IDEA

Innovations Deserving
Exploratory Analysis Programs

NCHRP HIGHWAY

New IDEAS for Highway Systems

Annual Progress Report

JANUARY 2006

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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

2006

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OF THE NATIONAL ACADEMIES

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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 2005 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 2005 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 2005 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).

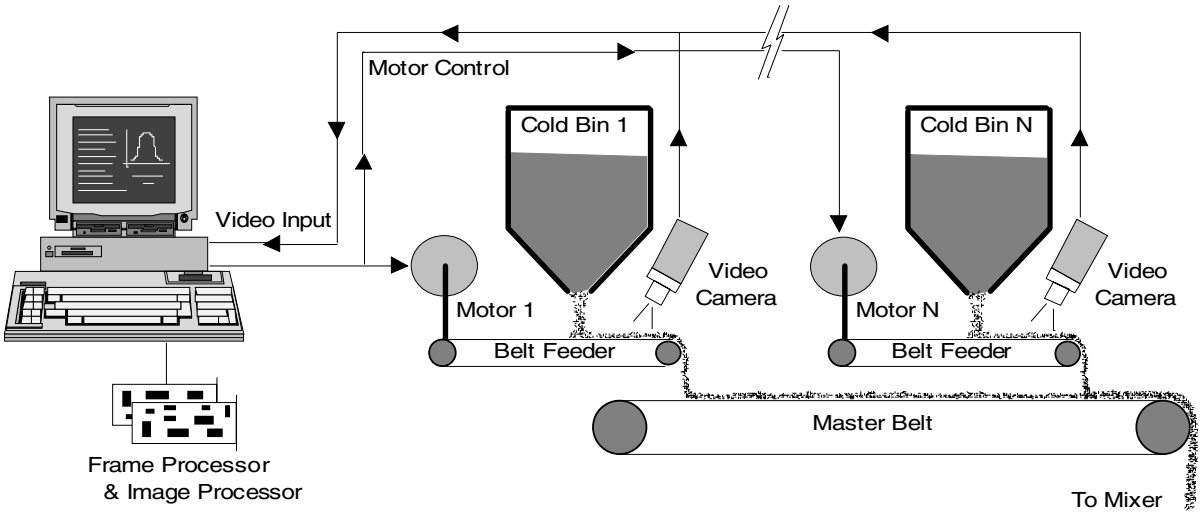

Figure 1

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).

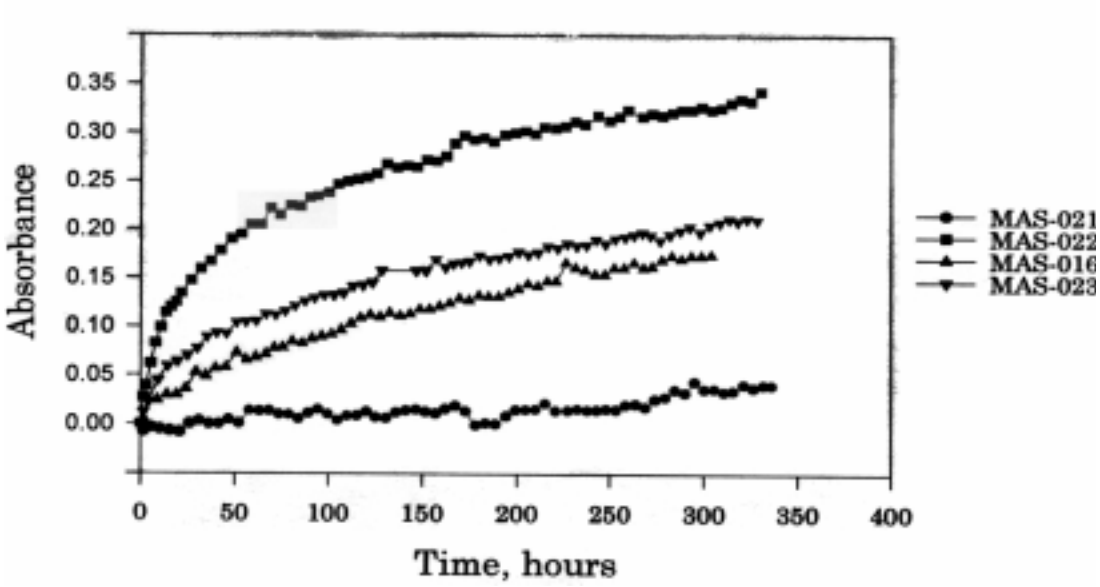

Figure 1

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).

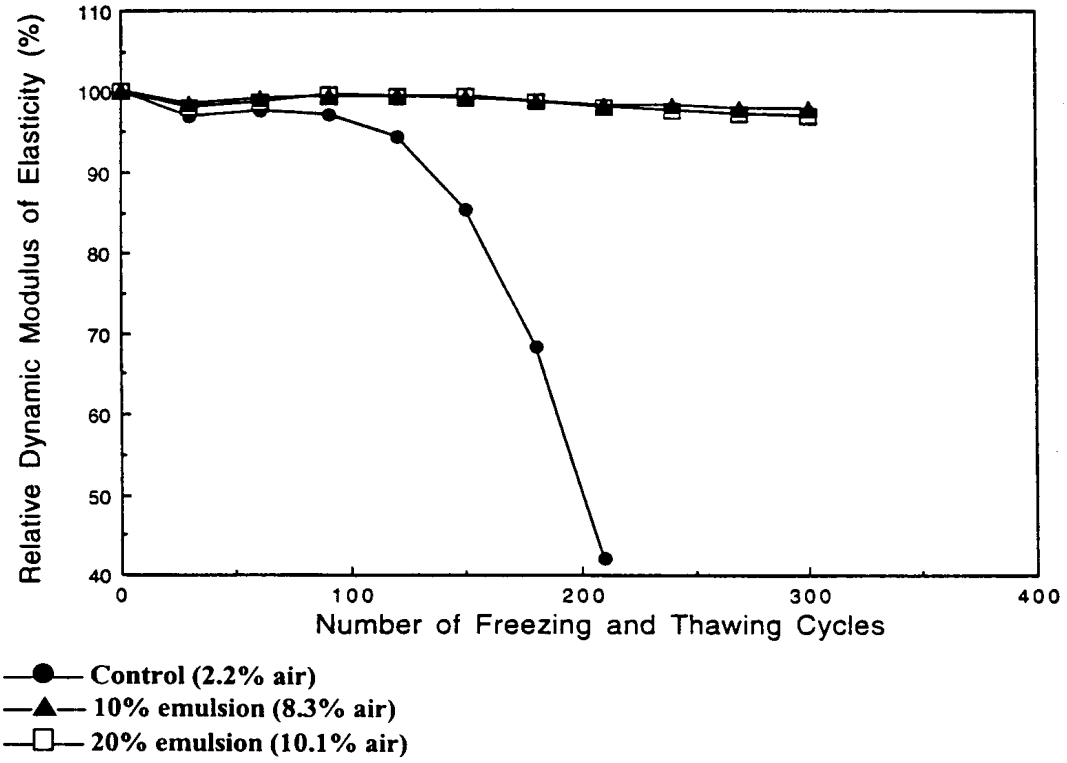

Figure 1

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).

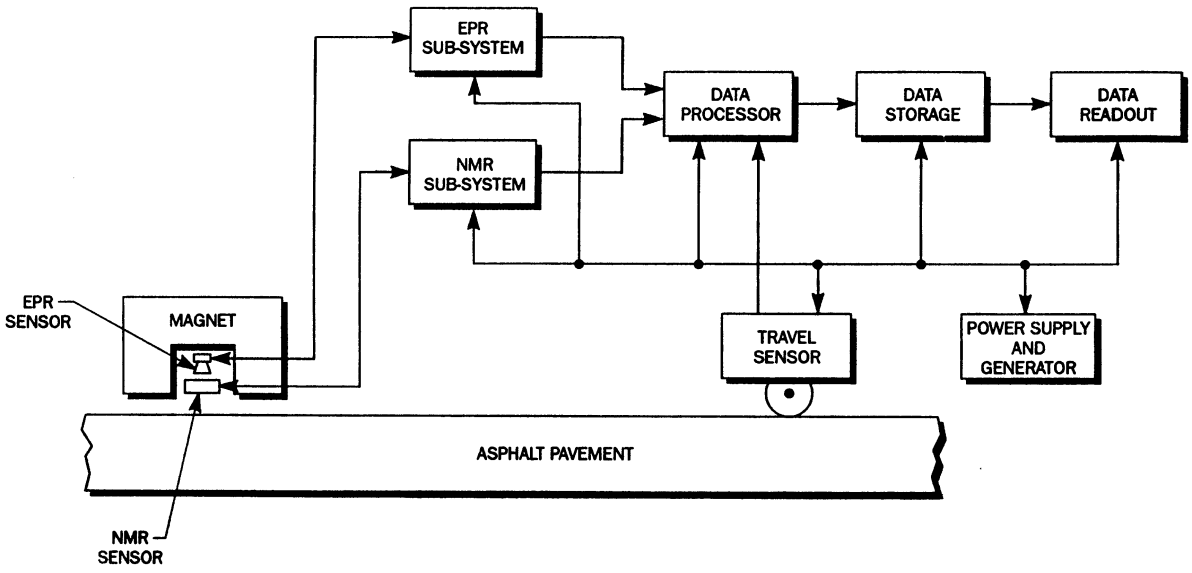

Figure 1

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).

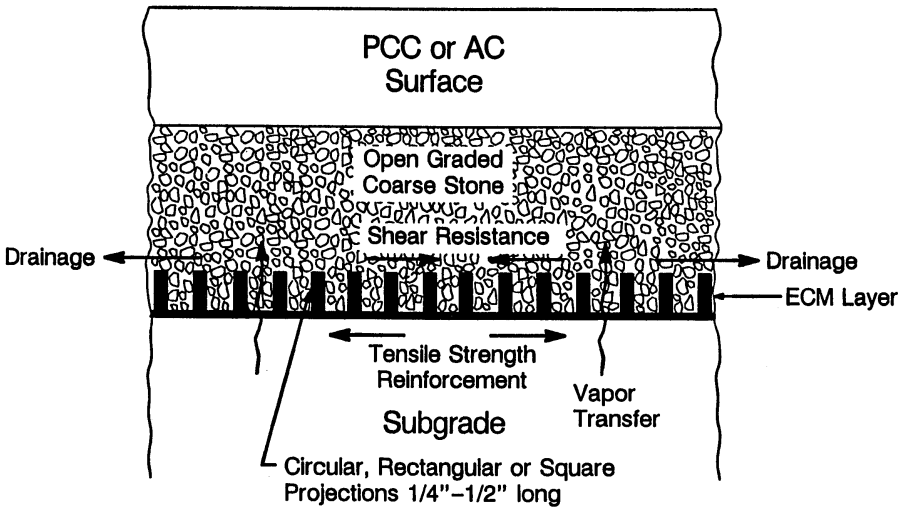

Figure 1

ECM layer concept and functions.

STRATEGY FOR COATING STRUCTURAL STEEL WITHOUT STRINGENT BLASTING REGULATIONS

NCHRP-IDEA Project 7

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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.

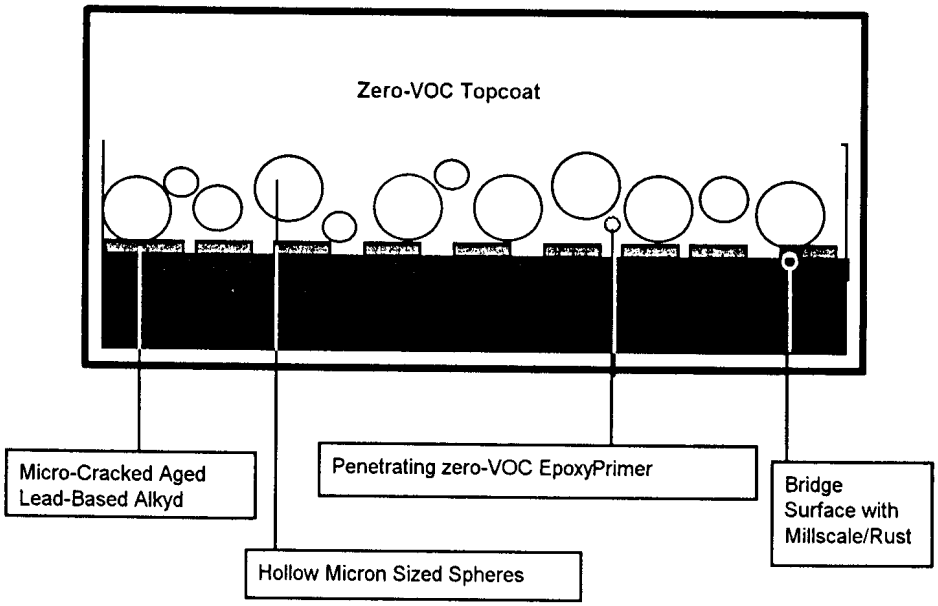


Figure 1

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).

