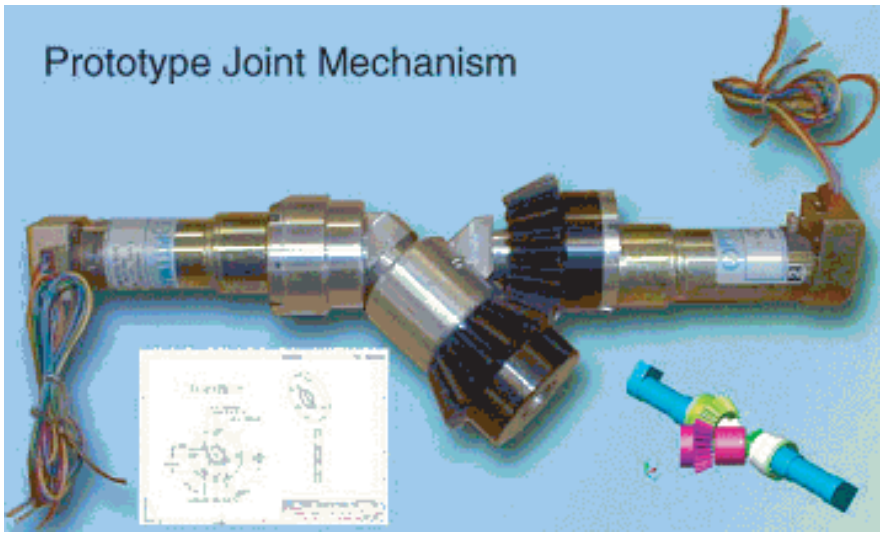


Figure 1

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, and 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. Tests were completed on the effect of soil permeability on drainage and on the clogging of wick drains. Field trials in additional states are being conducted. A video illustrating the technique for wick drain installation and use has been 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)*.

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.

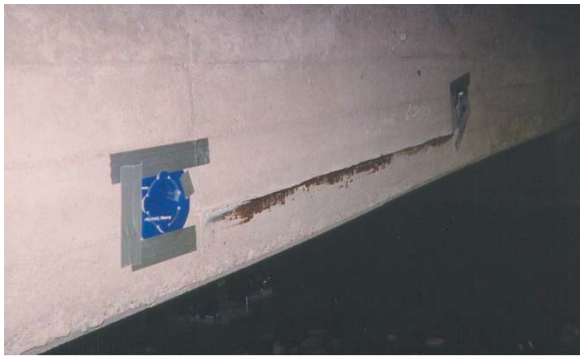


Figure 1

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 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.

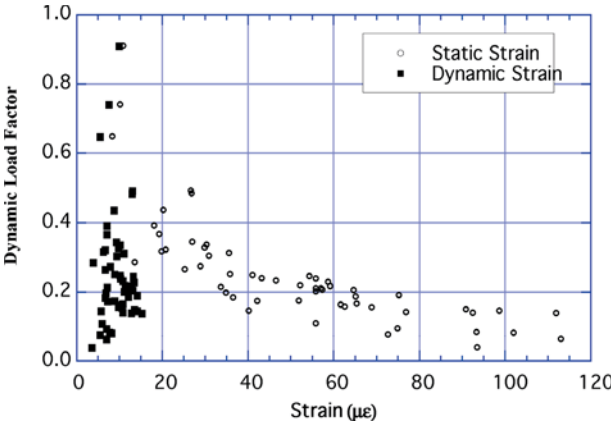


Figure 1

DLF vs. Static and Dynamic Strain.

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 truck traffic control can save a considerable amount of money for bridge maintenance because of a more accurate site-specific evaluation.

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 and 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. An equipment manufacturer is collaborating with the contractor to explore the commercialization of the device.

Figure 1

Portable PTDM

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 proposed PTDM would be available at a price comparable to other pavement nondestructive testing devices; and thus would be applicable for routine use by contractors, state highway testing organizations, and by private and contracted testing laboratories.

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 (Fig. 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.

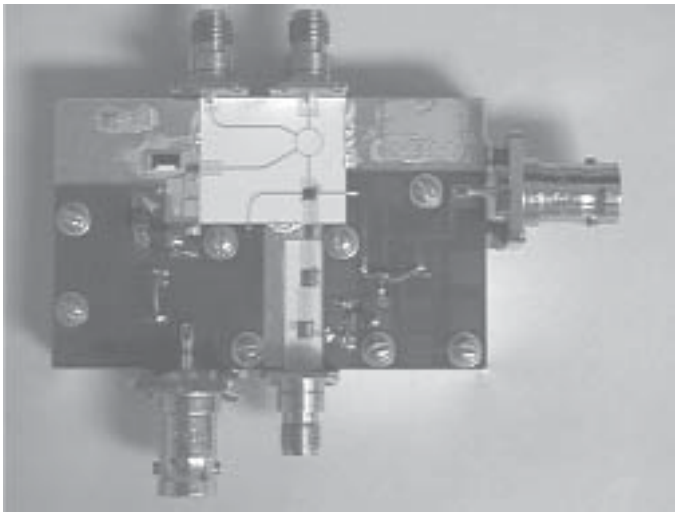


Figure 1

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 are being 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.

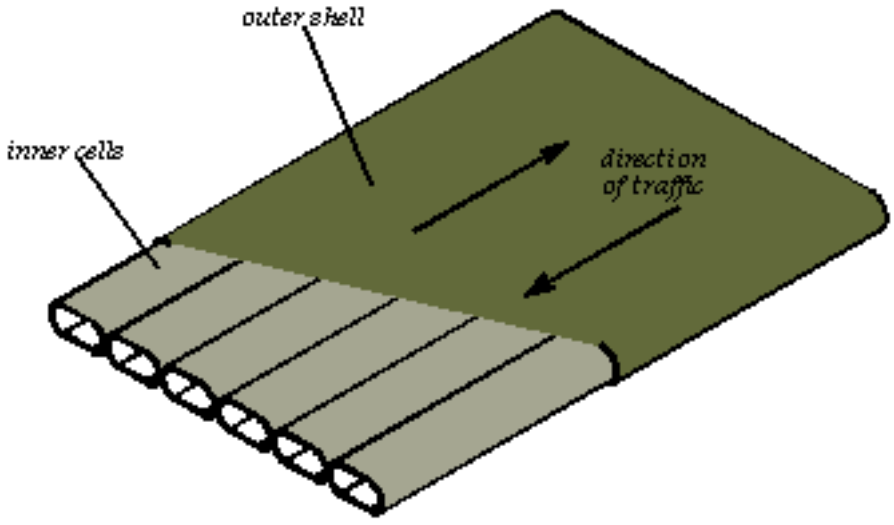


Figure 1

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

This project has been completed and the final report is currently under review. 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 (CT) 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 technology will be further evaluated at the FHWA in a systematic investigation of core samples obtained from experimental mixers and from field tests such as West Track.

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 building 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.

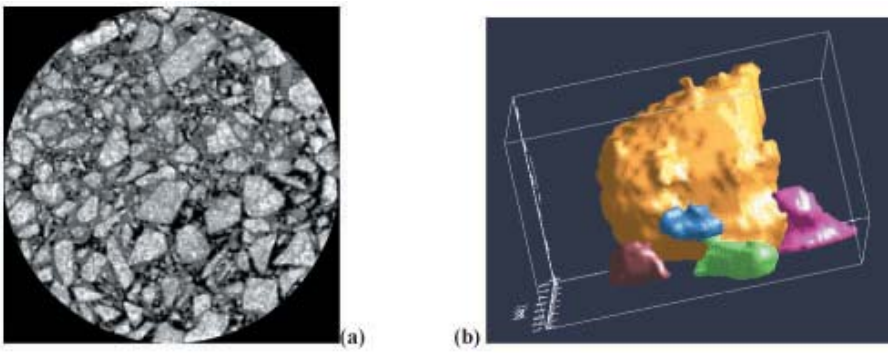


Figure 1

(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, 1 in. in diameter, were subjected to uniaxial tension, in full-scale tests. The bars were also subjected to cyclical strains up to 8% 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.

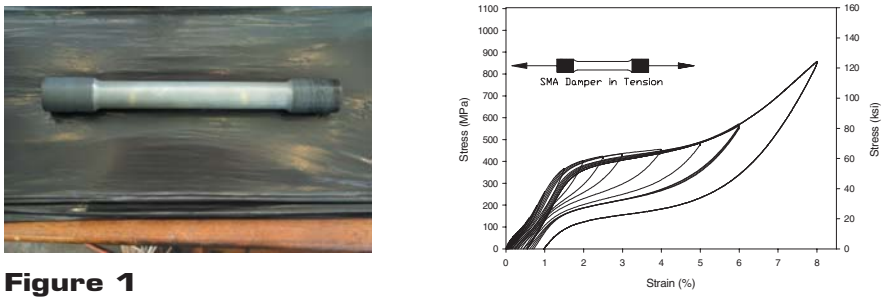


Figure 1

(a) Proposed SMA damper (b) 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. The state of California alone has spent nearly $750 million in seismic retrofit since the 1989 Loma Prieta earthquake. Many other state DOT's are now beginning to initiate similar retrofit programs, including New York, Tennessee, Illinois, and South Carolina. Should this technology prove effective and cost efficient, it can become a widely used seismic retrofit technology. Once the technology has been proven effective in reduced-scale experimental tests, the products will be developed and tested in full-scale. Representatives from various DOTs will be provided with the test results and will be invited to participate in future full-scale tests. Collaboration with Shape Memory Alloy manufacturers and end-users is essential to ensure the transfer of the research results to practice.

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 (Figs. 1 and 2) for attaching fiber-reinforced polymer (FRP) bridge decks to supporting steel stringers. The connector dimensions were defined through finite element analyses. The connector design was experimentally evaluated by first 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 is working with West Virginia and Kansas DOTs to implement this concept in future bridge projects.

Figure 1

Photo of steel-sleeve connector

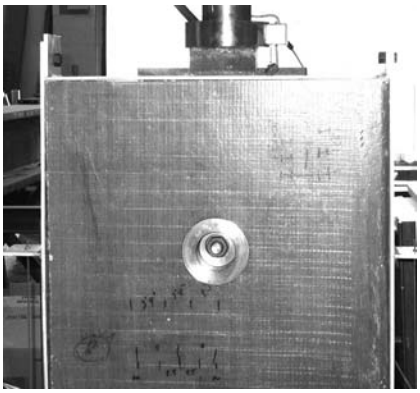


Figure 2

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 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. Plans are currently in progress to implement the composite sidewalk system on a bridge in Colchester, Vermont.

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 a more economical transport layer than the one tested in this project would make GCBD more affordable and implementable. The contractor is discussing the possibility of licensing the technology with a private manufacturer of geotextiles. The project was highlighted in a recent issue of *Progressive Engineer,* an on-line engineering magazine and information source.

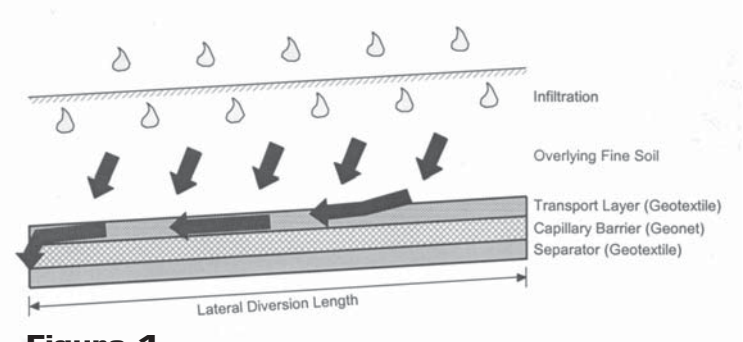


Figure 1

Geocomposite Capillary Barrier Drain.

The New York, Vermont, and New Hampshire DOTs were involved in the planning and testing of this research. Typical pavement materials specified and provided by these states were used for the construction of the test sections. These and other states are expected to coordinate implementation of these results via trial test sections. The project team has been involved in discussions with a number of geosynthetic manufacturers regarding commercialization of GCBDs.

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 (Fig. 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 6 days and retested in saturated state followed by testing in a partially dried state. The test data were correlated with chloride permeability 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.

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 non-resin 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 could be flamesprayed onto concrete substrates and 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 evaluating their long-term weather durability.

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. A major stay cable manufacturer, the FHWA's HNTB pooled fund study team, and the state of Alabama have expressed strong interest in advancing the commercial development of this technology.

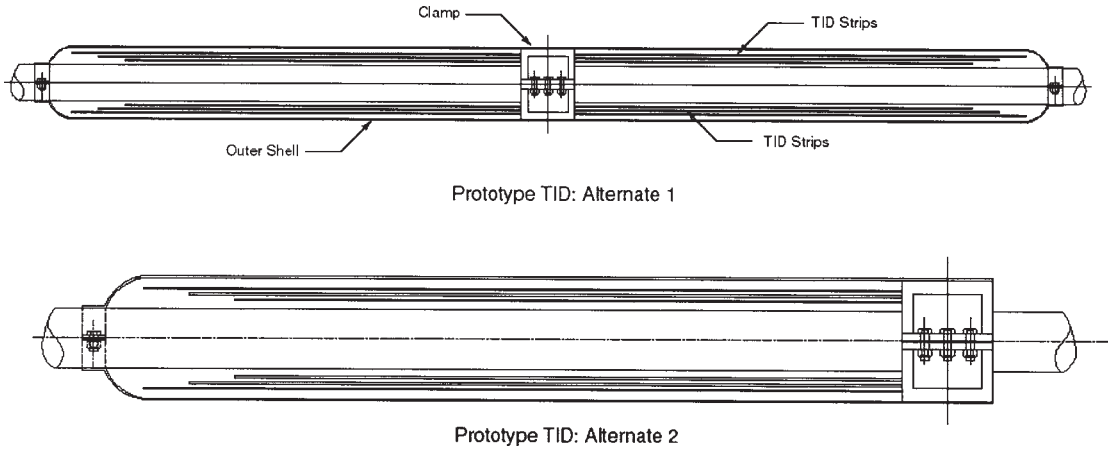


Figure 1

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 (Fig. 1) for removing both particulate and soluble lead from wash water generated by pressure washing of 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 Kentucky Transportation Cabinet has expressed interest in using this system.

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 (Fig. 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 non-uniform transverse temperature areas.

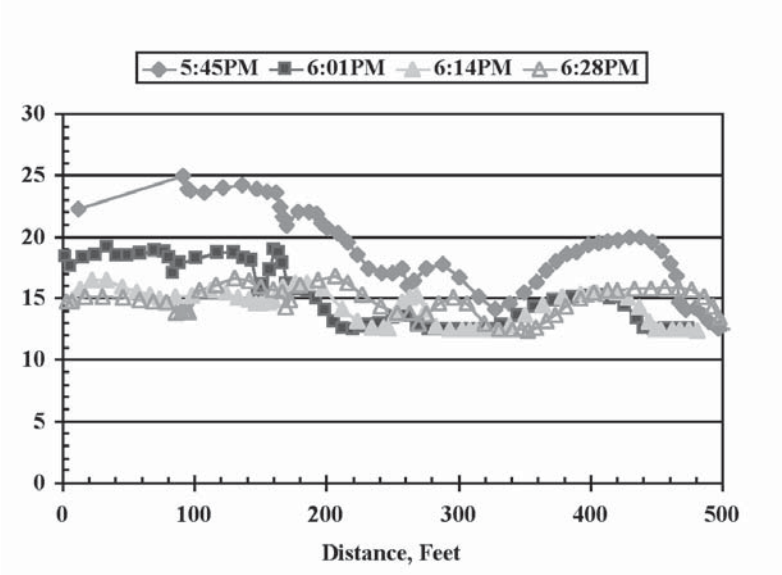


Figure 1

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] 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 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.

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, Rolla, MO

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.

Figure 1

Imaging equipment mounted in a vehicle.

STABILIZATION OF LANSDLIDES USING HORIZONTAL WICK DRAINS

NCHRP-IDEA Project 76

Paul M.Santi, Colorado School of Mines, Golden, CO (Tel: (303) 273-3108; Fax: (303) 273-3859, C. Dale Elifrits, University of Missouri-Rolla, Rolla, MO

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 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 8600 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 contractor is working closely with commercial manufacturers, American Wick Drain Corporation and the Nilex Corporation, and the Colorado, Missouri and Indiana DOTs for field implementation of this technology.