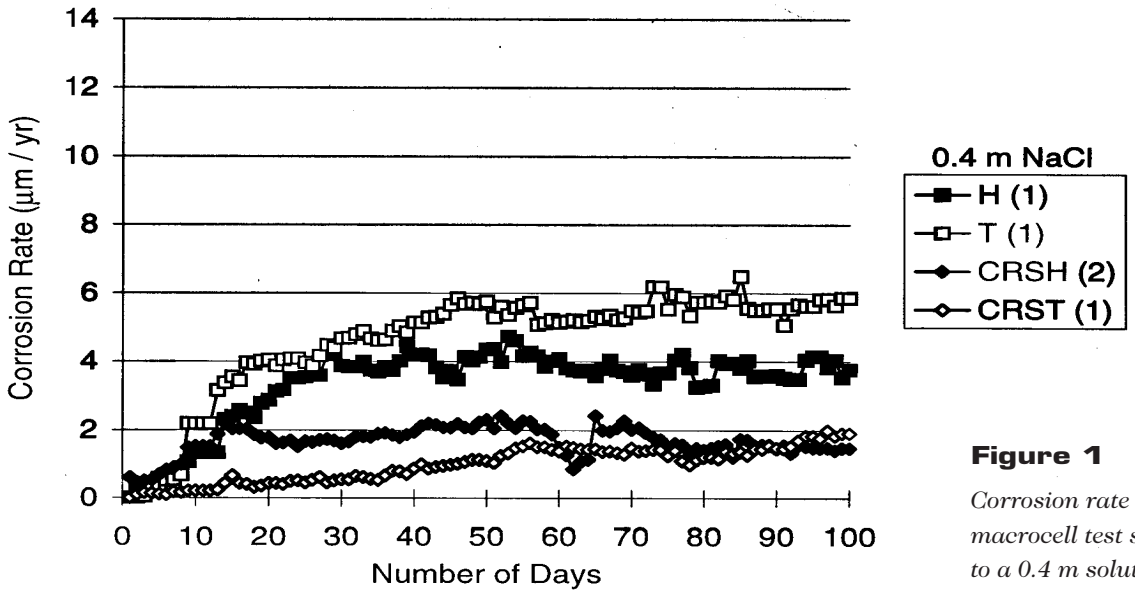


Figure 1

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).

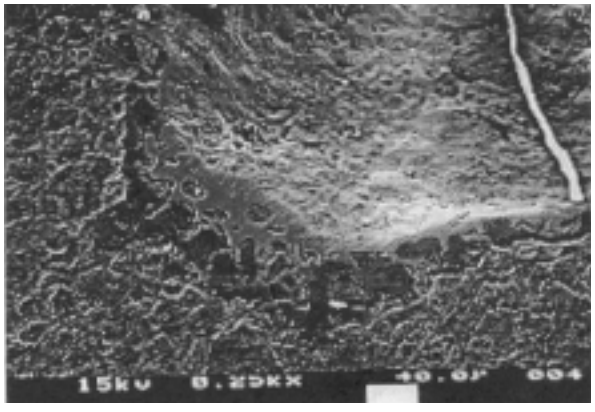


Figure 1

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).

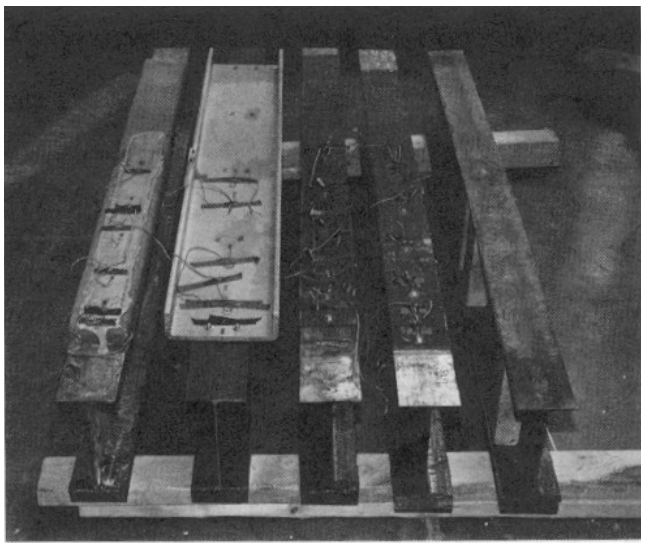


Figure 1

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).

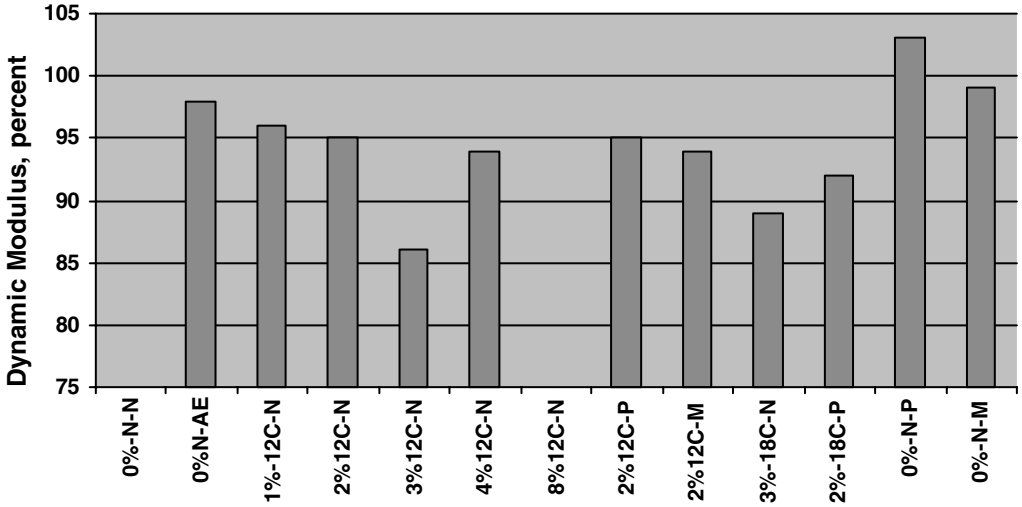


Figure 1

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).

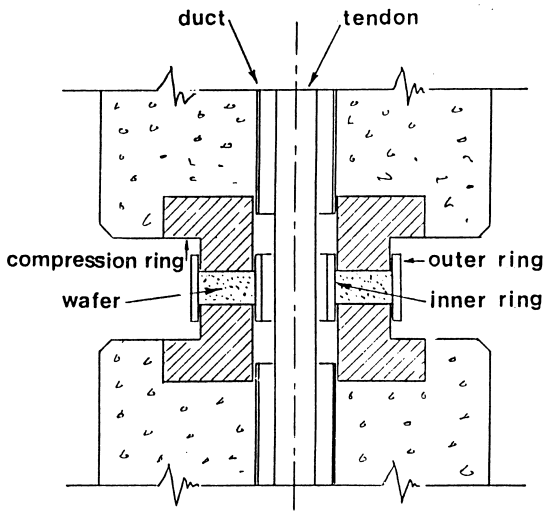


Figure 1

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).

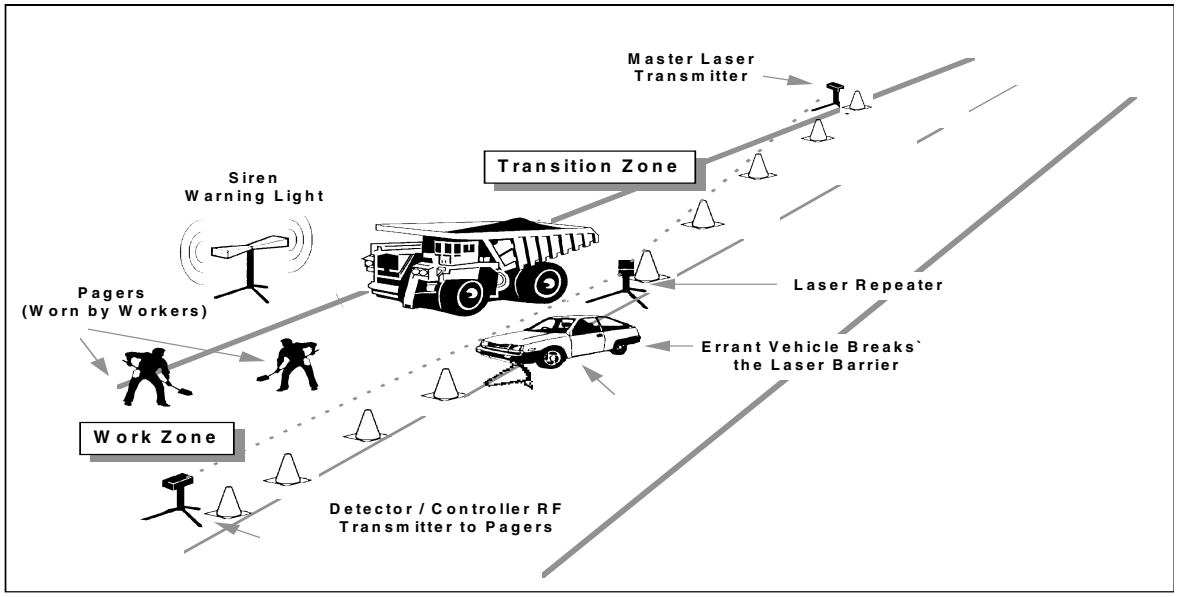


Figure 1

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).

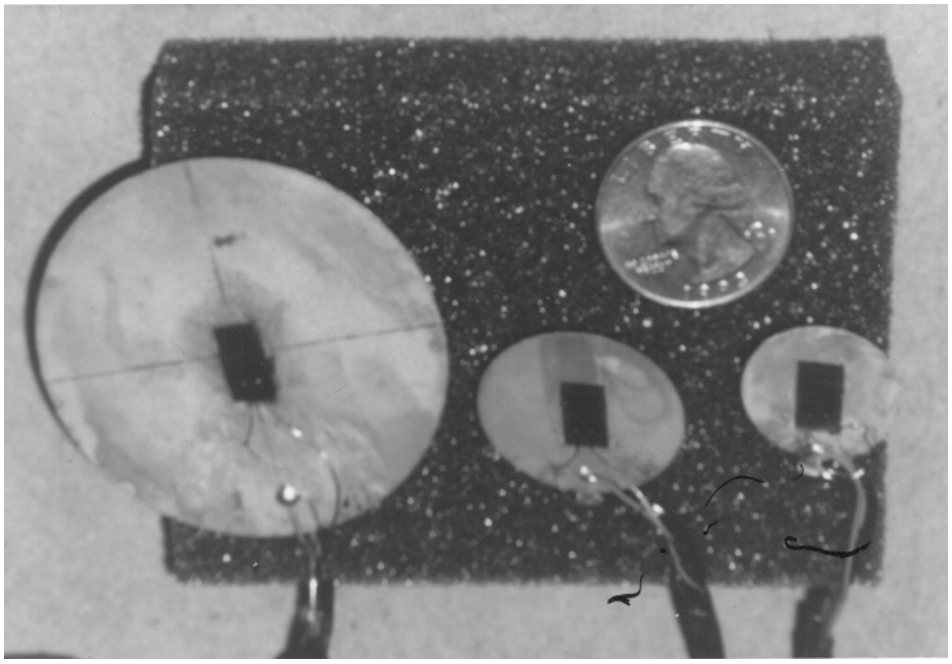


Figure 1

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.

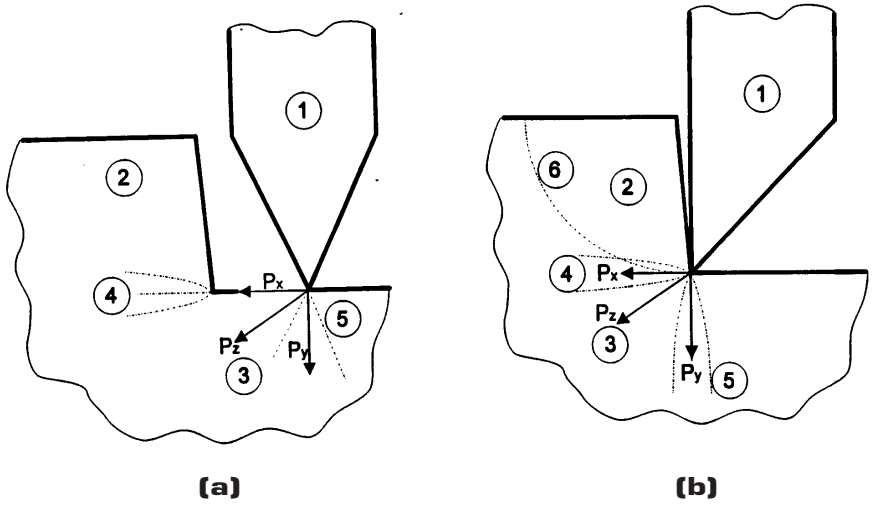


Figure 1

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).

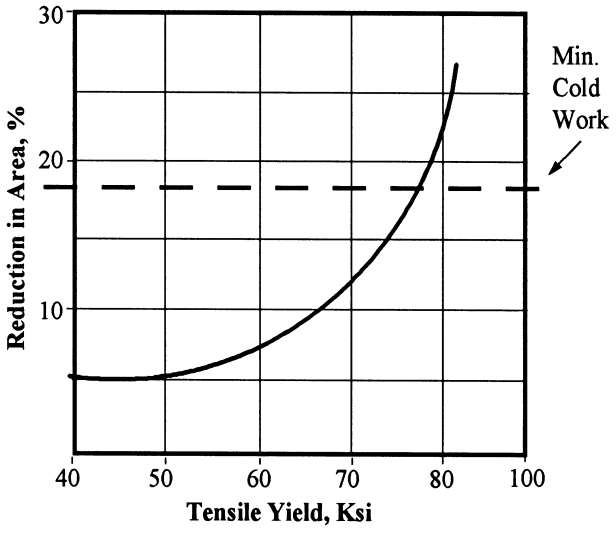


Figure 1

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

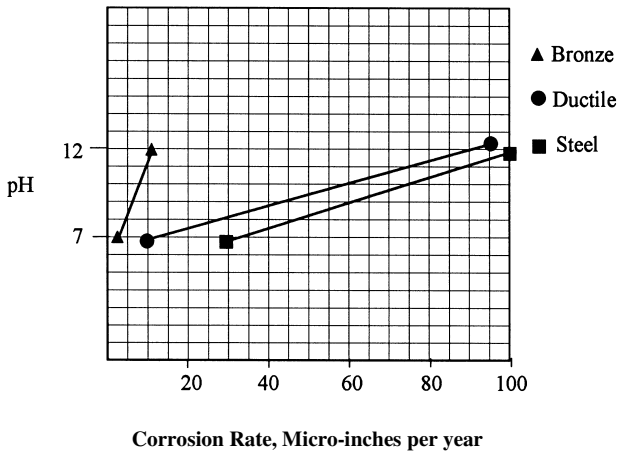


Figure 2

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.

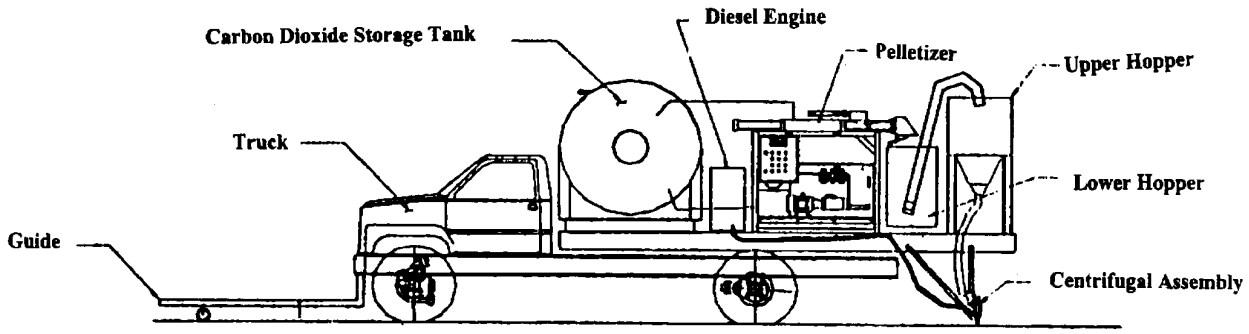


Figure 1

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).

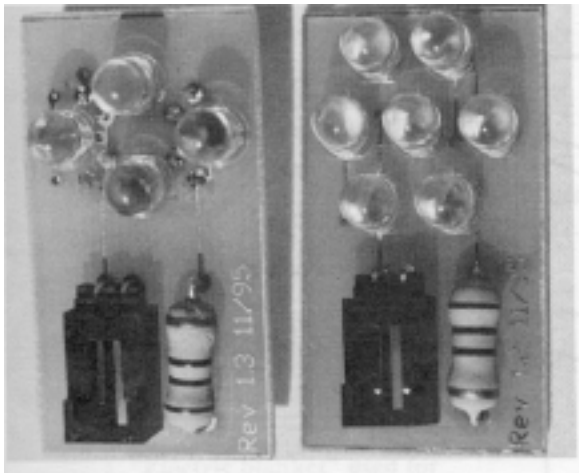


Figure 1

High- and low-intensity LED devices.

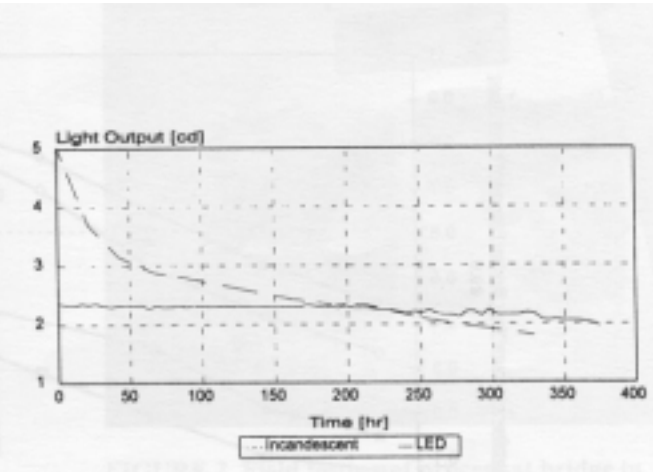


Figure 2

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).

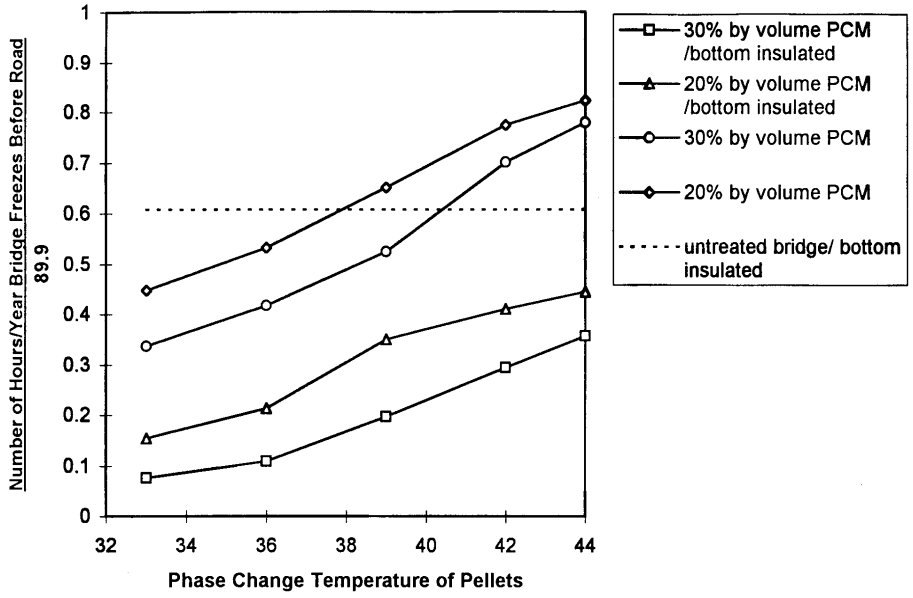


Figure 1

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).

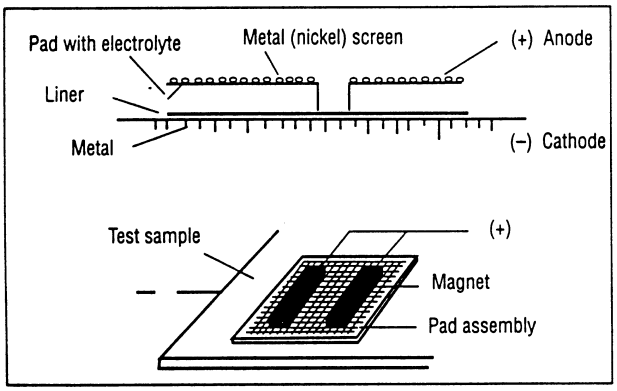


Figure 1

"Electric blanket" used for electrochemically assisted paint removal.

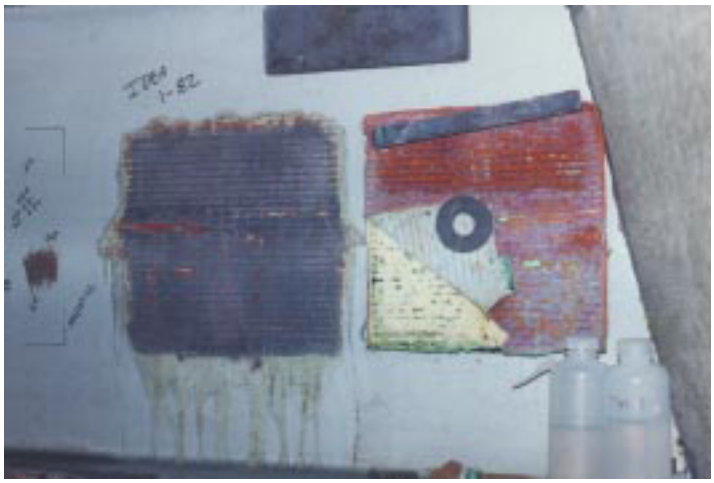


Figure 2

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).

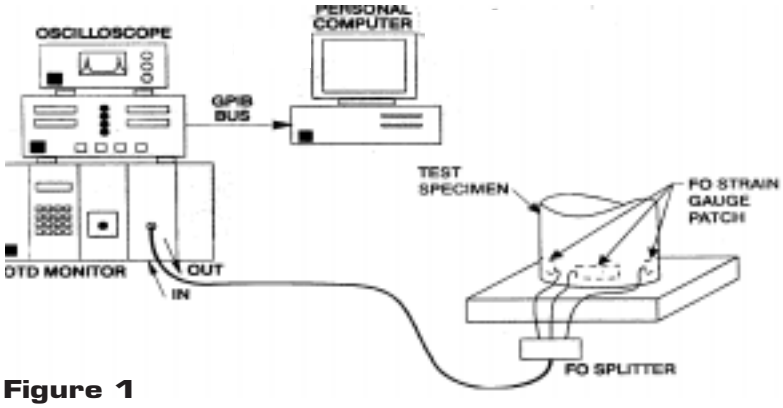


Figure 1

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).

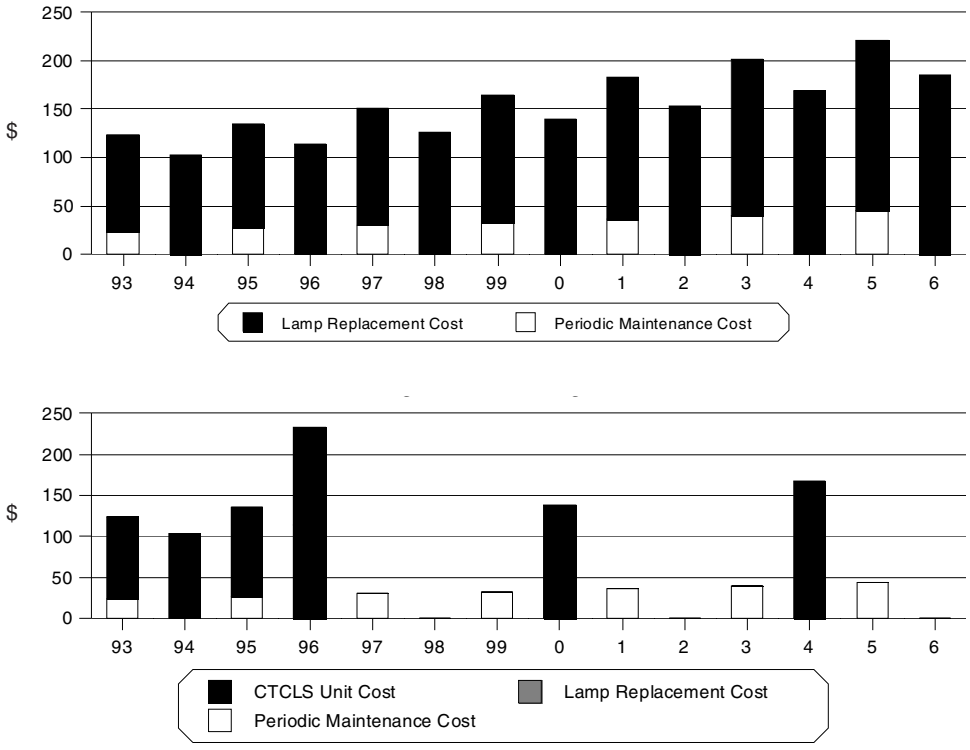


Figure 1

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).