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, WA

This project developed and tested an automated image analysis system for measuring aggregate shape characteristics (Fig. 1). The work involved development of a software and a hardware system. 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. The FHWA plans to use this device is its mobile laboratory for demonstration and training. The International Center for Aggregate Research (ICAR) is also using this device in several of its studies.

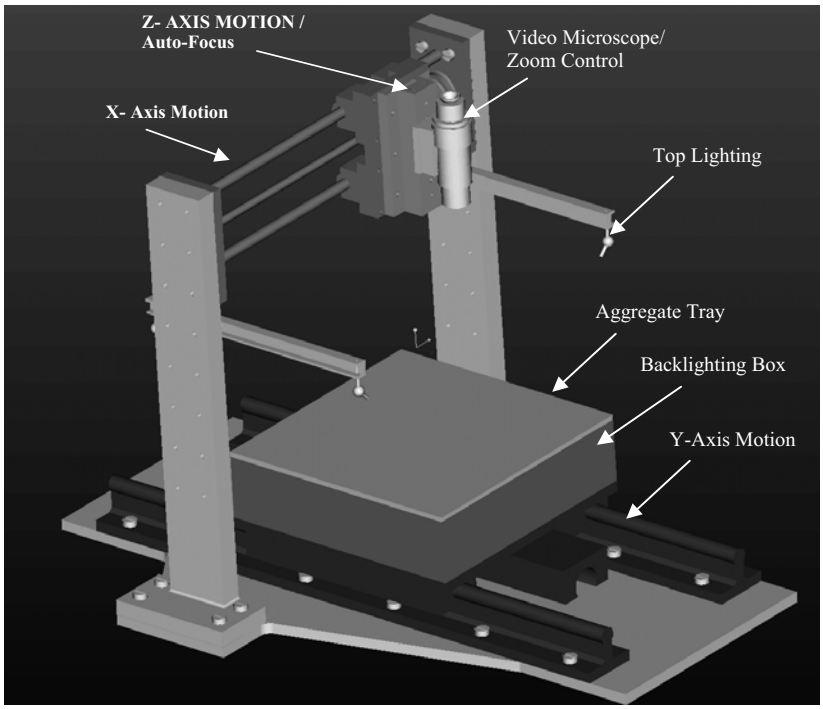


Figure 1

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, Rolla, MO

This project developed and tested a rapid method based on automated digital imaging technology to characterize aggregate shapes. A prototype automated imager analyzer (Fig. 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.

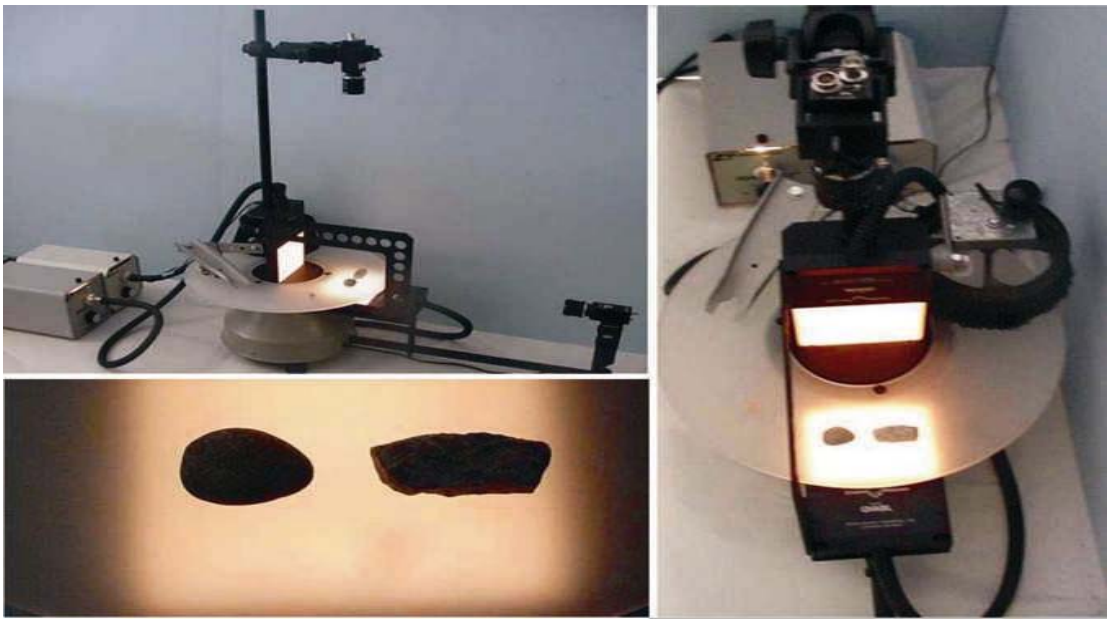


Figure 1

New flat and elongated image Analyzer

CONCRETE ROAD RECYCLER - HAMMER-ANVIL TEST RIG

NCHRP-IDEA Project 79

Deems Pfaff [Phone: 970-476-6577 Fax: 970-476-0504], Road Processing Resources, Inc., Vail, Colorado and Robert Burggren [Phone: 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 expressed interest in testing of the prototype system.

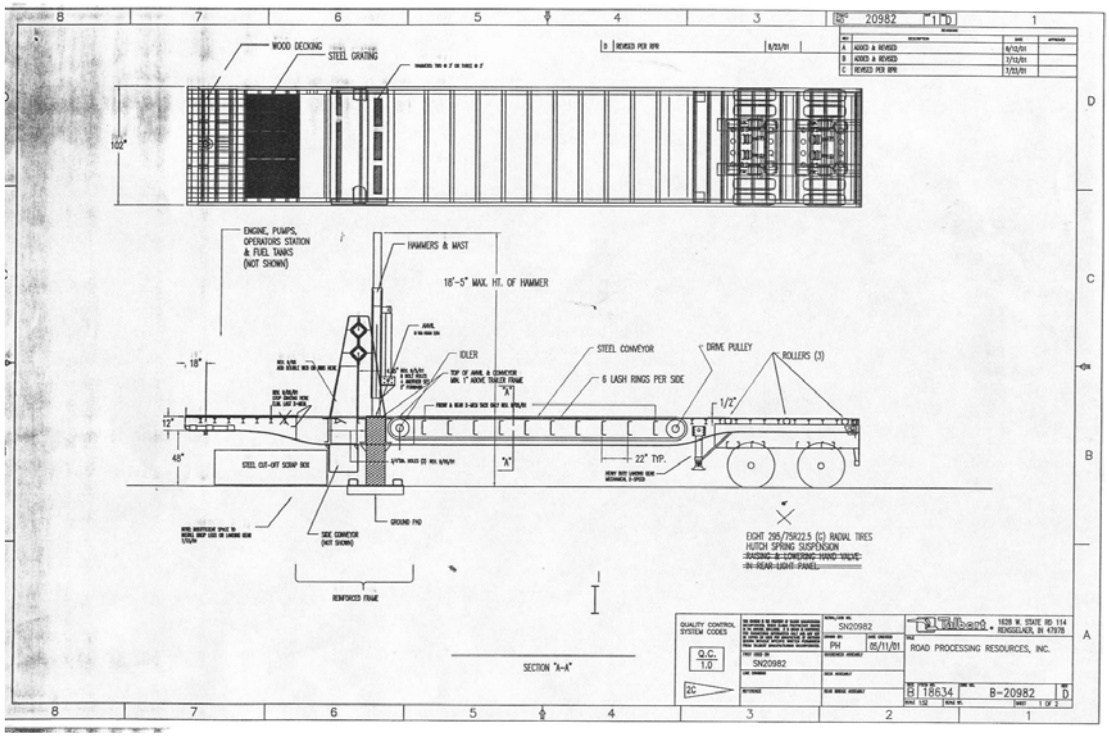


Figure 1

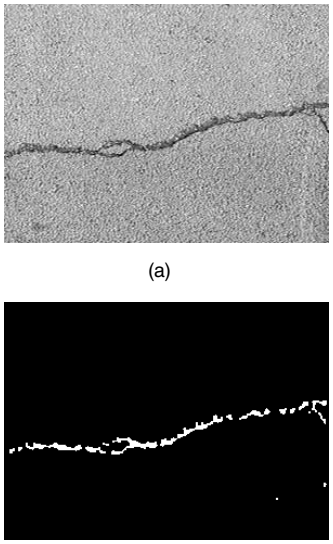
Schematic diagram of road recycling machine

AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION SYSTEM

NCHRP-IDEA Project 81

Heng-Da Cheng [Tel: (435) 797-2054,
Fax: (435) 797-3265],
Department of Computer Science,
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, etc. 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 project team is working closely with Utah DOT. Several private companies, including ROADWARE and LAW Engineering, have expressed interest in the implementation of this technology.

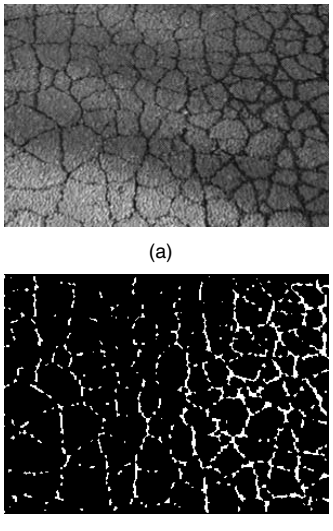


(a)

(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's 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 under way on the consolidation of the data acquisition and control systems. This IDEA project is being complemented by a FHWA/State DOT-sponsored pooled-fund study for further development and implementation of the impulse shear test.

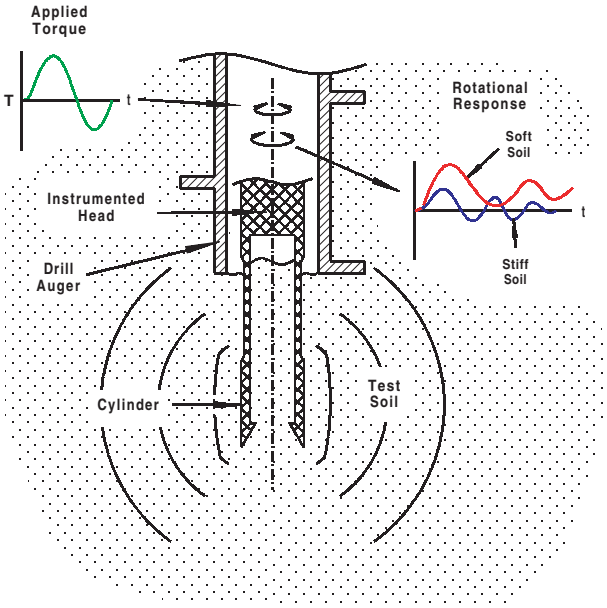


Figure 1

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, improving 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.

Figure 1

Prototype ice detection system

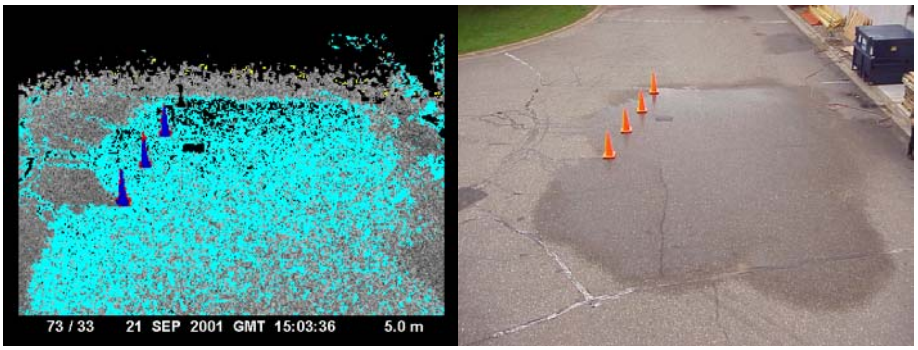


Figure 2

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, e-mail:
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 sections 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 to-date indicate a significant improvement of the IDEA test over SHRP tests for fracture and cracking predictions.

WATERPROOFING CONCRETE HIGHWAYS

NCHRP-IDEA Project 85

John L. Massingill, Jr. [Tel: (512) 245-9618, Fax: (512) 245-1892, e-mail: john.massingill@txstate.edu], Texas State University, San Marcos, Texas, and David W. Fowler, International Center for Aggregates Research, The University of Texas at Austin

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% SOPEP showed a decrease of only about 7% 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 show 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.

ADVANCED CONCEPT CONCRETE USING BASALT FIBER/BF COMPOSITE REBAR REINFORCEMENT

NCHRP-IDEA Project 86

Dr. Vladimir Brik, Research & Technology Corp., Madison, WI
Ph: (608) 244-1349; Fax: (608) 244-9071; v_brik@hotmail.com

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.

AN IN SITU SHEAR TEST FACILITY FOR ASPHALT CONCRETE PAVEMENTS

NCHRP-IDEA Project 87

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

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 is being 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.

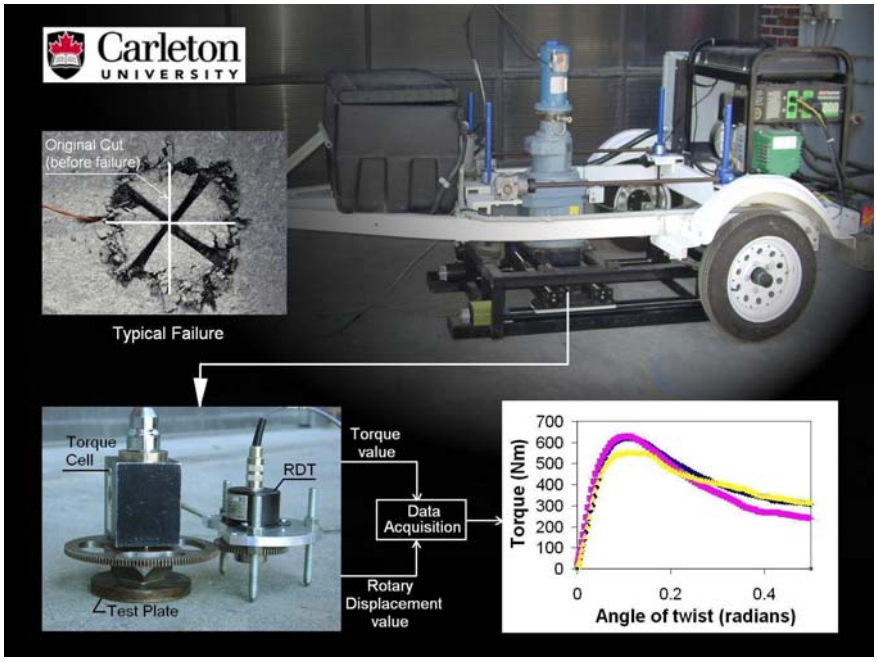


Figure 1

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 calibration program, distortion adjust program, matching program and some user interface. The algorithms needed further improvement to enhance accuracy. Initial tests have shown 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.

Figure 1

The dual-camera sub-system

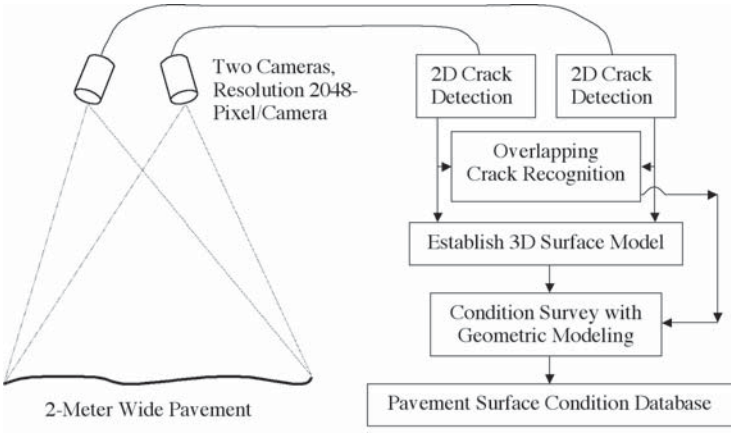


Figure 2

General procedures for automated condition survey with stereovision

ROBOTIC HIGHWAY SAFETY MARKERS

NCHRP-IDEA Project 90

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

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. In addition to Nebraska DOR, Caltrans and Texas DOT have expressed interest in this project. The project has received considerable national and international media attention.