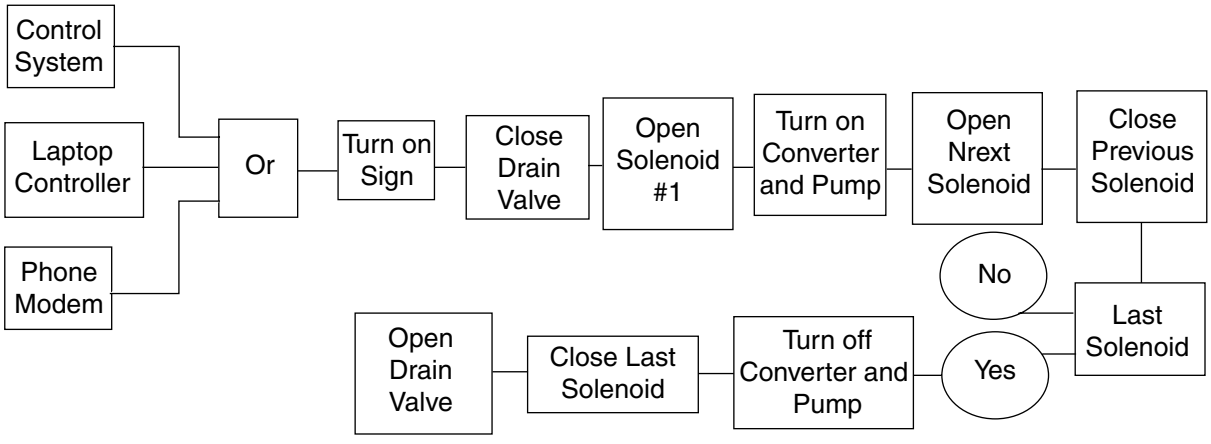


Figure 1

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

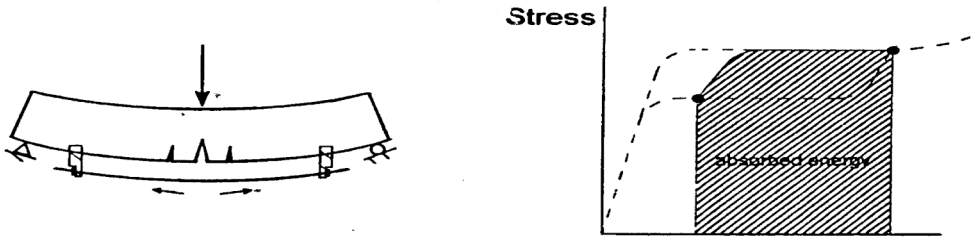
ASTM A615 and DFM steels after ex situ imposed polarization testing.

SUPERELASTICITY-BASED MATERIALS FOR BRIDGE REHABILITATION

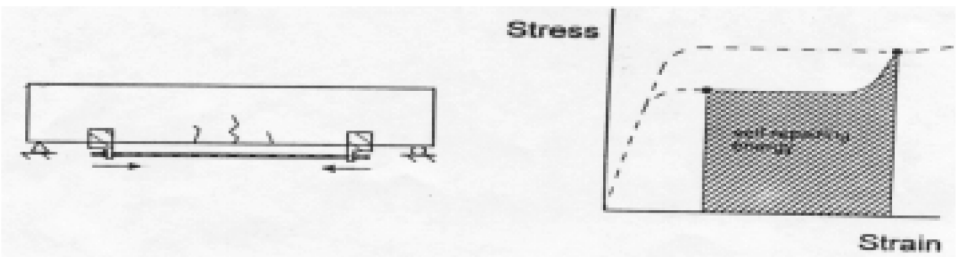
NCHRP-IDEA Project 29

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).

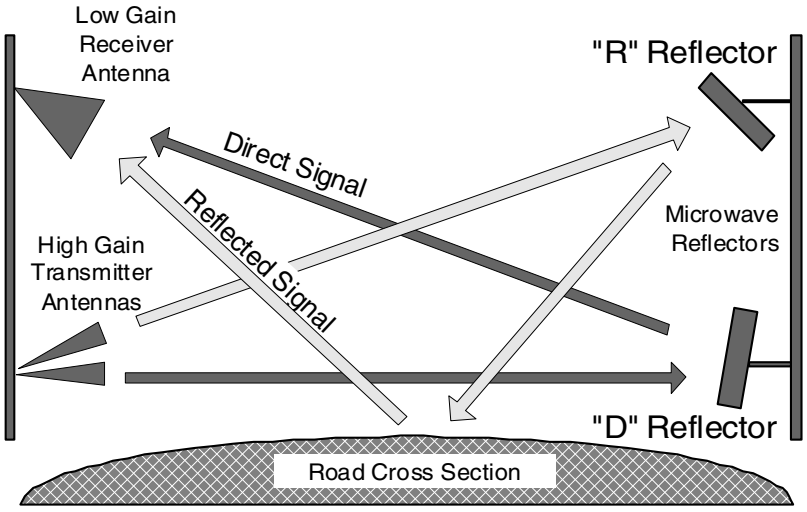


Figure 1

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

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Udaya B. Halabe, Sachin Kshirsagar, and Reynold Franklin,
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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

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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).

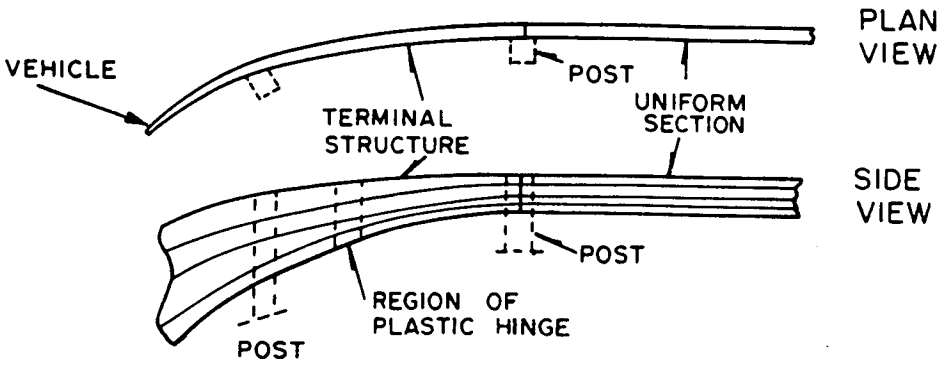

Figure 1

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.

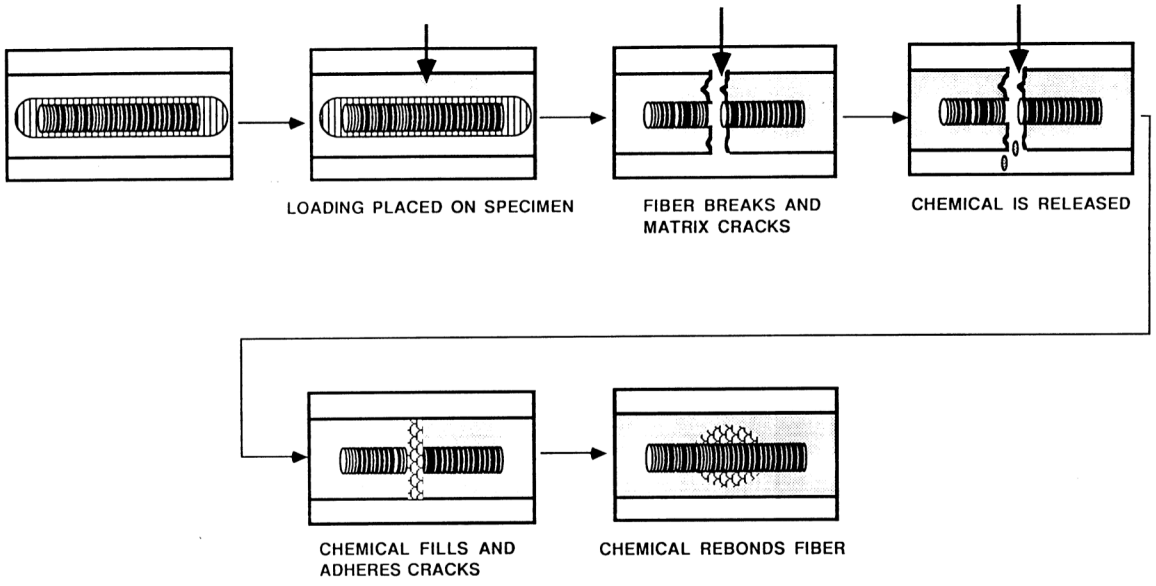

Figure 1

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

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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).

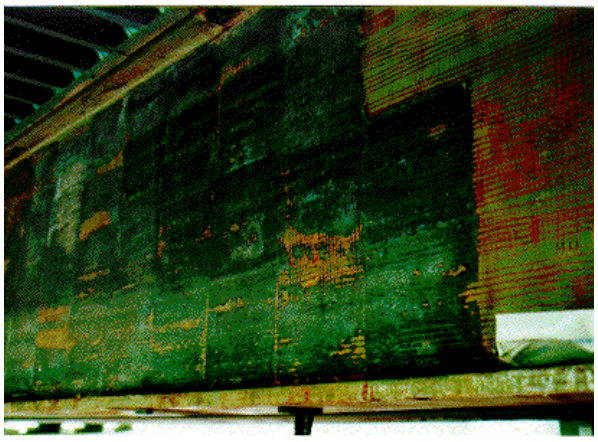

Figure 1

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).

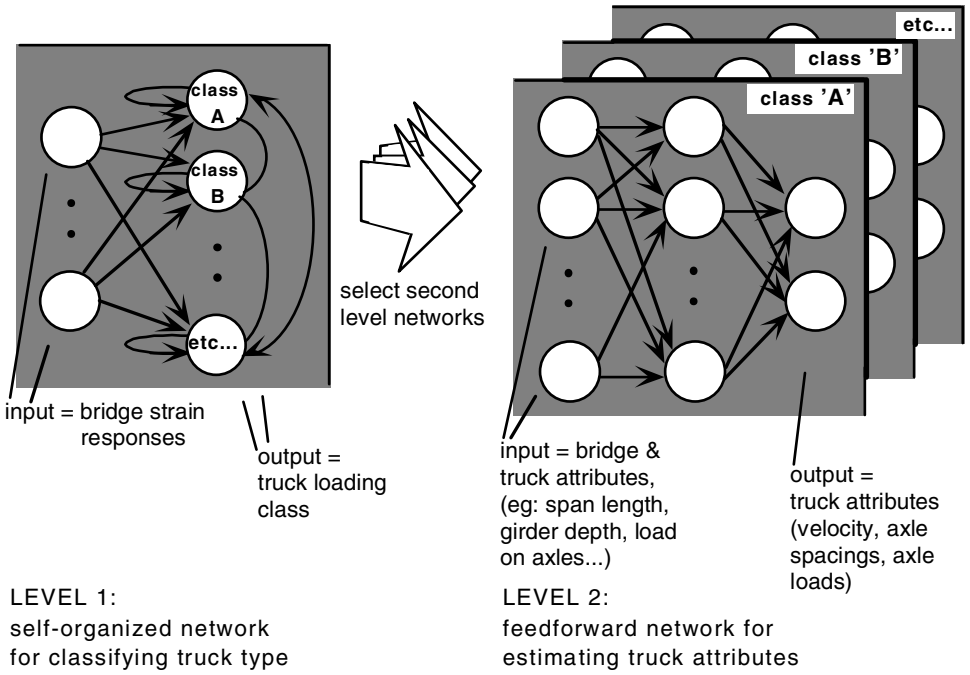

Figure 1

Architecture of Proposed Networking System

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

NCHRP-IDEA Project 41

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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.

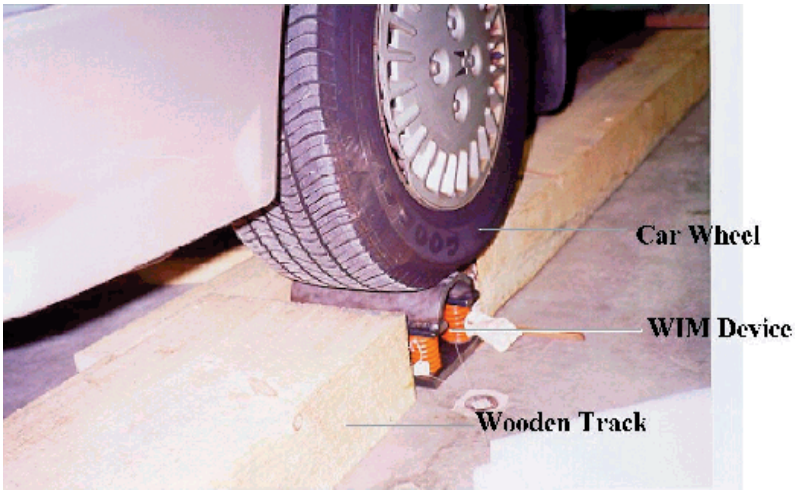

Figure 1

Car wheel testing in progress

ROBOTIC SYSTEM FOR UNDERWATER BRIDGE INSPECTION AND SCOUR EVALUATION

NCHRP-IDEA Project 43

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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

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

Figure 1

Prototype system for asphalt pavement density determination.

PERFORMANCE EVALUATION OF BASALT FIBERS AND COMPOSITE REBARS AS CONCRETE REINFORCEMENT

NCHRP-IDEA Project 45

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Research and Technology, Inc., Madison, Wisconsin

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

This project evaluated the suitability of basalt fibers and basalt fiber composite rebars in concrete as an economical and durable alternative to reinforcing steel. Concrete specimens reinforced with basalt fiber composite rebars and basalt fibers (up to 2% 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).