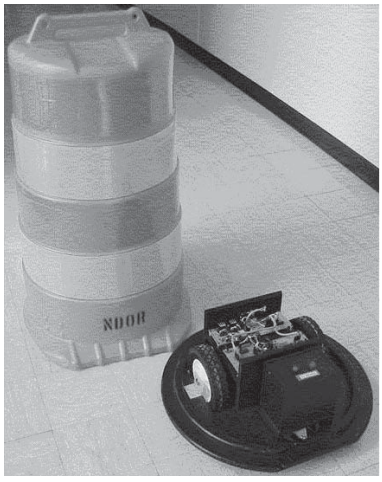


Figure 1

A Robotic Highway Safety Marker

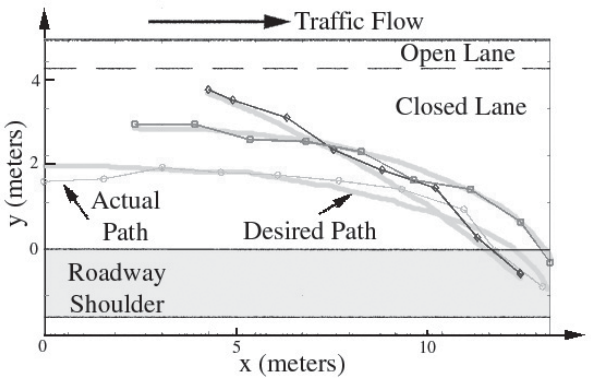


Figure 2

Desired and actual paths during field test

LIQUEFACTION MITIGATION USING VERTICAL DRAINAGE: FULL-SCALE TESTING

NCHRP-IDEA Project 94

Kyle M. Rollins [Tel: (801) 422-6334; Fax: (801) 422-0159, e-mail: rollinsk@byu.edu],
Civil & Environmental Engineering Dept., Brigham Young University, Provo, UT 84602

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% and produced volumetric strains of 2.5%. 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% of volume were produced for small charge masses and relative density was typically increased by 7-10%. 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% 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.

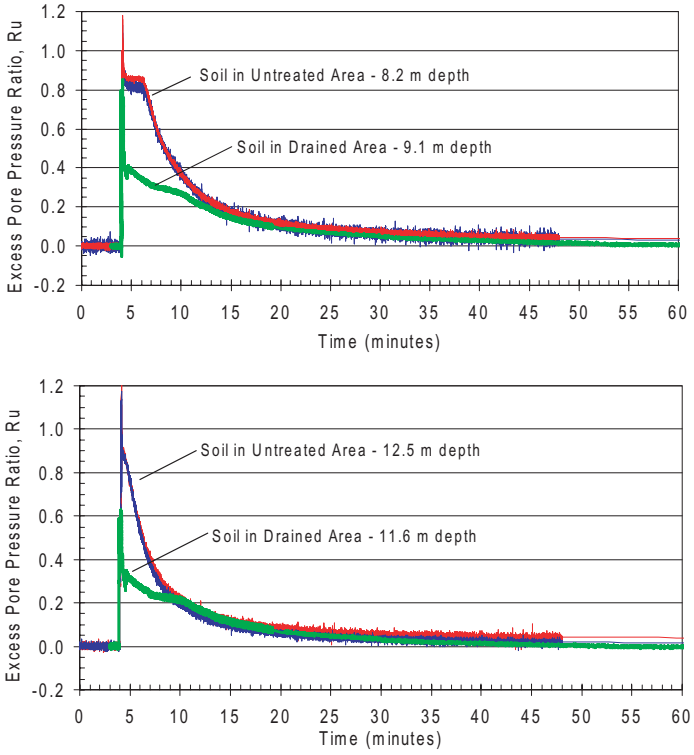


Figure 1

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

CONCRETE ROAD RECYCLER - HAMMER - ANVIL TEST

NCHRP-IDEA Project 95

Deems Pfaff [Phone: 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 6 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% 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 will continue with a goal to produce the final mobile version of the road-recycling machine.

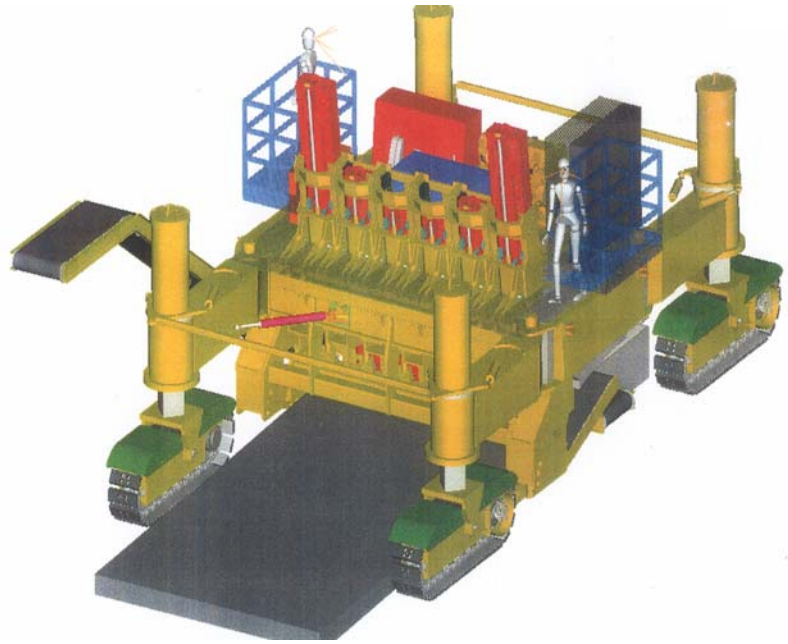


Figure 1

USING ULTRASOUND OF MHZ FREQUENCY FOR TESTING CONCRETE

NCHRP-IDEA Project 96

Sandor Popovics, PhD., P.E. [Tel: (610) 623-0116 and (215) 895-2345, E-mail: 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 researchers are in contact with Pennsylvania and Delaware DOTs and will work with these and other highway agencies for field testing and implementation. The researchers are also working with the American Concrete Institute's Committee 228 on Nondestructive Testing of Concrete to publicize their innovation.

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all NCHRP-IDEA projects that were completed or active during the 2004 program year.

DEVELOPMENT OF A GENERIC CONNECTOR SYSTEM FOR ATTACHING CONVENTIONAL BRIDGE RAILS TO FRP COMPOSITE BRIDGE DECKS

NCHRP-IDEA Project 80

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

IDEA Concept and Product

This NCHRP Project has 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 fiber reinforced polymer (FRP) composite bridge decks and superstructures.

Current federal standards require that railing systems for rehabilitated bridges must: 1) be crash tested or 2) make small changes in designs that do not materially change a crash tested system if it passes the specified test level (TL-2) static tests. Prior to this project no bridge railing system had qualified under these two criteria and none were available. Therefore the use of FRP composite bridge decks for the rehabilitation of bridges has been limited to bridges on which the bridge rail can be connected to the supporting beams of the structure. The number of bridges that cannot currently be fitted with FRP composite decks because a tested railing system has not been available is estimated to be at least 50,000. Therefore the need for a generic bridge rail system of both steel post and concrete barrier designs for generic FRP composite bridge decks and superstructures is a critical requirement for expanding the use of rapid installation composite decks and superstructures.

Planned Investigation

Since both steel post and concrete barrier railings have been crash tested, the strategy for this investigation utilized existing railing units and focused only on the development of an attachment system that does not compromise the strength of existing rails but focuses specifically on the direct connection of the railing to the deck.

The initial research consisted of a simple analysis of the loads that are imposed on an FRP deck by existing railings at the time the railings fail. Thus if the tested rails fail without damage to the FRP composite deck the probability is that the full railing system will successfully pass a crash test. The stresses arising in the FRP deck could be absorbed using a top and bottom steel plate system that spreads the impact load over a sufficiently large area of the composite deck. The area of the plates and the size and number of bolts was determined to be small enough so that two plate clamping systems on the composite deck appeared to be feasible. Also the use of concrete barriers appeared to be feasible if six connection bolts were used in place of the standard four.

Subsequently the plate/bolt connector design has been subjected to (TL-2) static testing and passed successfully. For the steel post railing, crash testing is not necessary since the railing system has not been materially altered. The plate connector design is now available for use on

FRP decks.

In the case of concrete barriers, the use of steel plates under the FRP decks has been statically tested to the TL-2 level. However, since no suitable crash test is available, it will be necessary to crash test the FRP deck connector system. As a compromise, a bogie test may be acceptable. This decision has not been made yet. In either the full-scale crash test or the bogie crash test there is a high probability that the connector system for concrete barrier bridge rails will successfully pass either mandatory crash test.

All testing is currently being performed at the Midwest Roadside Safety Facility by the Civil Engineering Department, University of Nebraska at Lincoln. A steel framework has been designed by BG Consultants of Manhattan, Kansas. This FRP panel support system is of a general utility and will be available for all FRP manufacturers to use to test their panels. The diaphragms will need to be modified to accommodate various steel support beam spacings.

Product Payoff Potential

It is estimated that the development of the two bridge rail systems will double the use of FRP composite decks for both new and rehabilitated bridge decks. Given the lightweight and rapid installation features of FRP decks, this will allow them to be replaced overnight on a lane-by-lane and section-by-section basis and will allow multi-lane commuter highways to maintain traffic. This procedure will provide greater flexibility in rebuilding failing bridges and greatly reduce commuter delay and frustration. KSCI has in the last few months actually demonstrated successfully the lane-by-lane closure feature, while the section-by-section feature is considered the easier requirement to meet for both FRP bridge decks and self-supporting superstructures.

This payoff feature is hard to give an exact value to but is very important.

Product Transfer

A cooperative effort will be carried out between KSCI and the Market Development Alliance of the FRP Composite Industry to make these designs for the connectors easily and directly available to fabricators of railings and contractors.

Two bridges with FRP superstructures in Missouri and New York have been built and have successfully passed the required TL-2 static test. The Missouri bridge has been installed, and the New York bridge was installed in June 2003.

Two bridge decks to be used on detour bridges with FRP composite decks are being fabricated now and will be installed in Kansas during the spring of 2004.

Thirteen FRP panels that represent a typical single lane bridge deck design, i.e., 8 inches thick and 8 feet wide by 14.5 feet long (100 feet total length), have been fabricated for test purposes. Future FRP panel testing by other firms will require that they fabricate only three or four panels for either bogie or full-scale crash testing, since KSCI will make the remaining panels available. This will make bridge rail testing by other firms significantly more economical.

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

NCHRP-IDEA Project 89

Andrzej S. Nowak [Tel: (734) 764-9299, Fax: (734) 764-4292, e-mail: nowak@umich.edu]
University of Michigan, Ann Arbor, MichiganIDEA Concept and Product

IDEA Concept and Product

Self-consolidating concrete (SCC) was first developed in Japan in 1988 and it has been successfully applied to many structures in Japan and Europe. SCC combines a high flowability with a high segregation resistance, which results in the self-compactability without any consolidation work even when the reinforcement is very congested. The features of this new material allow for the durability assurance of concrete structures independently from the skill of the laborers. Furthermore, self-consolidating concrete has the possibility to reduce the construction cost, to reduce the number of actions at the site, to shorten the construction period and to improve the working conditions. SCC has self-compactability and can be placed in every corner of the formwork without segregating because of vibration. This material is recommended for use on the construction site for structural elements with high percentage of reinforcement and for retrofitting projects, especially in closed forms with narrow openings to pour concrete. In precast product plants as well, SCC is highly effective in reducing noise, as it requires no vibration. Elements constructed with self-compacted concrete have a very clear, smooth surface without bubbles, spallings, or other imperfections, which also improves durability and slows down the degradation process. Development of self-compacting concrete is a very desirable achievement in the construction industry for overcoming problems associated with cast-in-place concrete. SCC is not affected by the skill of workers, and shape and amount of reinforcing bar arrangement of a structure. Due to high-fluidity and resisting power of segregation of SCC, it can be pumped longer distances.

Project Investigation

The objective of the project is to develop a guide specific to the Midwestern United States for design and use of self-consolidating concrete for bridges. The procedures are based on the technology currently used in Europe and Japan. The research work involves the development of mixing requirements and specification of the components. The properties of the mix and hardened concrete are tested at the University of Michigan laboratory. The SCC mix is developed using US/Midwest ingredients (cement, aggregates, water) and specific admixtures and plasticizers available on the US market. The fresh concrete mix is tested to establish required deformability, flow, and segregation resistance properties (Fig. 1). The hardened concrete is tested to find all mechanical properties required by US standards in general, and in particular those specific for bridge construction. The research program involves review of the available documentation and experience gained by European and Japanese researchers and construction companies. The work is done in cooperation with Premarc, Grand River Infrastructure, Inc., a concrete supply company located in Grand Rapids, Michigan, which offered to provide the ingredients for mixing samples and to share their expertise. The developed US/Midwest self-consolidating concrete will be applied in a demonstration project, selected by the Michigan Department of Transportation, in cooperation with the Michigan Roads Builders Association. A possible trial application can be a retaining wall or pier cap beam. The cost of construction and materials in the demonstration project is not included in this project budget.

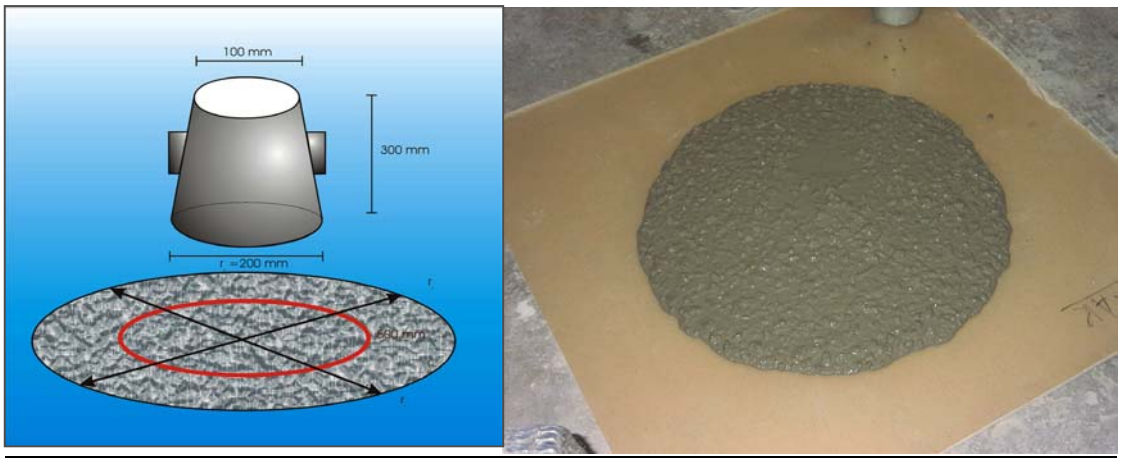


Figure 1

Slump Flow Test, Typical Range of Diameters for SCC is 26-32 inches and the time to reach 20 inches is 2-5 seconds

Product Pay-Off Potential

The proposed research will be directly applicable in bridge engineering practice. The final report will include the self-consolidating concrete mix design guide, with a step-by-step description of mix preparation and recommendations for use on bridges. The design guide will cover preparation of the SCC using local materials such as cement powder, aggregate, water, and special admixtures, which are available in the US. The usage of SCC will shorten construction time, simplify construction procedures (self-consolidating concrete does not require any vibration), and provide a better quality material for bridges. The final product, SCC, is dense, durable, better compacted compared with ordinary concrete, with a smaller amount of air voids and imperfections, a smooth and finished surface, and there is no problem with segregation that can occur during vibration of a regular concrete. Therefore, SCC is a preferable material for construction of bridges. A better performance can be expected under cyclic loading because fatigue changes in concrete start with air voids, imperfections, and micro-cracks caused by segregation and shrinkage. The ability of SCC to perfectly fulfill the mould makes it especially useful for on-site repairs of concrete bridge elements.