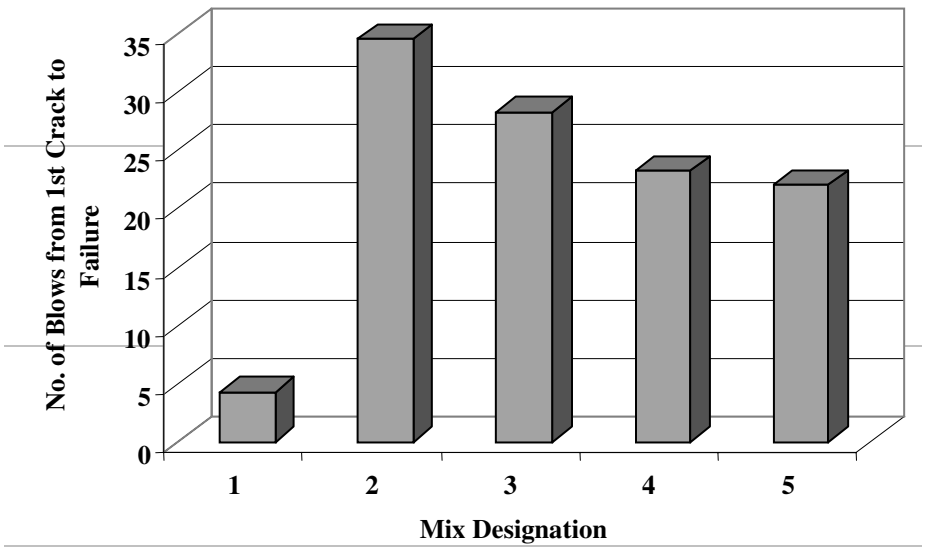

Figure 1

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

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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

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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

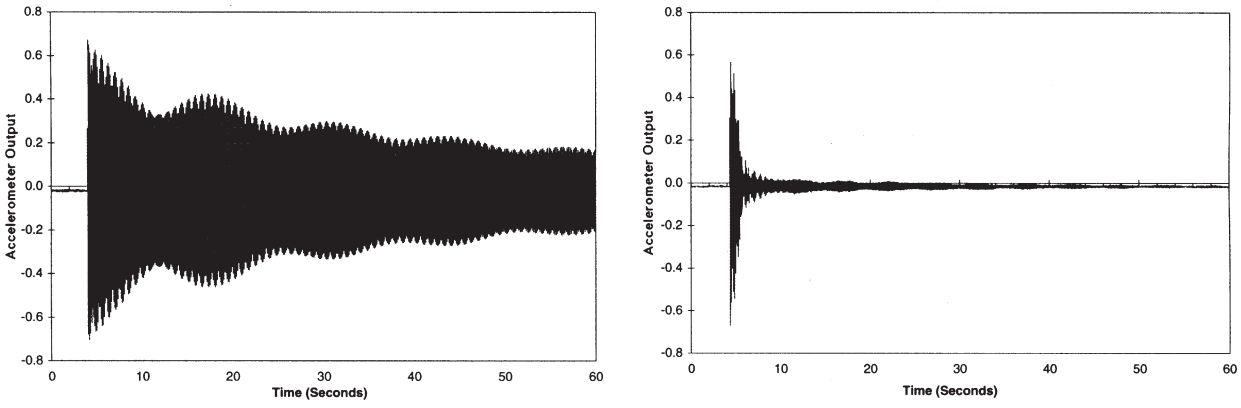
Truck-mounted RoadWriter™ prototype system in field operation.

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

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University of Delaware, Newark, Delaware

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

Figure 1

Bridge girders rehabilitated with carbon fiber-reinforced polymer plates.

ENVIRONMENTALLY FRIENDLY PASSIVATING COATINGS FOR STEEL REBARS

NCHRP-IDEA Project 52

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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.

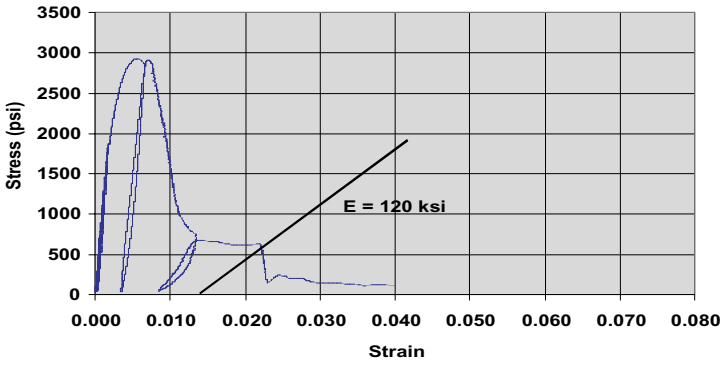

Figure 1. Stress Strain Response - Compression Test

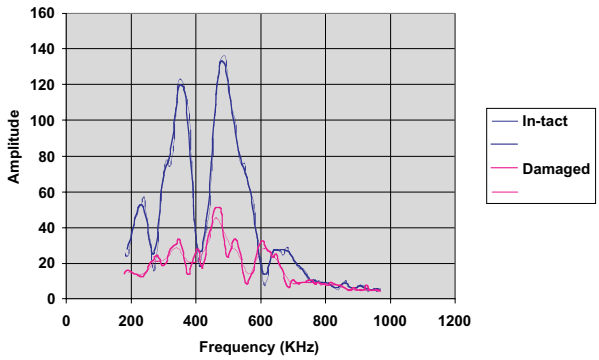

Figure 2. Voltage Amplitude vs Frequency : Incidence Angle 25 Deg

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.

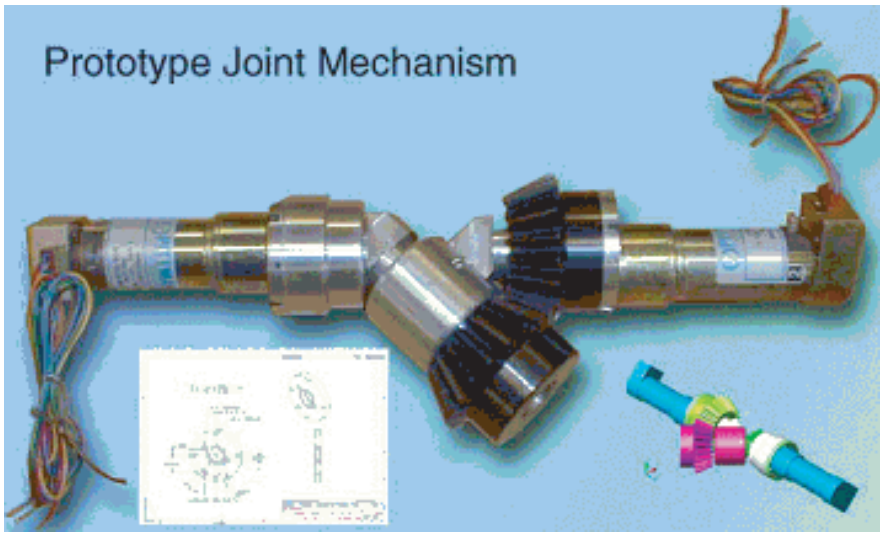

Figure 1

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.

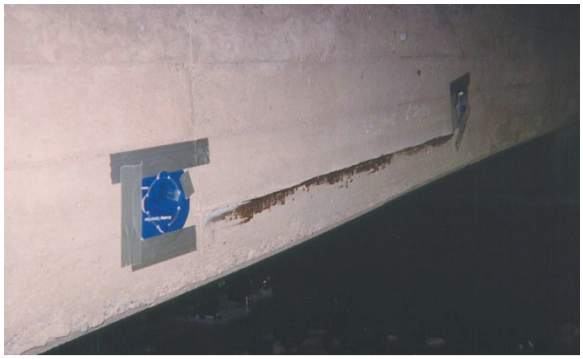

Figure 1

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.

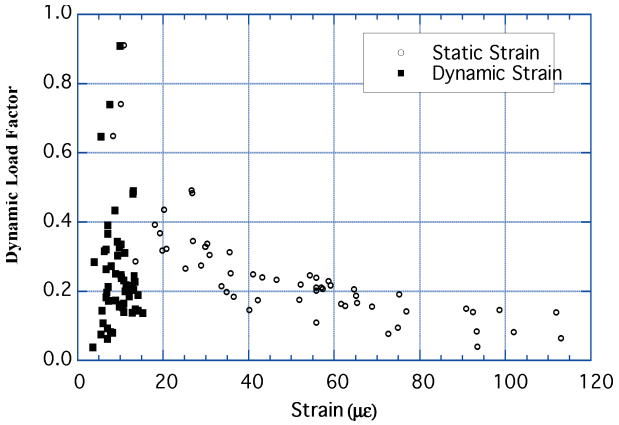

Figure 1

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.

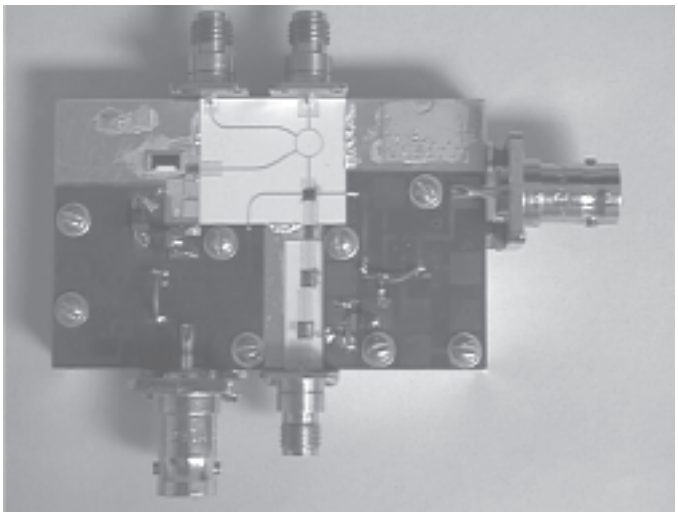

Figure 1

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.

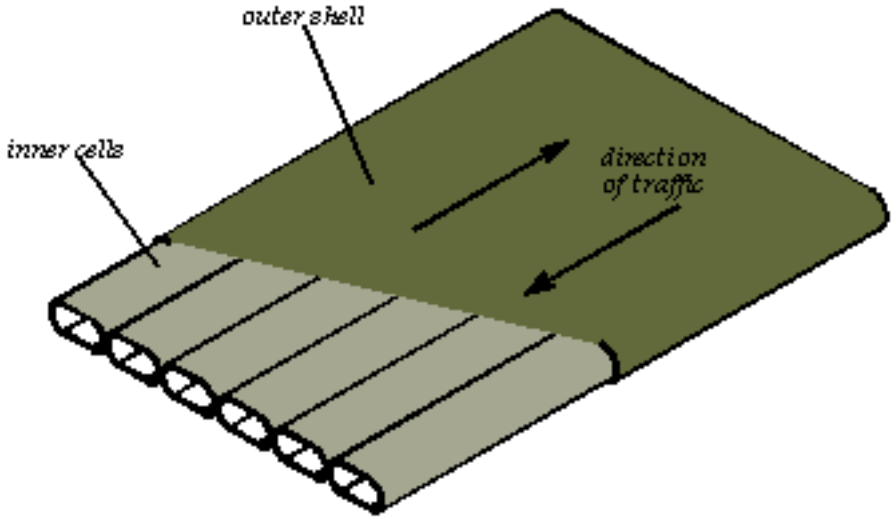

Figure 1

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.

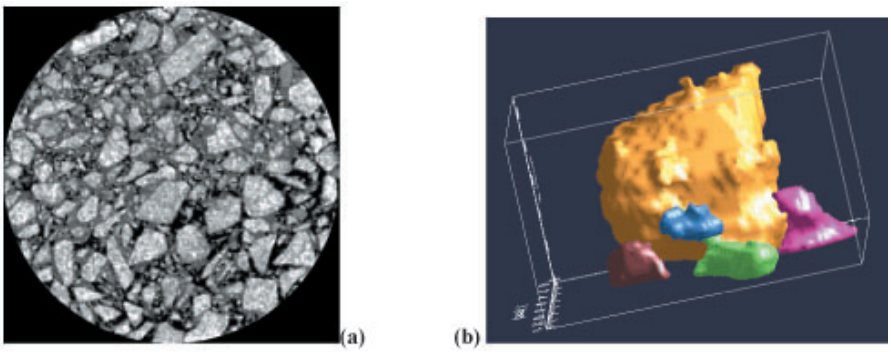

Figure 1

(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.

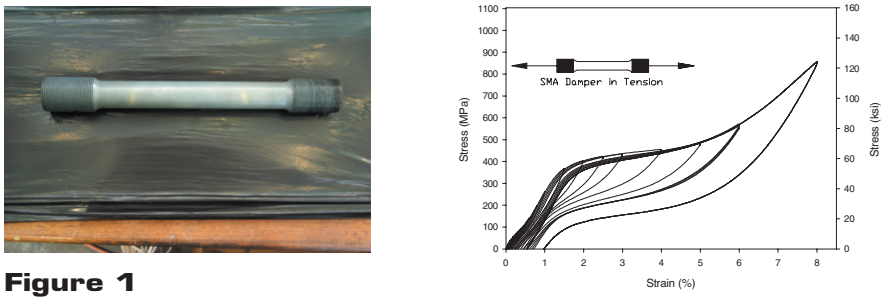

Figure 1

(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

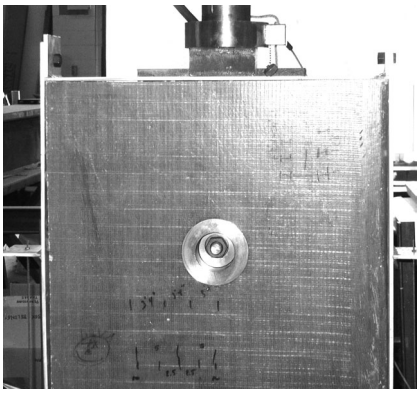

Figure 2

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.