Product Transfer

The results of this project will be presented at TRB meetings and conferences, ASCE conferences and ACI Conventions. Application of the developed mixture recommendations for a Michigan DOT (MDOT) project is also being considered.

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, 30332-0355

IDEA Concept and Product

The proposed research will develop seismic restraining devices made of shape memory alloys (SMA) that can be used for seismic retrofit of bridges. By placing the SMA restrainers in controlled locations in a bridge, these devices can be used to reduce the relative hinge opening and the demand on individual frames in a multiple-frame bridge, thereby enhancing the performance of these structures. A prototypical SMA-based restraining device will be developed and tested. Analytical models will be developed to determine the effect of these devices in typical bridges.

Planned Investigation

The goal of this study is to develop and validate the use of SMA restraining devices for seismic retrofit of bridges. Recent earthquakes have shown that conventional hinge restrainers used in the United States and Japan do not provide adequate protection from unseating, which can lead to collapse of bridges. Shape-memory alloys are a class of alloys that display several unique characteristics, including Young's modulus-temperature relations, shape memory effects, and high damping characteristics. In most current applications, the temperature-

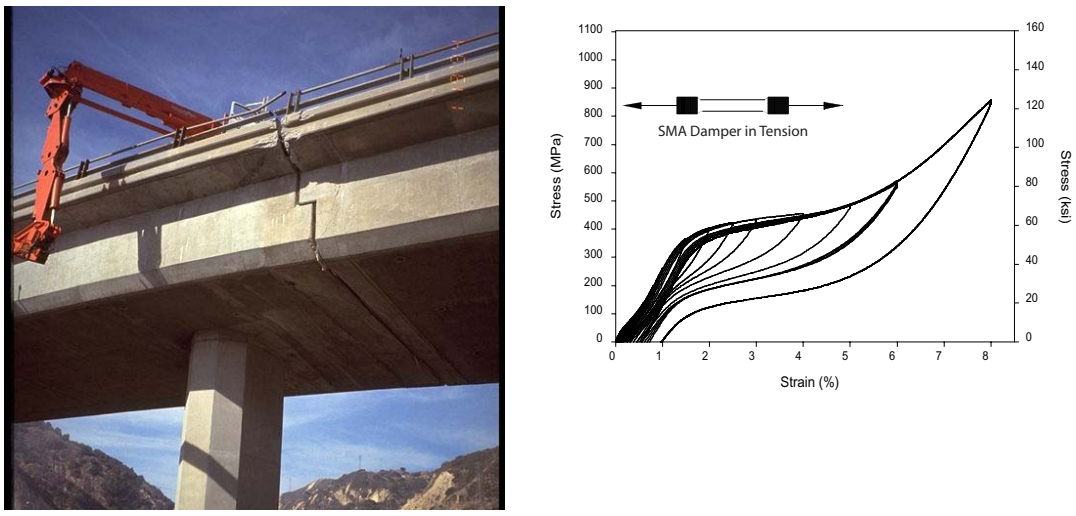


Figure 1

(left) Typical multiple-frame bridge damaged during the 1994 Northridge Earthquake, (right) Preliminary test results of a SMA restrainer that would be used at intermediate hinges.

induced phase change characteristic of shape-memory alloys is used. For some SMA, such as Nitinol, the phase change can be stress induced at room temperature if the alloy has the appropriate formulation and treatment. The planned investigation has three stages. Stage 1 will evaluate the cyclical properties of shape memory alloys, focusing on the effects of strain rate, loading history, and composition. Stage 2 will focus on optimizing the performance of SMAs via thermo-mechanical processing. Stage 3 will develop and test an SMA-based restraining device. The device will either be wire-based or will use SMAs in the form of a bar. The validation of the device will be performed using a shake table and two large masses representing bridge spans, as shown in Figure 2.

Product Payoff Potential

There are thousands of bridges in the United States that are in need of seismic retrofit. The state of California alone has spent nearly a billion dollars in seismic retrofit since the 1989 Loma Prieta earthquake. Many other state DOTs are now beginning to initiate similar retrofit programs, including New York, Tennessee, Illinois, and South Carolina. Should this technology prove effective, it can become a widely used seismic retrofit technology.

Figure 2

Test setup to be used to evaluate the effectiveness of SMA restrainers in multiple-frame bridge.

Product Transfer

Once the technology has been proven effective in reduced-scale experimental tests and shake table tests, the products will be developed and tested in full-scale. Representatives from the FHWA and various DOTs will be provided with the test results and will be invited to participate in future full-scale tests. Collaboration with SMA manufacturers and end-users is essential to ensure application of the research.

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, LA 70803

IDEA Concept and Product

There are over 20 major cable-stayed bridges in the U.S. and about 600 worldwide. Under certain combinations of light rain and moderate wind speeds (10 to 15 m/s), incidences of large-amplitude vibrations (on the order of 1 to 2m) of stay cables have been reported worldwide. It has been found that the rain-wind cable vibrations are often related to higher mode vibrations instead of the fundamental mode, implying that the tuned mass damper (TMD) designed for the first mode vibration is most likely not effective for higher mode vibrations. Traditional mechanical dampers are usually installed at the cable ends, which is not optimal for damping efficiency.

The objective of this study is to develop a TMD that will adapt itself to deal with different cable vibrations, whether first mode or higher (Fig. 1). The adaptive TMD will be designed by using controllable magnetorheological (MR) fluids that are the magnetic analogs of electrorheological (ER) fluids. The study is divided into three phases.

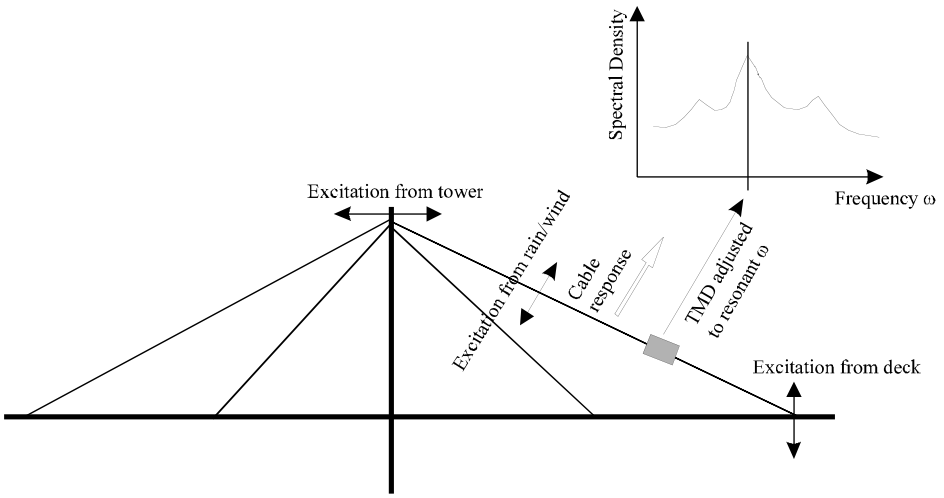


Figure 1

Sketch of cable vibration control

Investigation Plan

In Phase 1, the information necessary for designing the TMD was collected and the performance of MR damper was studied. The relationship between the cable parameters and TMD parameters was established. This work has laid a foundation for Phase 2 study.

The Phase 2 study mainly focused on developing the MR-TMD system. The performance of the MR-TMD was investigated. After the Phase 2 study the control strategy has been established, that is, how to adjust the current strength for the MR-TMD system to respond the vibrations.

In Phase 3, the developed MR-TMD system will be tested. The design will be refined according to the observed performance. Recommendations will be made and conclusions drawn.

Phase 1 and Phase 2 have been completed and Phase 3 is ongoing. The measured performance of the damper is shown in figures 2 and 3.

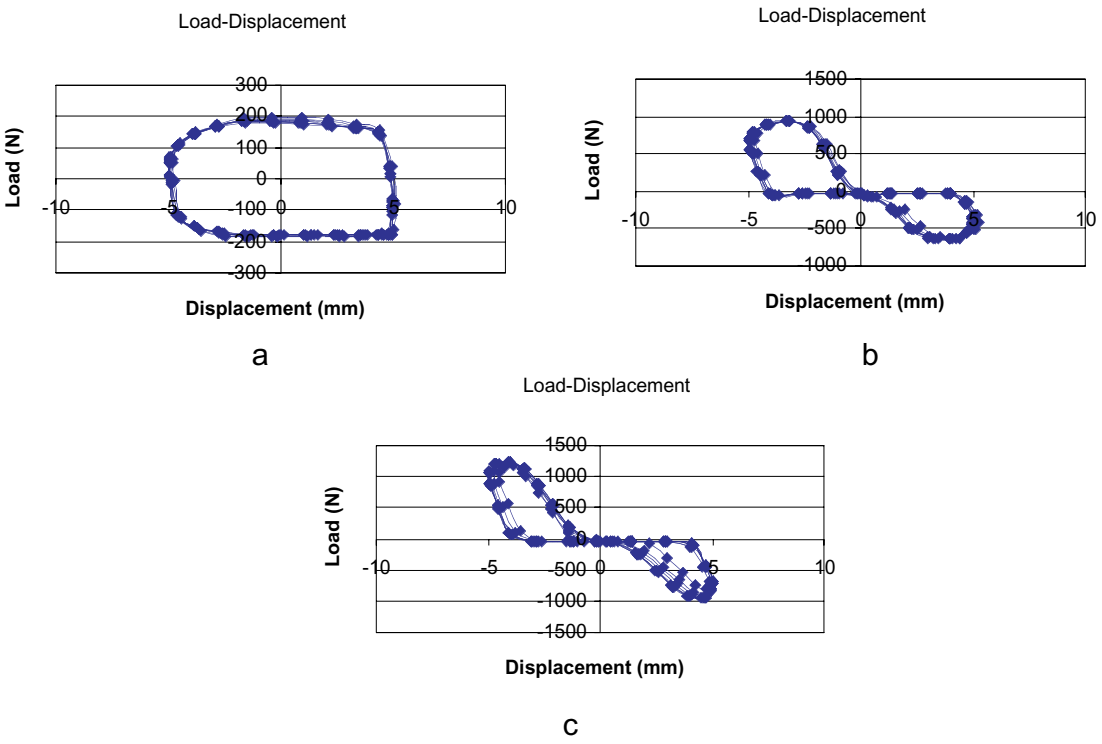


Figure 2

Load-Displacement Curve at T= 250 ms, S= 5 mm: a. 0 amp; b. 0.5 amps; c. 1 amps

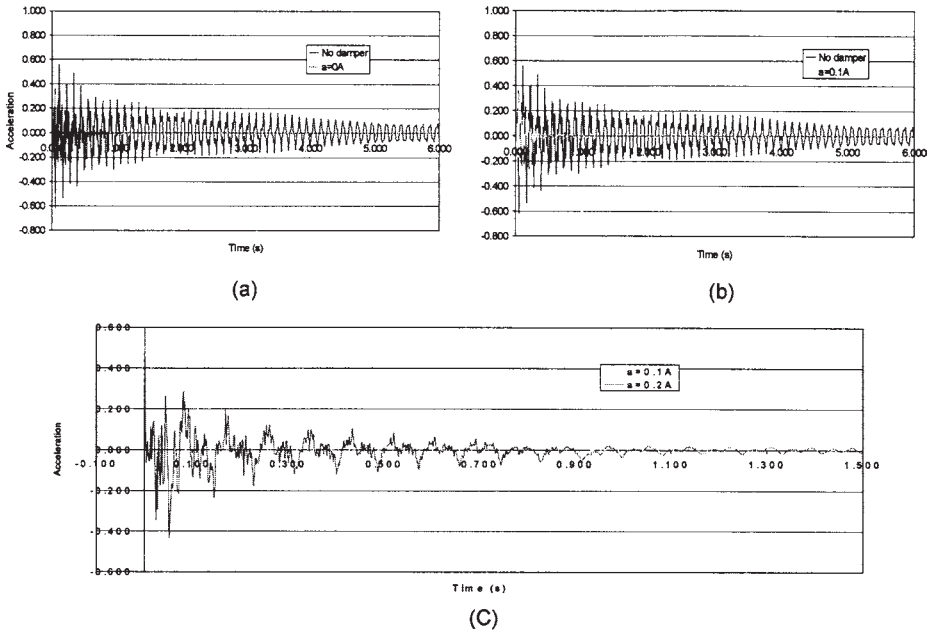


Figure 3

Acceleration Response of Cable with MR Damper

ADVANCED RELOCATABLE TRAFFIC SENSOR SYSTEM (ARTS)

NCHRP-IDEA Project 93

Eddie Neal [Tel: 703 276 3377 / Fax: 703 276 0996]
The Scientex Corporation, Alexandria, VA

IDEA Concept and Product

Advanced Relocatable Traffic Sensors (ARTS) refers to the traffic sensor system consisting of Doppler microwave system, angle sensors, and GPS, integrated to communicate within a local area network (LAN), attached to a Traffic Management Centers (TMC). Power management is based on solar power and re-chargeable lithium ion batteries. Initially it was proposed that the ARTS technology would use advanced wireless radio modems to communicate with the LAN. However, to make the ARTS truly "place and forget" in real-time, alternate communication technologies were explored and satellite communication was optimum for the ARTS application. The scope of this project was extended to replace radio communications with satellite communications to make ARTS more versatile and practical. Second quarter work identified, tested, and adapted satellite communications, which forms the vital link and the backbone of the ARTS sensor.

The core technologies proposed for the sensor system now include low-power microwave technology for radars, advanced satellite communications system, advanced battery management, GPS, and angle sensors. Power management and battery selection had to be re-visited to factor the power requirements for the satellite communication system.

Scientex negotiated a contract with TMI Communications and EMS to provide hardware, software, and communications testing. Based on the positive pilot test results, satellite communications was made an integral part of ARTS.

Investigation

The objective of the test was to establish feasibility and suitability of satellite communications to the ARTS application; adapt satellite communications to the ARTS effort and, if feasible, establish communication between the base station and the Data Terminal Equipment (DTE), consisting of PDT-100 satellite modems, Doppler sensors and CPU, via TMI's MSAT satellite communication network.

The test set-up and the communication channels are shown in the figure below. The DTE was set-up on the roof of a building and the base station was set-up at the Scientex office. Initially the DTE was connected to a laptop computer and the communication protocols were configured. Test messages were used to check response times and data integrity. Changes and improvisations were made in the software to improve performance and assist trouble-shooting.

In the second stage of testing, a Doppler sensor and tuning forks were used that simulated vehicle speeds of 55 MPH and 70 MPH as a part of a pilot run that was carried out to establish feasibility, suitability and adaptability of satellite communications to the ARTS application.

Schematic of the set-up and communications:

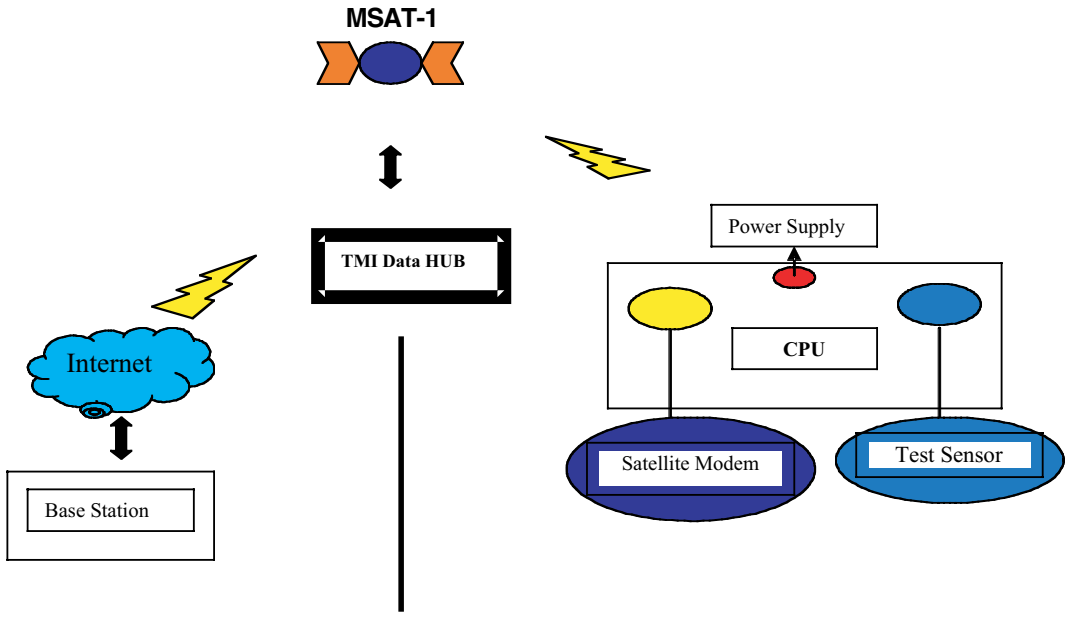


Figure 1

Schematic of the set-up and communications

The data so collected was received at the base station correctly within 5 seconds. This simulated test proved successful.