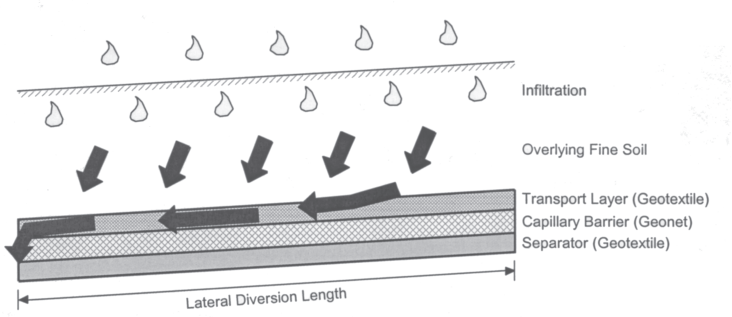

Figure 1

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.

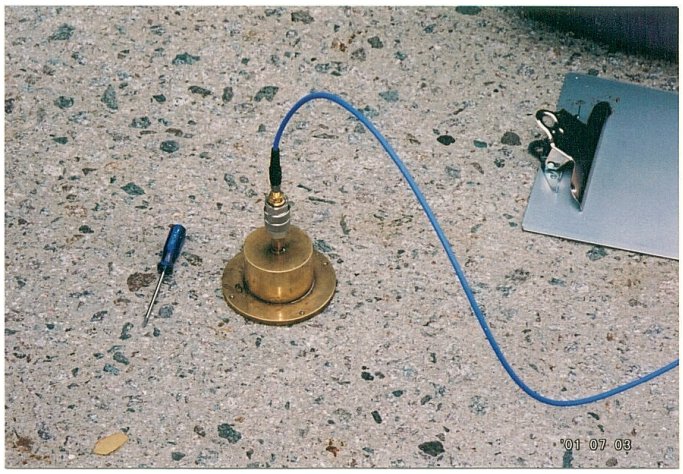

Figure 1

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.

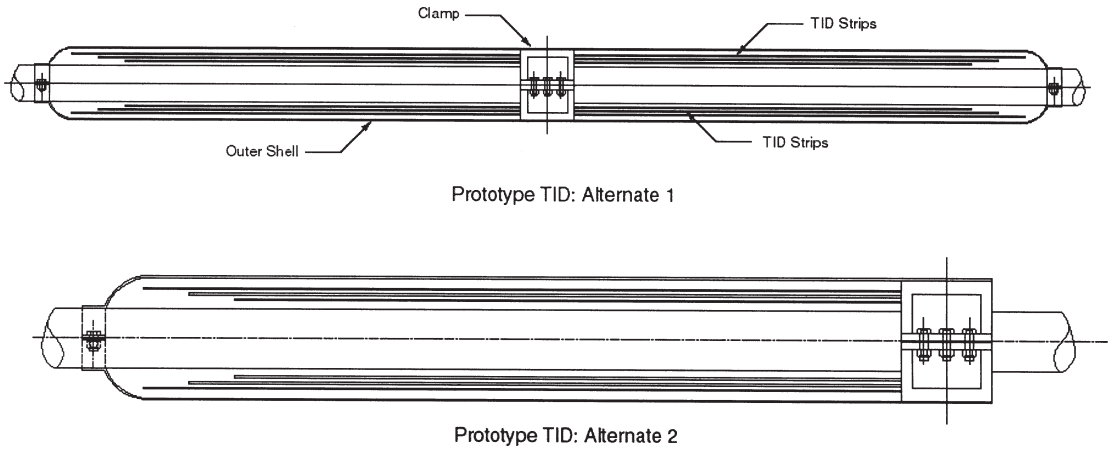

Figure 1

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.

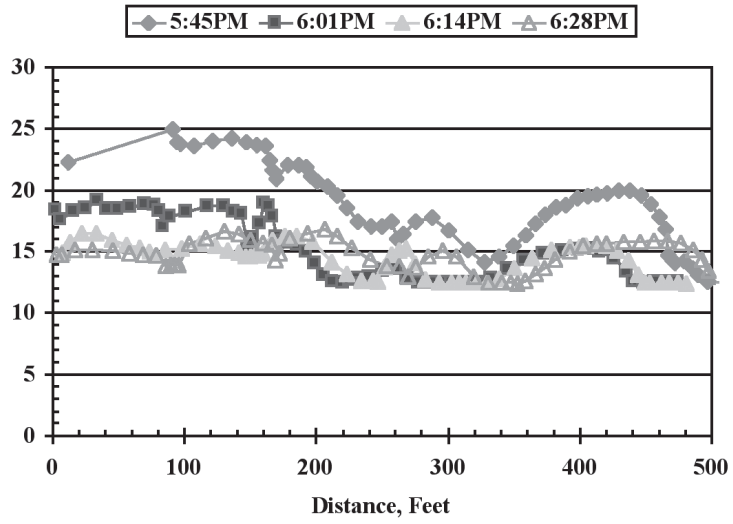

Figure 1

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.

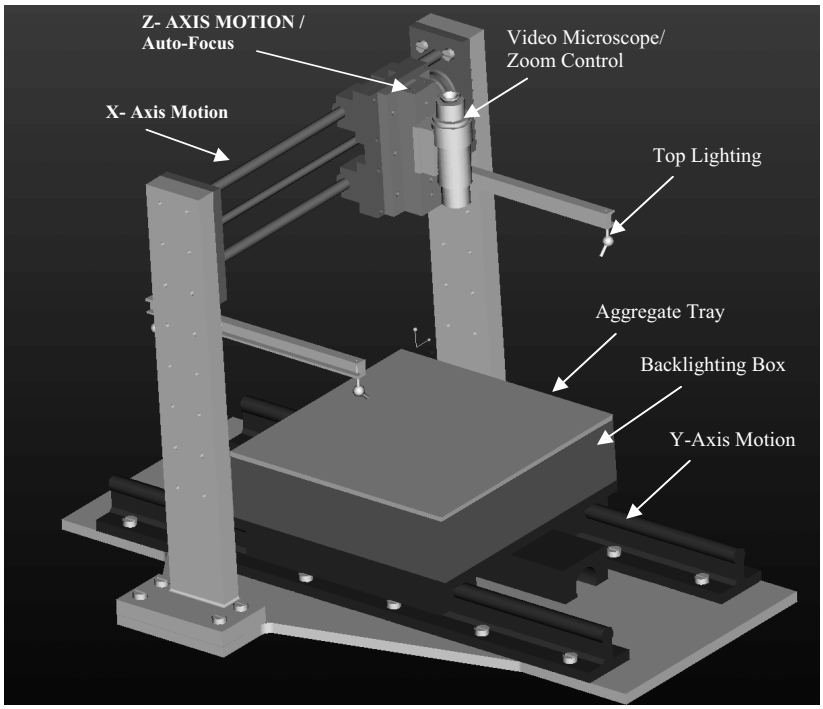

Figure 1

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.

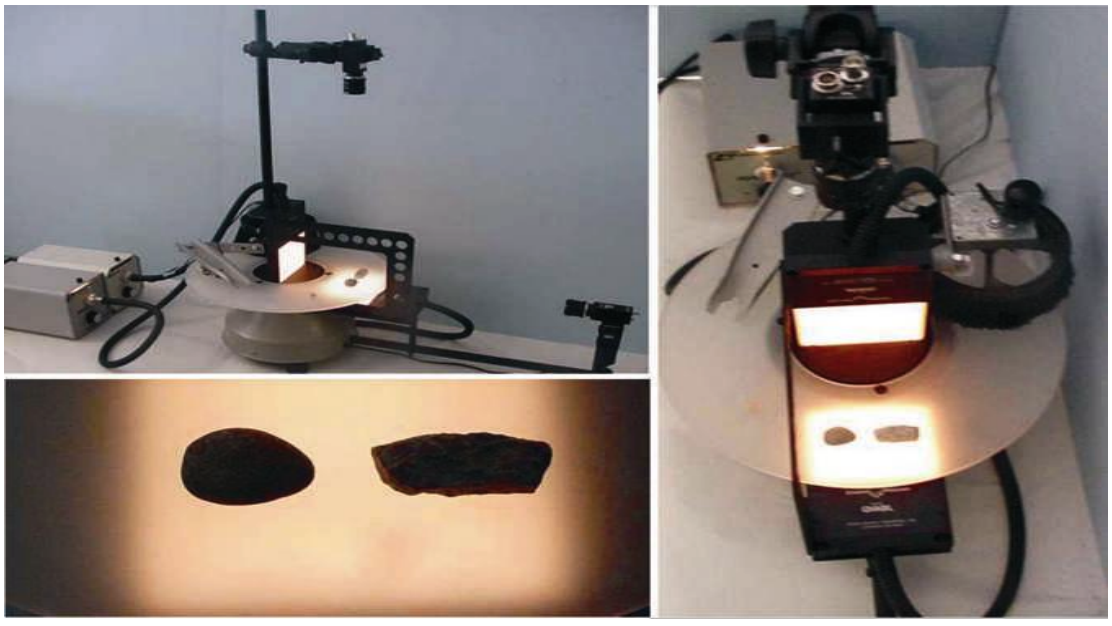

Figure 1

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.

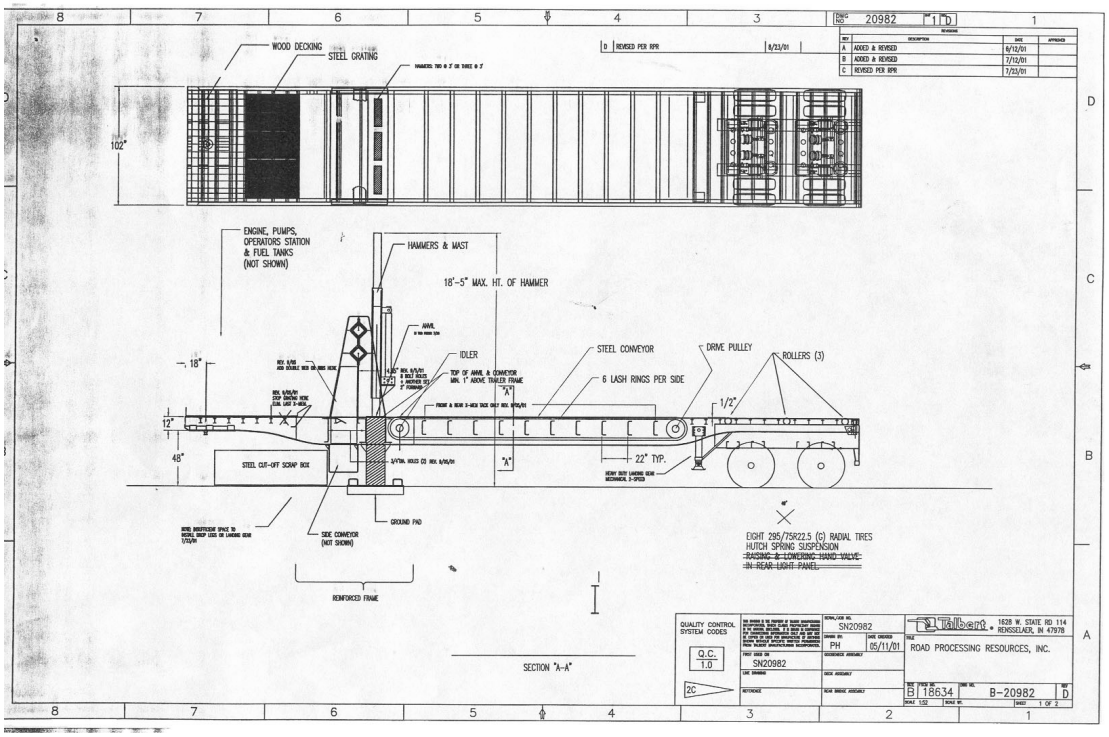

Figure 1

Schematic diagram of road recycling machine

AUTOMATED REAL-TIME PAVEMENT CRACK DETECTION AND CLASSIFICATION SYSTEM

NCHRP-IDEA Project 81

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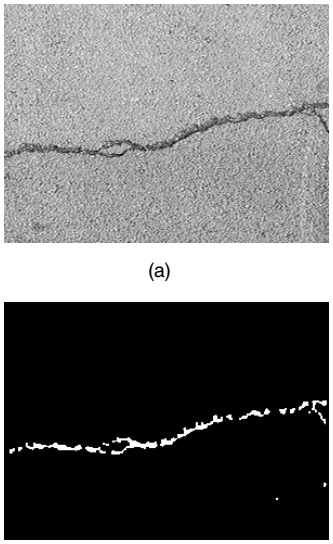
Utah State University, Logan, Utah and
Chris Glazier [Tel: (801) 965-4551],
Utah Department of Transportation,
Salt Lake City, Utah

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.

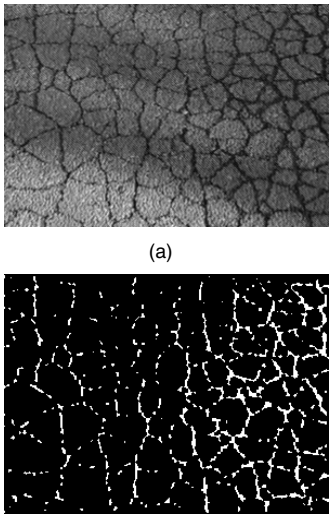


(a)

(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.

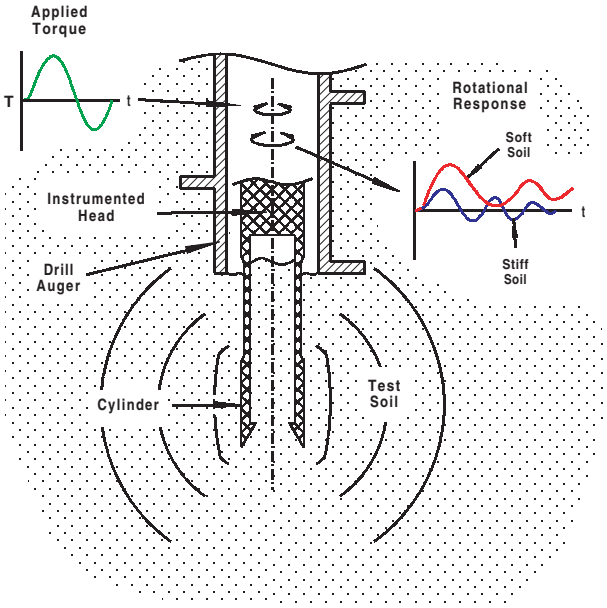


Figure 1

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

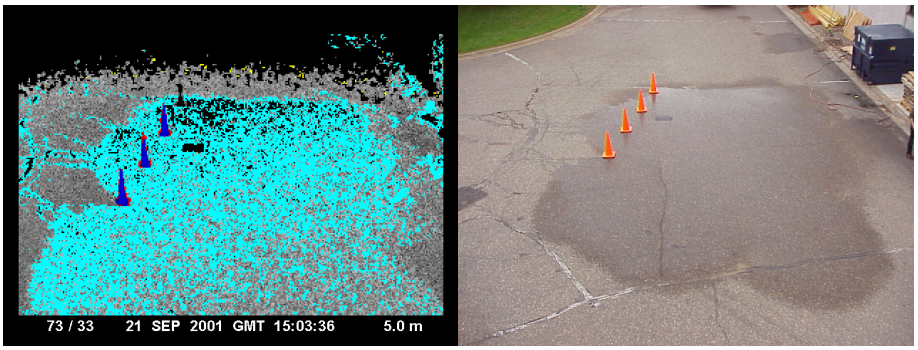


Figure 2

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

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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

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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.

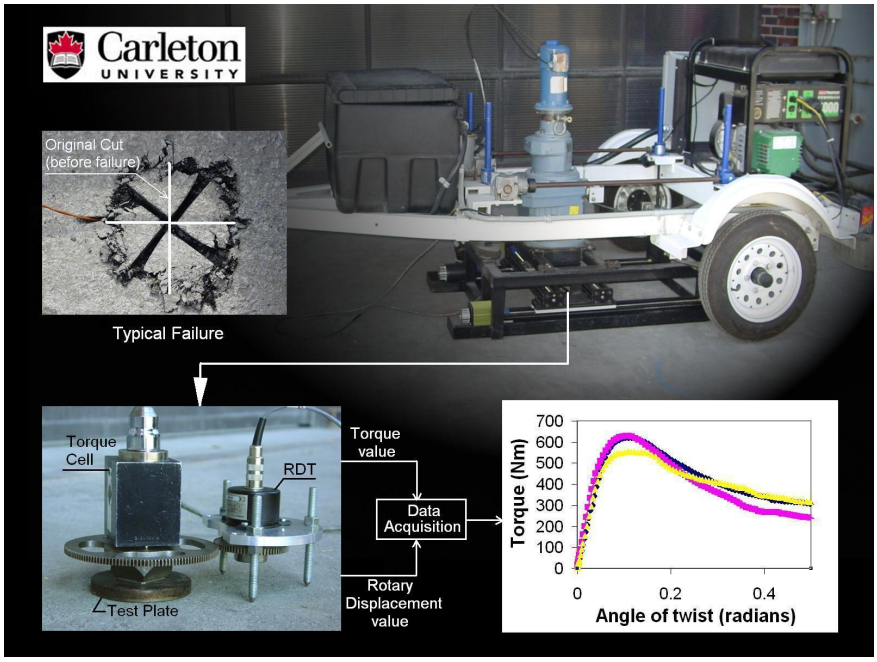

Figure 1

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

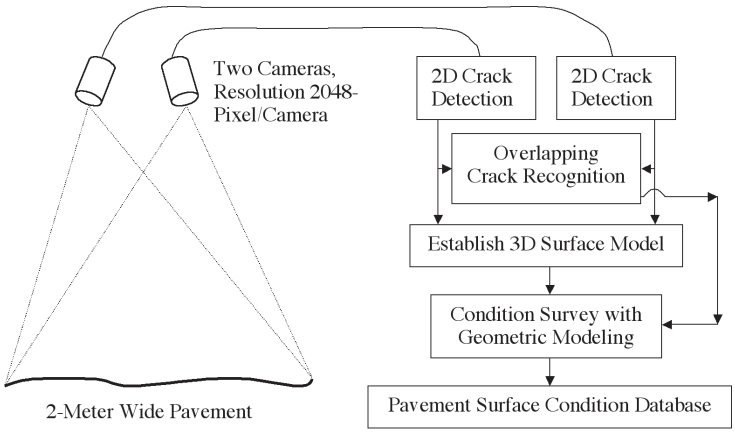

Figure 2

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

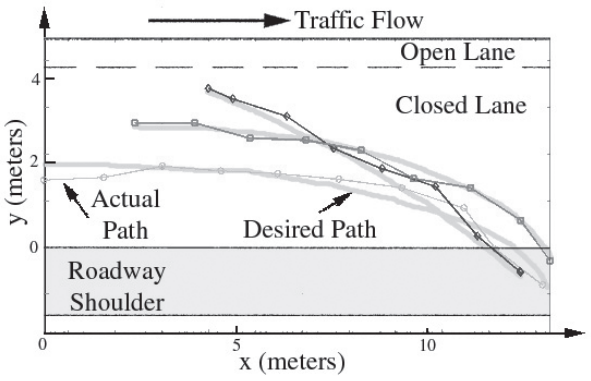

Figure 2

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.

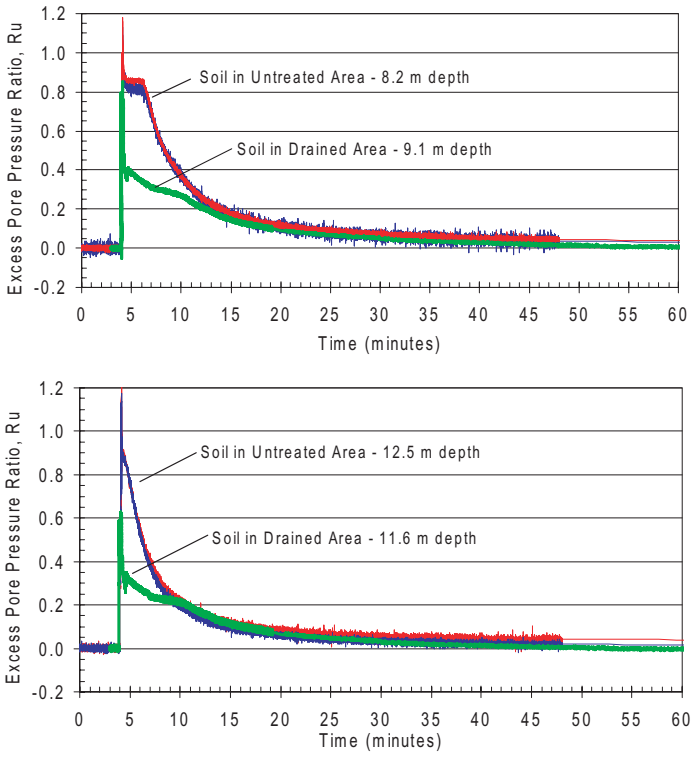

Figure 1

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.

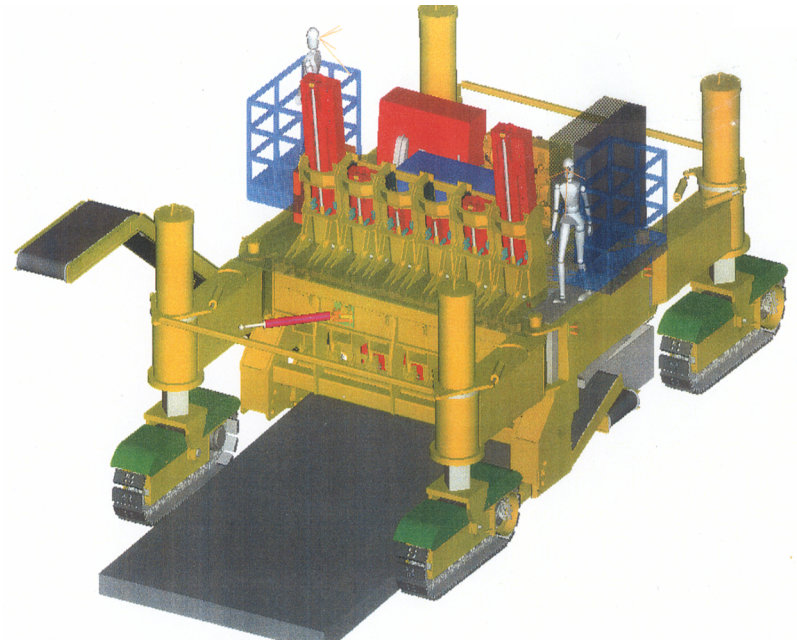

Figure 1

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.

ACTIVE HEATING INFRARED THERMOGRAPHY FOR DETECTION OF SUBSURFACE BRIDGE DECK DETERIORATION

NCHRP-IDEA Project 101

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Infrasense, Inc., Arlington, Massachusetts

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

A cost analysis estimate shows that for a standard overpass bridge, the infrared method is less than half the cost of the conventional chain dragging method and occupies the structure for one tenth of the time. For a four-lane bridge, 180 ft long and with a surface area of about 8600 sq. ft., the chain drag method cost over $7200, required 42 hours of field technician's time and 21 hours of lane closure. The infrared heating method cost about $3600, requiring only 4 hours of the technician's time and 2 hours of moving lane closure. Further field testing and demonstration is needed to implement this technology for highway application.

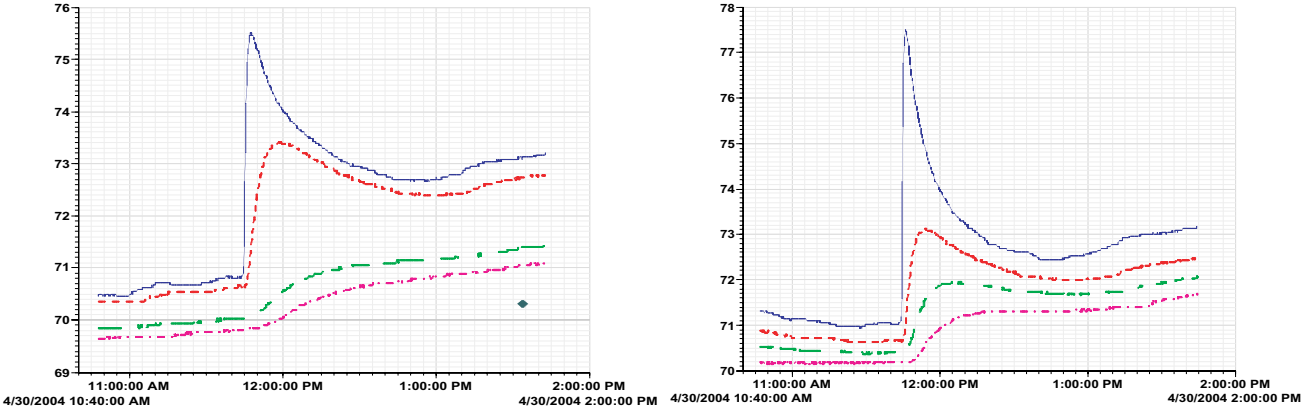

Figure 1

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

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all NCHRP-IDEA projects that were completed or active during the 2005 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 installed after having successfully passed the required TL-2 static test.

Two bridge decks on detour bridges with FRP composite decks were fabricated and installed in Kansas in the spring of 2005.