Initially, the power system for the ARTS project was based on lithium ion batteries, because they could be charged numerous times without reaching lower thresholds (at every charge as in the conventional batteries), and have relatively high energy density and compact size. Further, these batteries were to be slowly charged using solar power, when in use or on standby. However, research and exchange of information with leading lithium ion battery manufacturers for the present application revealed that these batteries do not charge well with solar power and the technology is yet to be made affordable.

In the light of this discovery and keeping the power demand of the ARTS sensor system in view, including the PDT-100 satellite modem, alternate battery sources are being explored. Though small power systems are available using Ni-Cd or Ni-Metal hydride batteries, higher capacity systems are not commercially available. Customization of such a system is found to be relatively expensive making it difficult to accommodate within the reduced budget of the present project.

Deep cycle battery technology has been around for many years now and it is now possible to find a reasonably compact, high energy density safe battery that can run for many years with no maintenance. Such a solution is being pursued.

The selection of solar power system is crucial and will dictate effectiveness of the ARTS system. Research on various commercial off-the-shelf solar panels and charge controllers was carried out and an economical option was found. These solar panels have been selected based on power requirements and the continued operation of the sensor system under adverse weather conditions. Commercial solar panels from two manufacturers have been identified and specifications finalized. Efforts are underway to develop a complete self-contained solar power system package that would simply latch on to the main sensor system. This would make ARTS easy to handle, transport, and install with the two components separated.

The output from K-band transceivers of the micro wave sensors is in the form of intermediate frequencies (IF), which need to be converted to voltage and then to data bytes as input to the software. This requires development of a circuit or drivers and related software and hardware are needed to accomplish this task.

A small electronic circuit must be designed to convert the IF analog output to digital and apply algorithms to read out the digital output in terms of speed. Analog-to-digital converter chips that meet the requirements of the microwave radar are available in the market. This small piece of circuitry with the relevant algorithms forms the driver for the microwave sensor. It is proposed to find a suitable single board computer that has additional features of analog-to-digital converters. Research has come up with options such as the PC-104 from Win-systems and the PC-520 AD from Octagon systems.

The remaining tasks to conclude development of the complete ARTS system entail:

1. Design and develop the interface board (PCB) that will supply power to the various ARTS components and handle logic control between these system components.

2. Fabrication of the solar power system.

3. Integrate all components with the interface board and develop interface between the power system and the sensor system, which are now envisaged to be separated to facilitate easy handling and transportation.

Potential Impact and Payoff

There is an urgent need for effective work zone safety and traffic management systems because of high accident rates and fatalities near work zones and major traffic incidents. Several ITS work-zone systems are currently deployed and such systems are envisioned in the National ITS architecture.

The effectiveness of ITS systems depends on the quality of traffic data available from the sensors used, which in turn depends on sensor placement, alignment and calibration, operability, number of sensors used, and the different traffic parameters measured by the sensors. The components of ITS systems most affected by the operating work zone conditions are the sensor systems, It is therefore crucial for work zone and incident management ITS sensors to be designed for operating under such real world conditions. While several non-intrusive sensors are currently available in the market, these are difficult to use in a work zone or incident management application since they are not designed for such portable use and do not utilize a high level of sensor integration.

The impact and pay-off for practice of the ARTS will be that it:

- Offers a practical solution to a real-world problem
- Improves safety by improving effectiveness of work zone and incident management ITS systems
- Improves sensor accuracy and provides the means to increase the number of sensors near work zones
- Is low risk as the core technologies required have been proven in other fields.

FIBER-REINFORCED PLASTICS FOR SEISMIC BRIDGE RESTRAINERS

NCHRP-IDEA Project 97

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

Idea Concept And Product

Successful development and testing of fiber-reinforced polymer (FRP) bridge restrainers led the authors to conclude that FRP restrainers are feasible. Further research and development will be required before design tools are developed and before restrainers are recommended for application in bridges.

This project consisted of four-parts; material tests, FRP/concrete bond tests, shake table tests, and development of a tentative design procedure. The material tests and bond tests resulted in the discovery that unlike homogeneous materials such as steel or concrete, there is no apparent strain rate effect on composite lamina. There is, however, an increase of strength with increase of strain rate on the bond between concrete and FRP. Concrete strength is directly related to bond strength and the strain rate effect seen in FRP/concrete interfacial bond is a consequence of this. An FRP restrainer design methodology was developed from both experimental data and existing literature on effective bond length. Three types of restrainers were developed, one with glass fibers (GFRP), one with carbon fibers (CFRP) and the third with combined carbon and glass fibers (CGFRP). The performance of the resulting GFRP, CFRP and CGFRP bridge restrainers was superior to both conventional steel restrainers and was comparable to shape memory alloy restrainers in reducing relative hinge displacement. Currently existing design methods are being reviewed for possible adoption in FRP restrainer design.

Planned Investigation

Initially the performance of FRP fabrics and their bond to concrete under dynamic tensile loading was studied and the most appropriate bond transfer length was identified. The effectiveness of FRP restrainers and the influence of different parameters were studied using a full-scale model of an in-span hinge (Fig. 1). The hinge model was tested with different FRP restrainers until failure of the restrainers or of the bond. Artificial earthquakes replicating response spectra for soft soil was simulated on a shake table. The intensity of motion was increased in successive runs until failure. From past research on the same test setup, data are available for the seismic performance of steel and shape memory alloy (SMA) restrainers. Hence, it was possible to compare the response of conventional restrainers with the performance of FRP restrainers as well as innovative restrainers such as SMA systems. Based on the measured data and the performance of FRP restrainers, the initial design assumptions will be evaluated and preliminary design guidelines will be developed. Illustrative examples will be prepared to assist engineers in applying the proposed design method. Figure 2 shows the effectiveness of GFRP restrainers in reducing the relative hinge movement.

Figure 1

Full-scale model of in-span hinge

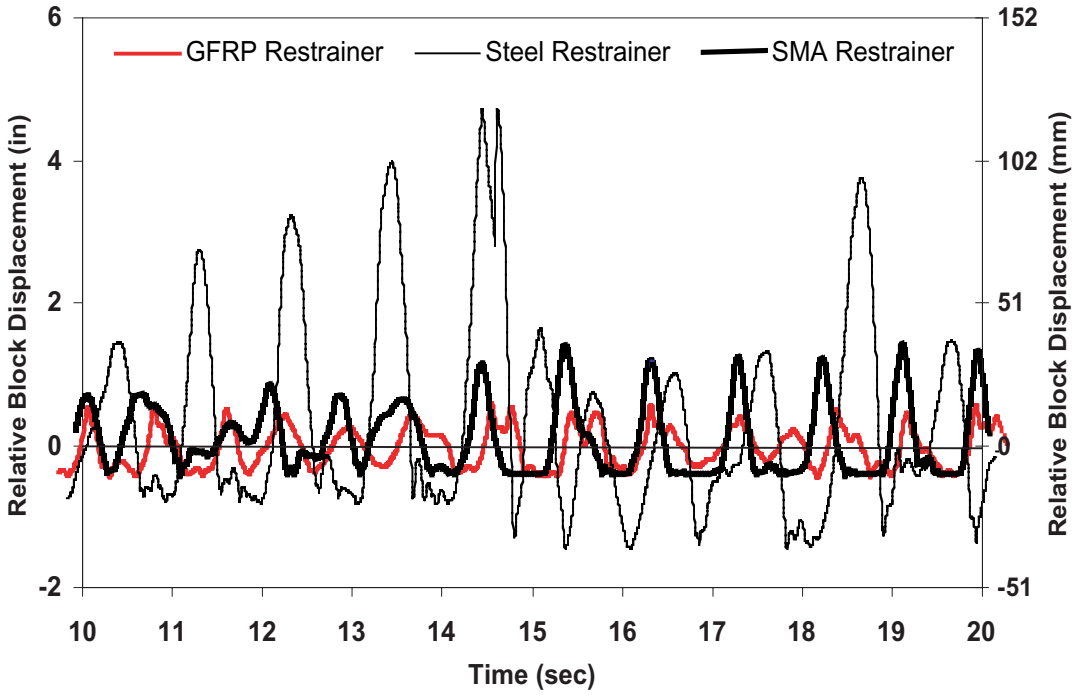


Figure 2

Relative hinge movement for different restrainers

Product Pay-off Potential

The objective of developing and using FRP restrainers in bridge hinges is to attempt a durable, lightweight material that is easy to install, with the ultimate goal being to facilitate the installation of restrainers. Unlike conventional restrainers, FRP fabrics do not require drilling and mechanical anchorage systems. Because they are exposed, FRP restrainers will be easy to inspect and replace following an earthquake. Although the use of FRP restrainers will be limited to hinges and simple supports, the substantial saving they could potentially offer in the cost of labor, ease of installation, and speed of retrofit would make them worthwhile.

Product Transfer

The development and application of FRP restrainers has not been attempted before. However, FRP fabrics have been successfully used in seismic retrofit of bridge columns, suggesting that they could potentially be used as restrainers in bridge hinges, pending appropriate research, development, proof testing, and design guideline development. The proposed study will explore the potential application of FRP fabrics as bridge restrainers in a systematic though limited way. The scope, level of funding, and the time frame for a Type 1 IDEA project would not allow for the development of comprehensive design guidelines. However, preliminary guidelines encompassing the scope of the variables included in the research will be developed. An advisory panel consisting of bridge engineers from different state transportation agencies has been already formed. Suppliers of FRP fabric products will be contacted to provide input in better utilization of FRP restrainers. The research results will be communicated to technical committees of various organizations, FHWA, and state DOTs to maximize the potential use of the proposed restrainer system.

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

NCHRP-IDEA Project 98

Robert Hunsperger [Tel: (302)-831-8031; e-mail: robert_hunsperger@usa.net or hunsperg@eecis.udel.edu],
Michael Chajes [Tel: (302)-831-2442; e-mail: chajes@ce.udel.edu],
University of Delaware, Newark, DE

IDEA Concept and Product

Both the US and the UK have significant concerns regarding the condition of post-tensioned segmental concrete bridges. The problem is that it is difficult to ensure proper grouting of post-tensioning tendons. When post-tensioned ducts are not completely grouted, and voids are present, the steel tendons are left vulnerable to premature corrosion.

The goal of this project is to develop an effective and economic nondestructive evaluation (NDE) procedure that will allow bridge owners to ensure that post-tensioned ducts are properly grouted (i.e., have no voids). The proposed NDE procedure will utilize Time Domain Reflectometry (TDR), a technique developed years ago by electrical engineers. TDR was originally developed to detect discontinuities in transmission lines. The technique involves sending a signal through a transmission line using a pulse generator, seeing whether or not the signal is reflected back using an oscilloscope, and, if it is reflected back, using the time elapsed to determine the location of the discontinuity. The necessary measurement apparatus is shown in Figure 1.

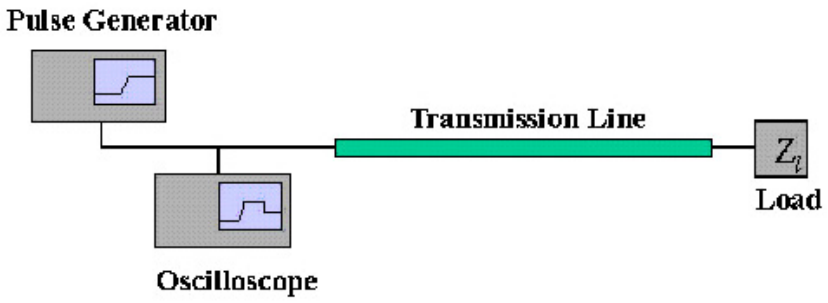


Figure 1

Time Domain Reflectometry measurement apparatus

To detect and evaluate voids, the transmission line is placed either in or adjacent to the region in which a void is suspected. The presence of a void affects the electric field surrounding the transmission line and causes a reflection. Investigators previously used TDR to locate and evaluate corrosion sites on concrete-encased steel strands by observing reflections of the pulse from damage sites (see *ASCE Journal of Materials in Civil Engineering* Vol. 14, Issue 3 (2001) pp. 217-223). In that case, the strand was used as one wire of the transmission line and a parallel sensor wire was added as the other. The corrosion represented a partial discontinuity in the line. In the case of a void, the discontinuity is in the material surrounding the transmission line. Such a change will also cause a reflection of the signal. In fact, preliminary studies indicate that the reflection due to a void is far stronger than that due to corrosion damage.

Planned Investigation

The investigation will try to determine if TDR can be used to effectively identify voids in grouted post-tensioning ducts. It will examine how various parameters affect the performance of the method. These parameters include the size and number of voids, the location of the void relative to the transmission line (a wire pair placed in the grouted duct or adjacent to it), the contents of the void (i.e., air or bleed water), and the state of the grout (i.e., uncured vs. cured). And it will consider how the methodology can be implemented successfully and economically in the field.

Using TDR, the investigators conducted a series of preliminary experiments on void detection under various environmental conditions and found that TDR appears to be well-suited for detecting voids as well as corrosion. It appears that further research and calibration will allow both the relative size and the position of the voids to be determined. When TDR is applied to detect both voids and corrosion, the steel strand must be one wire of a two-wire transmission line, and a sensor wire must be applied along the steel strand as the second wire of the transmission line. However, if only void detection is desired and corrosion is not to be evaluated, another kind of two-wire transmission line can be used instead of a steel strand and a sensor wire. Any two-wire, open transmission line can serve as the sensor. Thus relatively inexpensive lines can be used, such as 300 ohm "television twin-lead", or even two-wire lamp cord. In all cases, the two-wire transmission line can be modeled using distributed parameters to describe the behavior of electromagnetic fields propagating along it. Figure 2 shows the reflected signal returned from a 2-inch void.

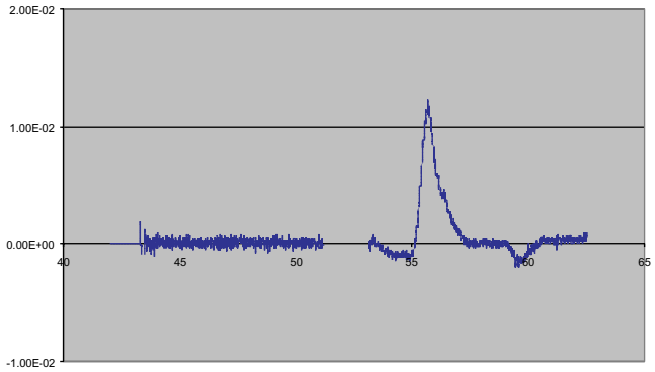


Figure 2

TDR differential signal from TV-cable passing through a void

The plot shows the differential reflected signal from a transmission line sensor (300 ohm TV cable) that passes through a void in a grouted duct. The simulated void was created by inserting a 2-inch hollow ball into the duct before pouring the grout. The sharp peak shows the sensitivity of even inexpensive standard transmission lines in internal void detection, and the smooth base line indicates the low noise that occurs in differential measurements.

Stage 1 of the project will focus on detection of voids with the sensing transmission line located within the grouted duct. Stage 2 will expand the work to evaluate void detection with the transmission line located outside of the duct, thus permitting retrofitting of the sensor to existing ducts.

Product Payoff Potential

It is difficult to ensure proper grouting of post-tensioning tendons. When post-tensioned ducts are not completely grouted, and voids are present, the steel tendons are left vulnerable to premature corrosion. This very issue led to the declaration of a moratorium on the construction of post-tensioned bridges by the UK's Department of Transport in 1992. More recently, distress and failure of post-tensioning tendons due to improper grouting were found in Florida on the Mid-Bay Bridge. While it is well known that incomplete grouting of ducts (i.e., voids) can leave tendons vulnerable to corrosion, effective and economic methods for detecting voids in post-tensioning ducts do not exist. In order to ensure that new post-tensioned, segmental concrete bridges will not prematurely deteriorate, which could result in major economic losses as well as potentially threaten the safety of the traveling public, new NDE methods are needed to ensure proper grouting in new post-tensioned applications. The research done on this project seeks to develop such a method.

Product Transfer

The results of this project will be presented at TRB meetings and conferences and at ASCE conferences. Also, we have ongoing cooperative efforts with VETEK Systems Corporation, a commercial supplier of corrosion detection technology, and with the Delaware Department of Transportation (DELDOT). These interactions will facilitate implementation of TDR as a void detection tool for field application.

DEVELOPMENT OF ASPHALT BINDER CRACKING DEVICE

NCHRP-IDEA Project 99

Sang-Soo Kim, [Phone: 740-593-1463 Fax: 740-593-0625 Email: kim@ohio.edu]
Ohio University, Athens, Ohio

IDEA Concept and Product

To determine the cracking temperature of asphalt binders, the Asphalt Binder Cracking Device (ABCD) uses the dissimilar coefficients of thermal expansion/contraction (CTE) of asphalt binders and metals. As shown in Figure 1, an ABCD ring consists of a hollow cylindrical metal (invar) tube with a uniform thickness and an electrical strain gauge glued to the inside. A thermocouple may also be glued to the inside of the tube to closely monitor the specimen temperature. The asphalt binder is molded onto the outside of the ABCD ring as shown in Figure 2.

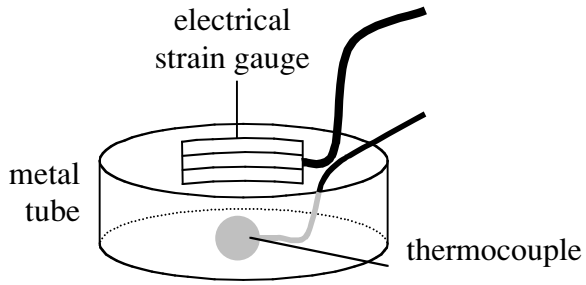


Figure 1

Asphalt Binder Cracking Device (ABCD) consists of 2 in. (O.D.) × ½ in. (H) hollow metal tube, electric strain gauge, and thermocouple mounted on the tube

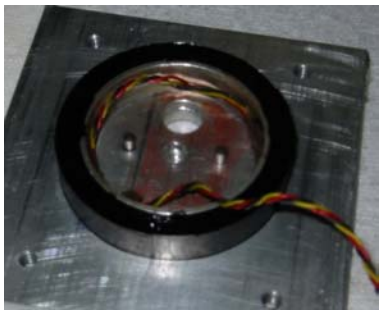


Figure 2

Asphalt binder molded onto an aluminum ring

Asphalt binders have much larger CTE than metals. As the temperature drops, the differential thermal contraction (more rapid contraction of an asphalt binder than that of metals) will cause thermal stress to develop and will eventually lead to thermal cracks. When the specimen cracks, the accumulated thermal stress is released and will be shown as a sudden drop in the strain measurement. Accordingly, the cracking temperature of the asphalt binder is directly determined as the temperature where the sudden drop of measured strain occurs. The strain of the ring measured by the electrical strain gauge can also be used to calculate the tensile strength of the asphalt binder at that temperature. Figure 3 illustrates typical ABCD test results obtained in this study.

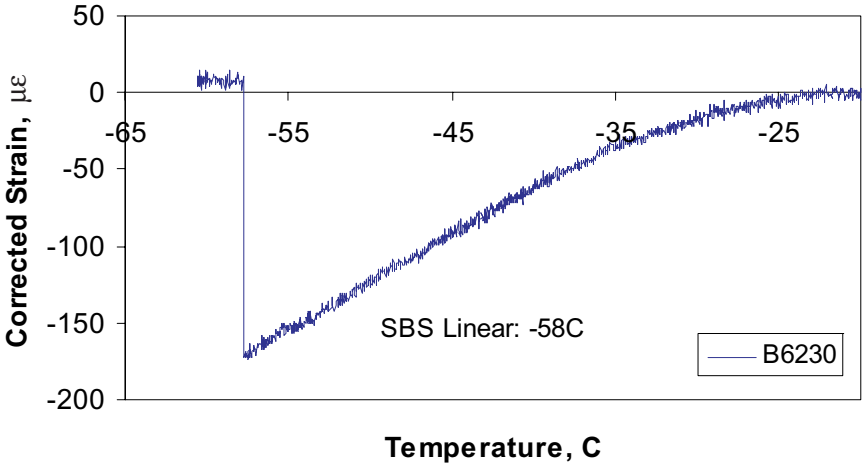


Figure 3

Example of ABCD test results of an asphalt binder (10°C/hour cooling rate; the sudden drop of strain represents cracking)

Project Results

The first generation ABCD test used aluminum molds to produce uniform round binder specimens. The results of tests performed on various modified and unmodified asphalt binder specimens showed relatively large test variability with about 5.0°C standard deviation. A second generation of ABCD is being built for repeatable cracking temperature and strength measurement. In the new ABCD test procedure, binder specimens are prepared with silicone molds and remain in the silicone mold until testing is completed, minimizing specimen disturbance from handling. Also 6.25 mm diameter holes are created at the middle of the specimen to induce stress concentration and consistent fracture. The repeatability of the ABCD tests performed on various asphalt binders is markedly improved with about 1.0°C standard deviation. Figure 4 shows the silicone mold and a cracked test specimen.

The cracking temperatures determined by ABCD were compared with other critical low temperatures using asphalt binders being studied by the Federal Highway Administration researchers (FHWA-RD-02-074 report). The binders included unmodified, air-blown and modified with linear styrene-butadiene-styrene (SBS), linear grafted SBS, radial grafted SBS, ethylene vinyl acetate (EVA), grafted EVA, ethylene styrene interpolymer (ESI), and chemically modified crumb rubber asphalt (CMCRA). FHWA researchers determined the critical

temperatures according to the current AASHTO specifications (M 320 and MP1a), the stiffness and m-value criteria determined from the bending beam rheometer (BBR). Asphalt mixtures were also prepared using diabase aggregate and the asphalt binders. The thermal cracking temperatures of the mixtures were determined by the Thermal Stress Restrained Specimen Test (TSRST, AASHTO TP10). Correlation coefficients (r) among the critical temperatures were determined as given in Table 1. Cracking temperature determined by TSRST was considered to be close representation of field conditions and used as basis of comparison. TSRST showed better correlation with ABCD (r = 0.91) than with MP1a (r = 0.69) or MP1 (r = 0.86). The correlation with MP1a was worse than with critical temperature based on BBR stiffness alone, indicating direct tension tester (DTT) strength data used in MP1a procedure caused the decline of strength of correlation. The critical temperature from MP1a procedure using ABCD determined strength data [MP1a (ABCD)], instead of DTT results, showed a much improved correlation with TSRST fracture temperature (r = 0.94). The ABCD cracking temperatures were highly correlated with MP1a(ABCD) with r = 0.98.

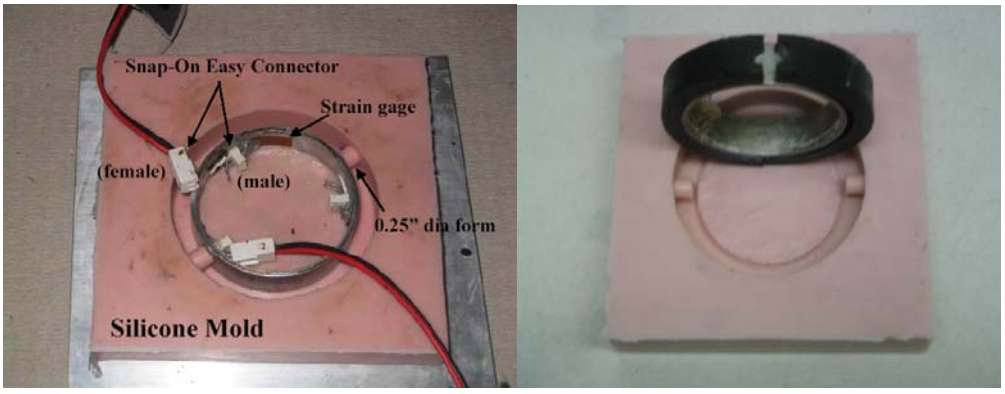


Figure 4

The silicone mold and snap-on easy connectors (left); An asphalt binder specimen tested and cracked (right).

Table 1

Correlation coefficients among critical temperatures (number of data =10)

	ABCD	MP1a (ABCD)*	MP1a	M320 (MP1)	S	m	TSRST
ABCD	1						
MP1a (ABCD)	0.98	1					
MP1a	0.71	0.72	1				
M320 (MP1)	0.83	0.85	0.90	1			
S (BBR)	0.87	0.86	0.91	0.92	1		
m-value (BBR)	0.69	0.69	0.82	0.92	0.78	1	
TSRST	0.91	0.94	0.69	0.86	0.84	0.73	1

*MP1a (ABCD): uses strength data from ABCD instead of DTT

Figure 5 shows the effects of polymer modification on the cracking temperatures and the fracture strength determined by ABCD. Except MRL 191 binder, all were prepared with the same base asphalt.

Product Pay-Off Potential

In the United States, several billion dollars are spent annually for asphalt pavement repairs and maintenance. Low temperature thermal cracking is a major reason for these repairs. The successful development of ABCD and its implementation into a standard specification will eliminate the premature failure of asphalt pavement due to low temperature thermal cracking, which is primarily an asphalt binder dependent problem. Ultimately, this will save valuable resources, reduce user delays due to repairs, and will help to maintain higher quality highway systems.

Product Transfer

The key deliverables of the project are development of more accurate and simpler test equipment and test procedures to determine the thermal cracking potential of asphalt binder. The progress of the project has been presented at several meetings and the results are summarized for a journal publication. Ohio Department of Transportation engineers are collecting typical asphalt binders used in the state to evaluate ABCD and to determine the possibility of ABCD adoption as its standard specification. After a successful completion of ABCD test validation, a pooled-fund study will be initiated.

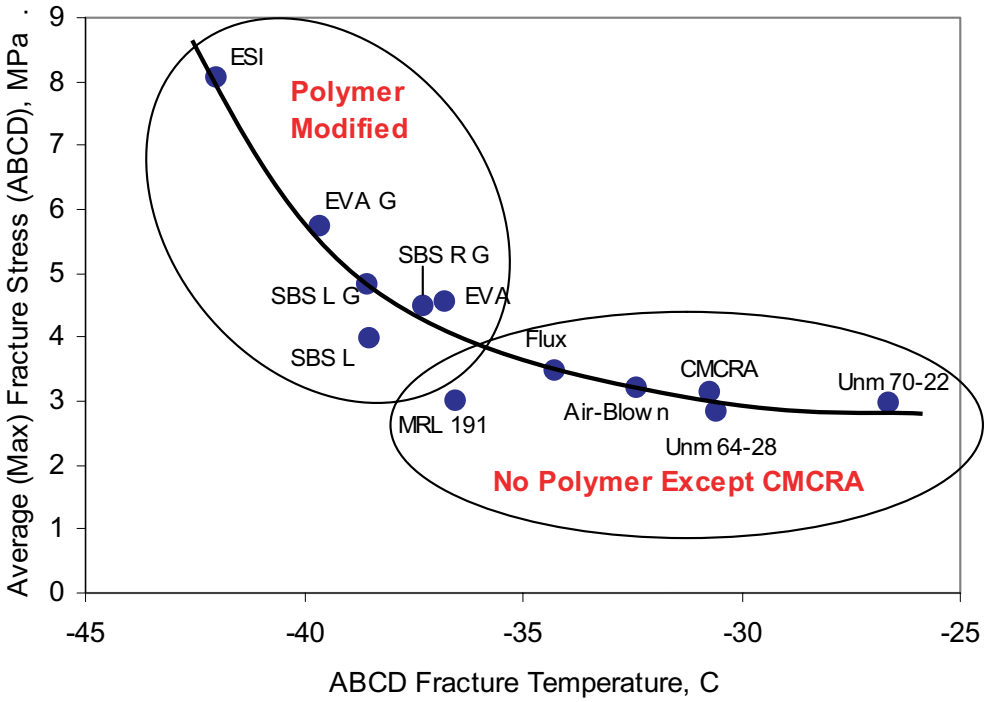


Figure 5

Fracture temperature versus fracture stress of FHWA binders determined by ABCD (silicone mold, invar ring, 10°/hr).

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

NCHRP-IDEA Project 100

W. Young and M. Funahashi,
Corrpro Companies, Inc., West Chester, PA
Tel: 610-344-7002, Fax: 610-344-7092, Email: wyoung@corrpro.com and mfunahashi@corrpro.com

IDEA Concept and Product

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 developed consists of 20 percent zinc, 0.2 percent indium with the balance aluminum. Indium is the key component, which 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 is to develop a galvanic anode mesh for bridge deck application. The concept was to develop an expanded mesh or perforated sheet meeting 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.

The sheet size is practical for transportation and field installation.

Planned Investigation and Results

Stage 1 of the investigation is to develop the anode mesh. An anode consisting of a perforated sheet is presently in the initial stages of production. Stage 2 is to install the anode on two bridge decks of 1,000 to 2,000 square feet surface area to evaluate the anode performance. A bridge in Missouri has been selected for the trial installation. Concrete test blocks have also been made to evaluate the various anode configurations being tested and to calculate anode consumption rate. The evaluation period for the bridges and test blocks is to be 12 months.

Product Pay-Off Potential

If this galvanic anode is successfully developed, a virtually maintenance free CP system for bridge decks will be developed. As a result, hundreds of millions of dollars could be saved on the repair of damage caused by corrosion of the nation's bridge decks.

Product Transfer

The implementation plans include (1) identification of the user community, (2) reports and technical papers encouraging and demonstrating the technical and cost benefits of this work, (3) effective report/paper distribution, and (4) working with the appropriate standards organizations to implement any changes to current methods.

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],
Infrasense, Inc., Arlington, Massachusetts

IDEA Concept and Product

This project developed a method for detecting delamination and deterioration in bridge decks based on the technique of active heating infrared thermography. The method involves briefly heating the deck with high-intensity pavement heaters, and then detecting the temperature differentials at delaminations using infrared thermography.

Project Results

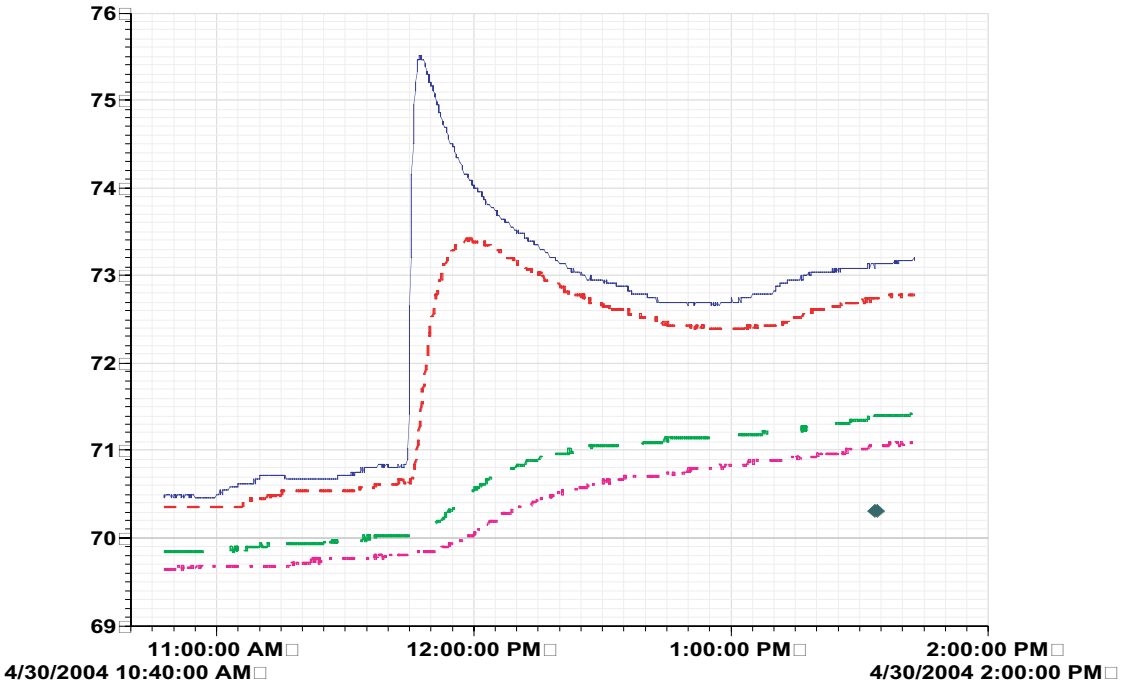
A review of infrared thermography was conducted with special reference to the nondestructive evaluation of civil structures. An evaluation of available equipment was carried out with reference to layout and configurations available for pavement heaters, the quantity of heat output, and the ability to control this output. Adaptation of standard pavement heaters was also considered. This was followed by analytical and laboratory studies. Analytical studies employed a thermal/mechanical model of the medium to evaluate its thermal and mechanical responses to proposed thermal inputs. The model incorporated geometric and material property variations to determine their effectiveness. The studies showed that detectable differentials can be produced using the output of a standard pavement heater with 5-10 seconds of heating application. The analytical studies were coordinated with laboratory studies. A 4 ft. by 8 ft by 7.25 in. thick laboratory test slab was built with simulated delaminations incorporated at different locations and depths. Ten-second heating tests were carried out on this slab using the same type of commercial heating equipment that would be used on a full-scale deck. The infrared data collected on the heated slab showed detectable temperature differentials at the delaminated locations proving the feasibility of using an active infrared system for bridge decks (Figure 1).

Product Payoff Potential

A cost analysis of the active infrared method based on a ten-second heating requirement shows that for a standard overpass bridge, the active 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 of 180 ft in length and a surface area of about 8600 sq. ft., the chain-drag method cost over $7200 and required 42 hours of field technician's time and 21 hours of lane closure, while active infrared heating cost about $3600 and required only 4 hours of the field technician time and 2 hours of moving lane closure.

Product Transfer

Extensive field testing and demonstration in collaboration with state highway agencies will be carried out to show the benefits of the technology in terms of savings in cost and time and improving highway worker safety and providing accurate and reliable results.



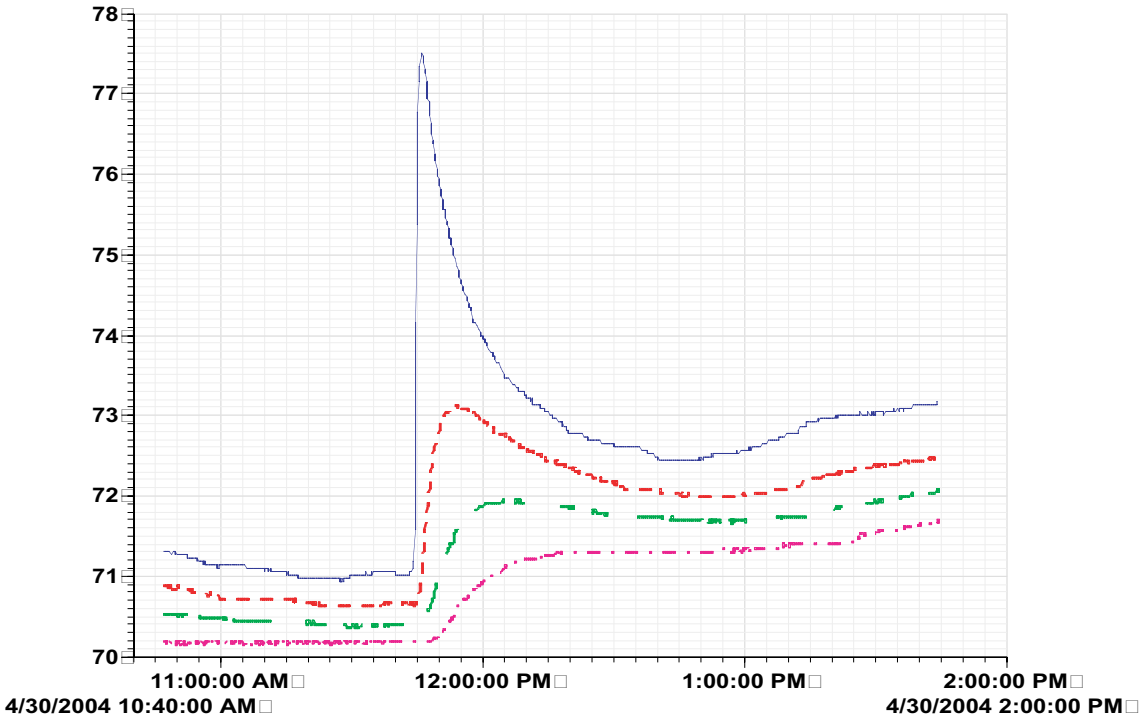


Figure 1

Temperature profiles: (top) at delamination and (bottom) 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, Ph.D. and Larry D. Olson, P.E.
Olson Engineering, Inc.
Tel: 303-423-1212, Fax: 303-423-6071, Email: yajai@olsonengineering.com

IDEA Concept and Product

This research project proposes to develop an effective and reliable nondestructive evaluation method to determine the internal grout condition inside bridge ducts using scanning stress wave techniques. The stress wave techniques of interest include Impact Echo and Ultrasonic Reflection tests. The scanning ability will provide economical data collection and processing to give three dimensional results for an easier and more comprehensive way of interpreting NDT&E results.

Project Results to Date and Planned Investigation

Initially the reliability of the current practice for Impact Echo testing will be evaluated. This task extends the previous work of the principal investigator and the Olson research team in the development of the Impact Echo Scanner (See Figure 1).

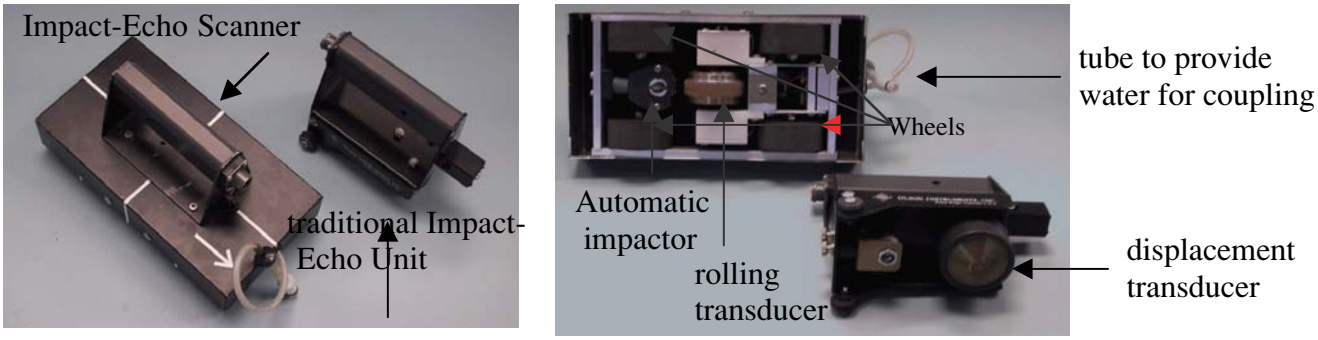


Figure 1

Impact Echo scanning unit and traditional point-by-point impact echo unit

In this first stage, the sensitivity of the current Impact Echo is being studied on mock-up specimens with ducts and known defect sizes. To facilitate the analysis part of the IE scanning, the research team has been developing a software package for three-dimensional Impact Echo Scanning. Example IE Scanning results in 3-D and profile views showing changes in the thickness of a mock-up slab are presented in Figure 2.

The next step will focus on an improvement of efficiency and practicality of the use of Ultrasonic Reflection. In this stage, scanning ability will be added to the ultrasonic reflection system to expedite the testing process and facilitate the analysis procedure. Finally, the results from the improved impact echo and ultrasonic reflection tests will be combined to provide redundancy of the test results. This has the potential to significantly increase the reliability of the proposed methodology

Product Payoff Potential

The potential result of the proposed project is improved quality assurance programs for new post-tensioned bridges. The results can also be integrated into bridge maintenance programs for existing post-tensioned bridges to help prevent partial or catastrophic failures by identifying ungrouted duct areas with tendon corrosion risks. The results from this research project can also be used to investigate voids and honeycomb in other concrete structures aside from the post-tensioned bridge ducts. With the scanning ability to expedite the field tests, facilitate the analysis and more reliable results from the combined tests, this will encourage the use of non-destructive evaluation for internal condition assessment of a wide variety of structures/ infrastructure.

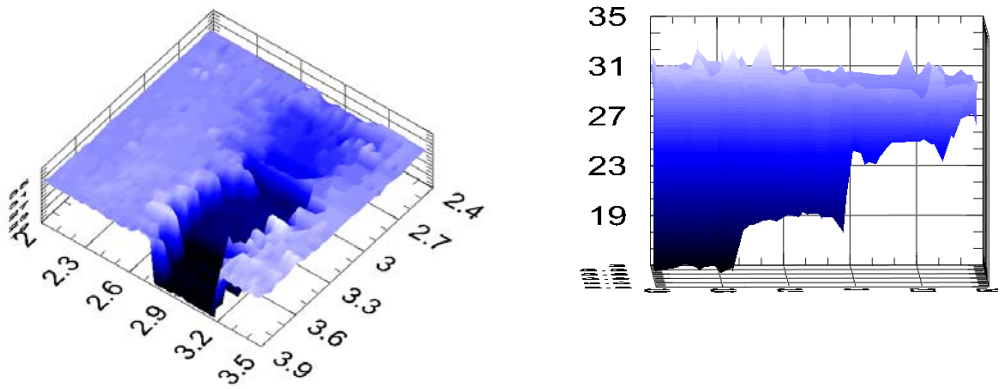


Figure 2

Impact Echo scanning results in 3-D showing changes in slab thickness and its profile view

Product Transfer

Olson Engineering has a sales/marketing alliance agreement with Dywidag-Systems International (DSI-Repair and Strengthening Unit) to be a part of their investigation team for the internal grout condition of bridge ducts. Olson/DSI have used Impact Echo Scanning and GPR on PT ducts on the bridge across the Charles River in Boston and several bridges in Chicago, Spokane, and Los Angeles already. With DSI's long involvement in PT materials, engineering, and now repair; and Olson Engineering's national and international consulting, the benefits of this research will be immediately available to state DOT's and other bridge owners. DSI will contribute their extensive experience in PT duct investigation and repairs to this research. Should the research result in a commercial product with a large market, the instrument could be marketed by Olson Instruments, Inc. (www.olsoninstruments.com).

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], Civil & Environmental Engineering Dept., Brigham Young University, Provo, UT 84602

IDEA Concept and Product

Liquefaction resulting from earthquakes causes significant damage to roadways, bridges, lifelines, and port facilities. Typically, liquefaction hazards have been mitigated by densifying the soil in-situ, but these methods are expensive and time-consuming. This study involves a field investigation of vertical composite drains (Earthquake Drains) for rapidly dissipating pore water pressures so that liquefaction and its resultant consequences are prevented. The drains are rapidly installed with a vibrating mandrel as shown in Figure 1. When liquefaction occurs around a pile or drilled shaft foundation, the upward skin friction may decrease to zero, thereby reducing the load-carrying capacity. Then, as the liquefied sand layer settles around the pile following the earthquake, downward (negative) skin friction could develop which would further decrease the load capacity. Previous field investigations (NCHRP IDEA Project 94) suggest that Earthquake Drains could prevent these problems, but no direct evidence is presently available and this inhibits the implementation of this mitigation strategy. If drains could be proven effective, significant cost savings could be realized for deep foundation applications.

Figure 1

Installation of slotted drain pipe within vibrating mandrel.

Research Investigation

To evaluate the effectiveness of these drains around deep foundations, a pattern of small explosive charges will be detonated to simulate the liquefaction process produced by an earthquake. Pilot testing will be 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. One 300 mm steel test pile instrumented with strain gauges will be surrounded by 35 drains in a triangular pattern at 1.22 m spacing. Behavior of this test pile will be compared with that of an identical instrumented test pile at an untreated adjacent site as shown in Figure 2. The testing will be conducted at a site consisting of about 9 m of saturated loose liquefiable sand underlain by clay and denser sand. Although considerable site characterization work has already been performed at the site, prior to drain installation, additional cone penetration and shear wave velocity logging will be completed. In addition, permeability will be measured in-situ. Post-installation cone penetration tests will also be performed to evaluate improvement with time after drain installation and after blasting.

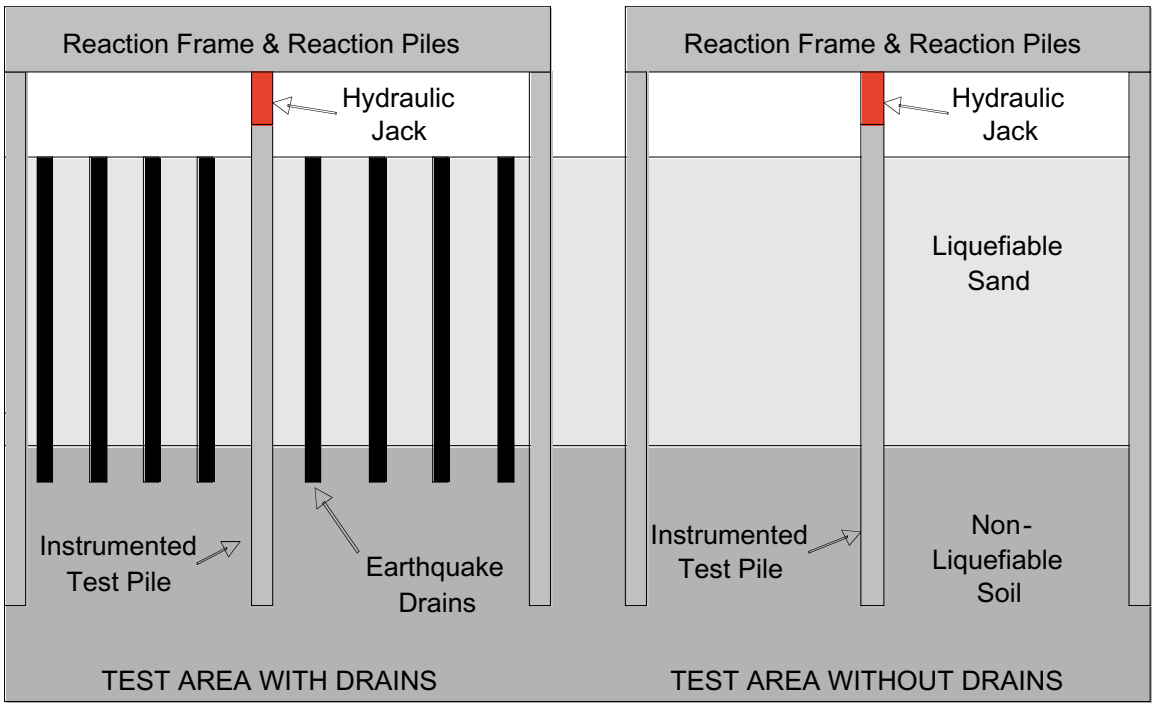


Figure 2

Illustration of test piles with and without vertical earthquake drains to prevent liquefaction and resulting loss of skin friction and potential downdrag on the piles.

Initially, a static axial load test will be performed on each test pile, then the axial load will be decreased to working stress levels and blasting will be carried out. During each blast test, monitors will measure ground settlement, pile load, pile settlement, and strain in the pile, as well as pore water pressure generation and dissipation. The strain measurements will be used to determine the decrease in skin friction due to pore pressure rise along with the negative skin friction due to settlement in the liquefiable layer as pressures dissipate. Based on the measured data, comparisons will be made of the differences in induced pore pressure, loss of skin friction, and negative skin friction for the two cases. Dr. Rollins of BYU worked with Nilex, Inc, the developer of the drains, to plan the testing program. Nilex is donating the materials, equipment, and personnel. In a collaborative project, Prof. T. Weaver (University of Idaho) will conduct statnamic load tests on an adjacent test pile to evaluate axial capacity under dynamic loading.

Product Payoff Potential

Earthquake drains can be installed more rapidly and at a fraction of the cost of competing systems. For example, for a 12 m-thick layer, treatment with stone columns would typically cost $115/m^2 of surface area and vibro-compaction would cost $75/m^2, while the drains only cost $30 to $50/m^2 (Nilex, 2002). In addition, the drains can be installed in about one-third to one-half of the time required to treat a profile using conventional means.

FRACTURE MECHANICS-BASED ASPHALT BINDER TEST METHOD FOR LOW-TEMPERATURE AND FATIGUE PERFORMANCE GRADING

NCHRP-IDEA Project 104

Simon A.M. Hesp [Tel.: (613) 533-2615, Fax: (613) 533-6669]
Queen's University, Kingston, Ontario, Canada

IDEA Concept and Product

This project is a follow up on IDEA Project 84 which developed simple single-edge notched three-point bend (SENB) and compact tension (CT) tests that can accurately measure fracture energy (G_{Ic} or G_f) and crack mouth opening displacement (CMOD) under realistic conditions of severe tensile constraint in a notched asphalt binder sample in the brittle state. Further, a simple double-edge notched tension (DENT) test was developed that can accurately measure the essential and plastic works of fracture in the ductile state (w_e and w_p). It is hypothesized that a specification system based on these fracture mechanics-based properties (i.e., G_{Ic}, G_f and CMOD in the brittle and brittle-to-ductile states and w_e and w_p in the ductile state) is able to provide superior performance prediction for all asphalt binders at low and ambient temperatures, irrespective of their composition or manufacturing process.

The main product of IDEA Project 84 is an improved laboratory standard test method for fracture performance grading of asphalt binders *Laboratory Standard for Fracture Performance Grading of Asphalt Binders* (Test Method LS-296, Laboratory Testing Manual, Ministry of Transportation, Downsview, Ontario, Canada, August 2003). The new method better recognizes the importance of chemical and physical hardening as well as fatigue cracking as potential aggravating factors in low-temperature failure. An advantage of the method is that no new equipment is required; all tests can be done with only slight modifications to the instrument originally purchased for the SHRP DTT. The product of IDEA Project 104 will be an accompanying binder specification which sets realistic limits on grade temperatures and fracture energies in both brittle and ductile states for a given location and traffic level.

Ongoing Investigation

To come to a definitive field validation of the proposed fracture mechanics-based specification system, it was imperative that a new test site be constructed with a number of carefully chosen binders. All binders should possess a *single* SHRP grading that provides a reasonable degree of certainty that within the first few years of service the sections will all be exposed to a temperature that guarantees some transverse stress cracking. The onset of cracking and the severity can then be correlated with the limiting temperatures and fracture energies as provided by the various grading methods. The Ministry of Transportation of Ontario has just included such a test site within a large Superpave® contract for highway 655 in the far north of Ontario. It has seven side-by-side sections containing binders with nearly the same performance grade as measured with the SHRP bending beam rheometer but large variations in fracture properties. The project involved a design of two layers, 50-mm binder course and 40-mm surface course, with the same binder in both lifts on both lanes of each 500-m section.

The test sections experienced severely cold weather just three months after the end of construction. Whereas the road was designed to withstand a minimum surface temperature of –34°C after some 7 to 8 years of service, the pavement temperature hit an all-time low for the area in early January 2004 when the air temperature reached to approximately –47°C. For a total of eight days in January 2004 the air temperature dropped below –40°C and the pavement temperature as measured at 5 mm depth dropped below –30°C. Given the fact that the road was designed to withstand a surface temperature of –34°C after some 7 to 8 years of service, this was a near-perfect accelerated pavement test.

On April 24, 2004, the site was visited to look for distress and to download the pavement temperature data. Surprisingly, a large amount of wheel path cracking was observed in Sections 2, 3, and 4 and a lesser amount in Section 6. Section 2 with 60 m of wheel path cracking also showed six transverse cracks, although these were all located either at the beginning or end of the section. Section 3 with 40 m of wheel path cracking showed only a single transverse crack that was less than half a lane wide towards the end of the section. Section 4 also had about 40 m of wheel path cracking and only a single transverse crack about half a lane wide approximately 180 m into the section. Section 6 showed approximately 5 m of wheel path cracking about 325 m into the section. Section 7 had only a single transverse crack about half a lane wide approximately 230 m into the section. Finally, only Sections 1 and 5 showed no detectable damage. Figure 1 shows a picture of (a) a transverse crack that has occurred in Section 2 and (b) the typical wheel path cracking that occurred in Section 3.

Early test results on the binders are able to explain the vast differences in fracture distress between different sections. Sections 1 and 5 with no cracks show the highest fracture energies in the ductile and brittle states. Section 2 with the most severe damage shows a high tendency for reversible ageing at low temperatures and has low fracture energies in both the brittle and ductile states. Section 3 with 40 m of wheel path cracks shows a very low plastic work of fracture. For a more detailed analysis of these early results refer to *Iliuta et al., Proceedings, Canadian Technical Asphalt Association, 2004, pp. 125-159* or contact the Principal Investigator for additional information.

(a) *(b)*

Figure 1

(a) Transverse Crack in Section 2 and (b) Wheel Path Crack in Section 3

Product Payoff Potential

If the project succeeds in developing an improved low-temperature specification system for asphalt binders, the potential benefits to North American transportation agencies are significant. A big advantage is that roads constructed according to the proposed fracture mechanics-based specification will more closely meet expected performance levels. Costly failures such as those investigated in this project will no longer occur, and superior asphalt binders are more easily identified once all the pertinent properties are included in a binder purchase specification.

Product Transfer

The key deliverable from the proposed effort *LS-296 Laboratory Standard for Fracture Performance Grading of Asphalt Binders* is a practical and improved low-temperature binder specification test method. Researchers are 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. It is expected that once the method is validated with additional data from the new test sections on Highway 655, other provinces in Canada will follow by accepting this method as their asphalt binder specification standard. Initial contacts with selected state transportation departments have been made and the response has in general been positive.

DEVICE TO PRECISELY MEASURE WATER-TO-CEMENT RATIO OF FRESH CONCRETE

NCHRP-IDEA Project 105

Art Crotzer, (ph: 405-372-9595 fx: 405-372-9537 acrotzer@nomadics.com),
Steve Trost, and Michael Fox, Nomadics, Inc., Stillwater, Oklahoma

IDEA Product

The negative impact of high ratios of water-to-cementitious materials (WCM) on concrete strength and durability is widely recognized. Even so, the uninhibited addition of temper water at the job site is a widespread practice within the concrete construction industry. Whereas the ability to accurately and precisely measure WCM of fresh concrete has been elusive, highway agencies have experienced considerable difficulty controlling the quality of placed concrete, particularly as it relates to the total amount of water in the mix.

This in-progress research project will develop a rugged, robust solution to this problem that will enable highway agencies to easily and adequately protect against low-strength and low-durability concrete. As such, state highway agencies will be able to save millions of dollars in unnecessary and/or premature repairs and rehabilitation costs caused by low-quality concrete. The device will be rugged and highly automated, making it suitable for everyday use by contractors, state highway testing personnel, and testing laboratories. In short, the resulting device will create capabilities for the measurement and enforcement of concrete quality at unprecedented levels.

Concept and Innovation

Previous research performed by Kansas State University demonstrated considerable promise in terms of the technical capabilities of the concept of using a turbidity sensor to determine the water-cement ratio of fresh concrete. Despite the extremely promising results demonstrated by the Kansas Water-Cement Ratio Meter, it has not yet been made commercially available. Improvements to the Kansas system are included in the scope of this research. Additional methods are also being investigated and will be compared with the results of the Kansas system. The most promising methods will be incorporated into the final device. The additional methods under investigation are proprietary and confidential and cannot be publicly disclosed at this time.

Investigation

Two separate approaches are being incorporated into this investigation. The first approach is to ensure that the device will be able to distinguish changes in the water content of fresh concrete when the only variable from batch to batch is the amount of moisture contributed by the aggregate sources. The second approach is to also be able to precisely detect water that has been added after batching, such as at the job site or wash water that was left in the mixing drum prior to batching.

Plans for Implementation

Marketing, manufacturing, and commercialization of the results of this research will be managed by Engius, LLC. Engius was formed in December 2003 as a majority-owned subsidiary of Nomadics, Inc. Engius was created to manage the commercialization of Nomadics' first product for the construction industry—the intelliRock Concrete Quality Control System. With a strong concrete-industry client base already developed, Engius is well-positioned to commercialize the results of this research. 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.

AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION

NCHRP-IDEA Project 106

H. D. Cheng, Utah State University
Tel: (435)797-2054, Fax: (435)797-3265, Email: hengda.cheng@usu.edu

IDEA Concept and Product

Pavement crack detection and analysis is an important component of pavement management systems. Conventional visual and manual pavement crack analysis techniques are very costly, time-consuming, dangerous, labor-intensive, tedious, and subjective; have a high degree of variability; are unable to provide meaningful quantitative information; and almost always lead to inconsistencies in distress detail over space and across evaluations.

Pavement monitoring and evaluation are essential requirements for effective pavement management. An ideal automated crack detection system should detect all types of cracking and other surface distress, of any size and at any collection speed. It should be affordable, easy to operate, and capable of daylight operation. Pavement management programs would be very adequately served by devices that give meaningful, repeatable distress ratings to sections of pavement, providing the critical information for maintenance decisions.

Problems with the existing automated crack detection systems are as follows:

1. They require special devices (special lights, lasers, etc.) that would increase cost and limit the application of the system or method;
2. Some systems have very low processing speed and low accuracy;
3. They can deal only with certain kinds of distresses; if there is a need to deal with more kinds of distresses, the complexity of the system would greatly increase or it could not handle the additional work;
4. They cannot achieve real-time processing; some systems can only record in real-time (on film or videotape) and then perform offline processing and analysis.
5. The distress severity can only be measured qualitatively.

Planned Investigation

The project is expected to develop fast and accurate algorithms for detecting and classifying cracks in different materials and under different lighting conditions. The main characteristics of the automated system are:

1. All the segment related information is handled automatically.
2. The image data is linked to the segment automatically.
3. High accuracy rate (>97%) and the result is in an intuitive format.
4. The pavement image data acquisition and the pavement crack detection are done in real-time. Vehicle can travel as high as 85mph. No need to store images that would require a huge amount of computer storage capacity.
5. All types of cracks (longitudinal, transversal, diagonal, alligator, combined) can be detected automatically and accurately.
6. The severity will be measured quantitatively and qualitatively based on the users' choice.

The integrated system will be installed on a vehicle as shown in Fig. 1. The system will be easy to operate and maintain. To validate the performance of the system, field tests will be conducted, and more images will be gathered.

Product Payoff Potential

The system will perform real-time pavement crack detection and classification with high accuracy automatically. It will save money and manpower, and increase safety for pavement management.

Figure 1

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

NCHRP-IDEA Project 107

John A. Lopez and Yi Liao, Argus Technologies, 240 West E Street, Ste.B, Dixon, CA
Tel. 707/678-5691; Fax 707/471-6502 Email: johnlopez@argustec.com

IDEA Concept and Product

Argus Technologies, Inc. has developed the EM^3, a mobile geophysical instrument for near-surface (upper 10 meters) electromagnetic investigations. It is capable of covering over 140 lane-miles per day (equivalent to ~200 acres), thereby making total site coverage technically and economically feasible. Both apparent conductivity and magnetic susceptibility data are acquired for three volumes/depths simultaneously, resulting in a tremendous increase in data, consequently greater confidence regarding subsurface conditions. This information is very useful within a number of decision making arenas of project development, particularly, design engineering, geotechnical, environmental, and ROW/utilities. By identifying potential problems during the planning and design phase, the "unforeseen" is avoided, reducing design errors and omissions, schedule slippage, scope creep, and cost overruns.

Planned Investigation

The first step in the project will be to establish collaborative multifunctional work teams for two pre-identified California Department of Transportation (Caltrans) projects. Initial meetings will be held with the project manager and functional managers to identify specific needs and expectations, obtain existing documentation, create a schedule consistent with their timelines, and develop lines of communication/coordination.

Figure 1

Fieldwork will involve surveying the navigable portions of the area of potential effect according to our predetermined route programmed by hand-held geographic information system software. Data will be acquired along the road axes. Sinusoidal lines will also be run to improve coverage and the ability to interpret linear features (e.g., utilities). Line spacing will be based on the level of detail required by project planners. Above-ground features such as barbed wire fences, irrigation ditches, etc., will be noted for further understanding of the data, along with any surface geomorphology.

Initial data analysis will be performed using Surfer™ 7.0 and EMIGMA™ software. The latter will be used to construct 2D contouring and 3D inversion models of both apparent conductivity (quadrature data) and magnetic-susceptibility (in-phase data). Potential explanations for certain anomalies (differences standing out from the background data) will be developed based on shape, size, nearness to known above- and below-ground facilities. All data and anomalies will be discussed between the project manager and functional unit managers, bringing to their attention those anomalies that may warrant further investigation or groundtruthing.

Results will be evaluated through groundtruthing conducted by Caltrans. For the Arboleda Freeway Project, for example, researchers plan to compare the EM^3 data with approximately one dozen geotechnical borings already completed. Additional verification and accuracy checking will be achieved through their potholing budget. Similar arrangements can be made for the Colorado River Bridge Replacement Project. Caltrans will also test all anomalies potentially associated with contamination plumes, providing the outcome of testing. A preliminary assessment of the technology can be made before construction gets under way, but the final outcome will not be known until the project(s) are complete, several years down the road.

Potential Impacts and Payoffs

More than 50% of all construction claims and change orders are the result of insufficient subsurface information, one of the top five reasons cited for delays during highway construction (Ellis & Thomas 2003). By supplying EM^3 data to various functional unit project managers early in the planning stages of project delivery, a solid basis for understanding subsurface site conditions can be attained. This enables designers and planners to carry out subsequent efforts such as modeling, risk assessment, remediation, and design engineering, with much greater confidence and accuracy, while minimizing uncertainties, assumptions, and opinions. Armed with advanced knowledge, projects should be more easily completed, experiencing fewer change orders and construction claims, thus less schedule slippage, scope creep, and decreased cost overruns, if not savings. Payoffs have the potential to be quite substantial (as much as 14% of construction dollars). AASHTO estimates a 5% reduction in unit costs or delay claims would amount to millions of dollars nationally (NCHRP 20-24(12)).

Product Transfer and Implementation

The objective is to seek ways to integrate the technology/applications into Caltrans' project development procedures by distinguishing overlapping, parallel, and sequential data needs within their system of workflow tasks and work breakdown structures and ultimately, develop measures to streamline/enhance project delivery. Following the post-application assessment (quantifying cost and time savings as well as identifying any added value), Caltrans plans to make information on the technology accessible on their "Project Delivery Acceleration Tool Box" Web page.

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.

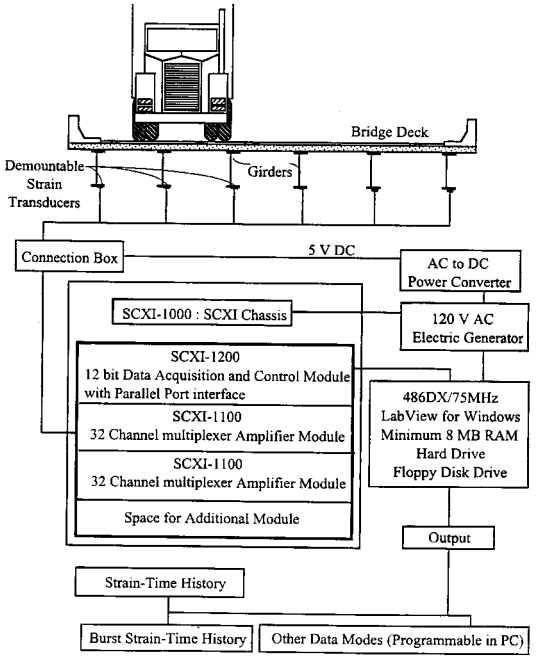


Figure 1

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.

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