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 high flowability with high segregation resistance, which results in the self-compactability without any consolidation work even when the reinforcement is very congested. Self-consolidating concrete could reduce construction cost by reducinge the number of actions at the site, shorten the construction period and 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 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 Results

The objective of the project was to develop a guide specific to the Midwestern United States for design and use of self-consolidating concrete for bridges. Therefore, mixing requirements and specification of the components were developed. The properties of the mix and hardened concrete were tested at the University of Michigan laboratory. The SCC mix was developed using US/Midwest ingredients (cement, aggregates, water) and specific admixtures and plasticizers available on the US market. The fresh concrete mix was tested to establish required deformability, flow, and segregation resistance properties (Fig. 1). The hardened concrete was tested to find all mechanical properties required by US standards in general, and in particular those specific to bridge construction. Materials were provided by Premarc, Grand River Infrastructure, Inc., Master Builders, Sika, and Axim. The following conclusions can be drawn:

- SCC flows into formwork (through reinforcement) under the influence of its own weight; thus no external vibration is needed
- SCC has very high compressive strength compared to conventional concrete
- SCC can be produced with locally available materials, even though the mix is very sensitive to proportioning
- SCC has a tendency to segregate if too much superplasticizer is used or the water to cement ratio is too high, so quality control is of utmost importance

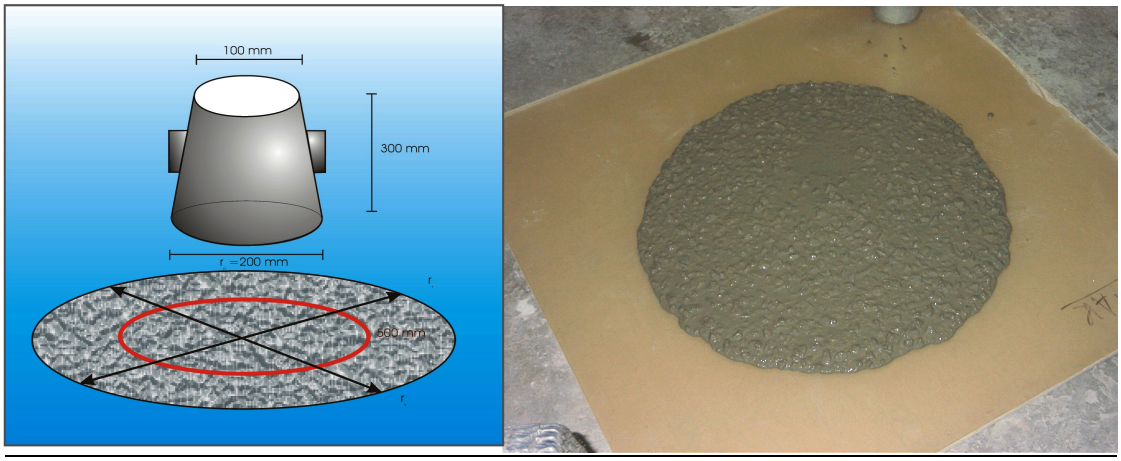

Figure 1

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

- SCC demonstrates a very good resistance to frost damage even with low air content
- SCC can be particularly useful to bridge repair projects, during new construction, and whenever dense reinforcement exists because of its good workability.

The advantages and disadvantages of the self-consolidating concrete are summarized in Table 1.

Table 1

Advantages and Disadvantages of SCC

Advantages of SCC	Disadvantages of SCC
No noise (better working environment, increased productivity, reduced health and safety risks)	Higher unit cost (SCC can be 40-60% more expensive compared to the conventional concrete)
No vibration (less wear and tear of formwork)	Sensitive mix (even small changes in proportioning may change the properties of freshly mixed concrete)
Reduction in site manpower (additional cost of SCC paid for by the ability to fill complex molds efficiently)	Segregation (when occurs, it may lead to undesirable performance)
Better surface finish	Control of workability is critical
Faster placing time (increased productivity)	Quality control (more skillful labor required)
Savings in labor and equipment (lower project cost)	Lack of industry guidance, standards and specifications
Feasibility of otherwise impossible project requirements	

Product Pay-Off Potential

The research results are directly applicable in bridge engineering practice. The final report includes the self-consolidating concrete mix design instructions, with a step-by-step description of mix preparation using local materials such as cement powder, aggregate, water, and special admixtures, and recommendations for use on bridges. The usage of SCC shortens construction time, simplifies construction procedures (self-consolidating concrete does not require any vibration), and provides 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. 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 mold 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 Michigan DOT and Nebraska DOR projects is also being considered.

APPLICATION OF SHAPE MEMORY ALLOYS IN SEISMIC REHABILITATION OF BRIDGES

NCHRP-IDEA Project 91

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IDEA Concept and Product

This research project developed seismic restraining devices made of shape memory alloys (SMA) that can be used for seismic retrofit of bridges. Shape memory alloys are a class of materials that can undergo large displacements and revert to their original shape. 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 was developed and tested. Analytical models were developed to determine the effect of these devices in typical bridges.

Project Results

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-induced phase change characteristic of shape-memory alloys is used. For some SMA, such as Nitinol (NiTi SMA), the phase change can be stress-induced at room temperature if the alloy has the appropriate formulation and treatment. Passive energy dissipation devices using SMA have taken advantage of the high damping

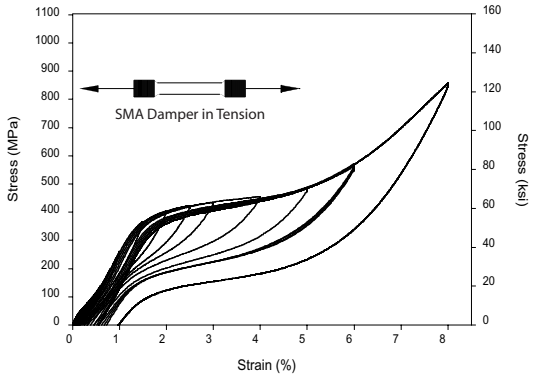

Figure 1

(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.

characteristics of these devices. This research investigated using SMA restrainer rods and cables to dissipate energy and recenter at the intermediate hinges in a bridge. The restrainers have multiple roles. First, they can limit the relative displacement between frames, thereby reducing the risk of collapse due to unseating of frames at the hinge. Second, by concentrating energy dissipation in controlled locations, these devices can be used to reduce the demand on individual frames in a multiple-frame bridge, thereby enhancing the performance of these structures.

Experimental tests of SMA bars and wires provided detailed information on the force-displacement relationships, recentering capability, effects of loading frequency, temperature, and material size on the strength of the devices. Analytical studies have been performed, based on experimental results of the SMA restrainers. The analytical studies illustrate that SMA rods may be very effective in limiting hinge displacement in bridges (Figure 2). The energy dissipation characteristics help reduce the displacements in bridges due to earthquake loads 25-50% more than conventional steel cable restrainers.

A $^1/_4$-scale bridge test, shown in Figure 3, was performed in the laboratory to assess the performance of SMA-based restrainer devices. The device showed that SMAs are very effective in limiting displacements in bridges, and validated the results of previous analytical studies.

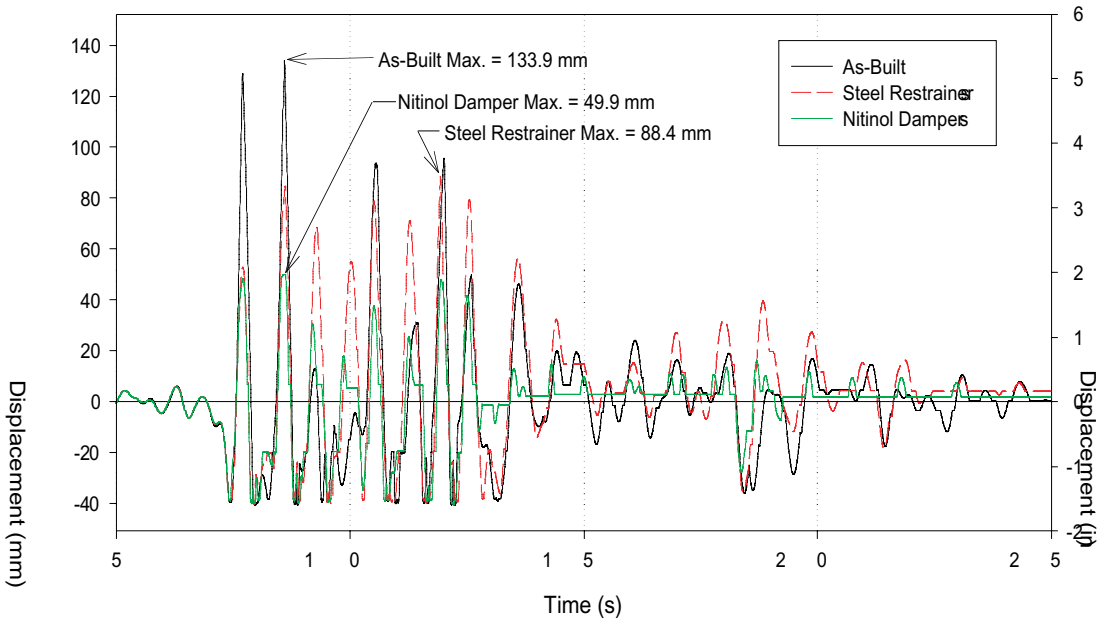

Figure 2

Results of Analysis Showing Relative Hinge Opening with Steel Cable Restrainers and SMA Restrainers.

A detailed cost analysis showed that while SMA restrainer cables are slightly (approximately 13%) more expensive compared to traditional steel restrainer cables, the improvement in bridge performance may warrant the increased cost. Also, when considering life-cycle costs, and the cost to replace damaged steel restrainer cables, the use of SMA restrainer cables may be a more cost-effective option.

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. This technology has significant potential to replace the restrainer cable technology currently used in the United States.

Product Transfer

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.

Figure 3

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

DEVELOPMENT OF AN ADAPTIVE DAMPER FOR CABLE VIBRATION CONTROL

NCHRP-IDEA Project 92

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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.

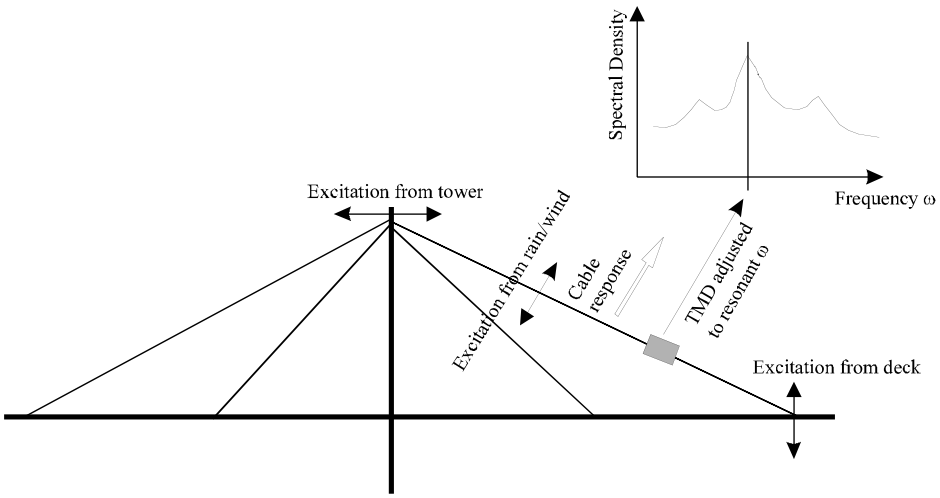

Figure 1

Sketch of cable vibration control

Project Results

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 laid a foundation for Phase 2.

The Phase 2 study mainly focused on developing the MR-TMD system. The performance of the MR-TMD was investigated. After Phase 2 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 was tested. The design was refined according to the observed performance. The measured performance of the damper is shown in figures 2 and 3. Recommendations have been made and conclusions have been drawn.

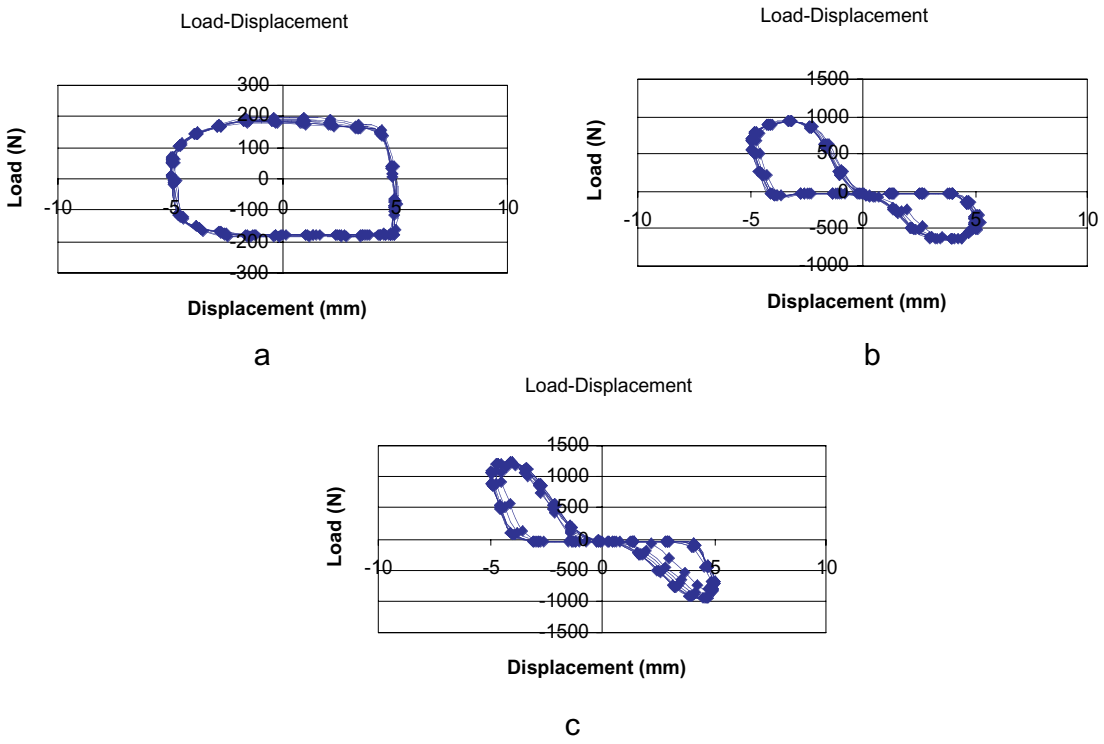

Figure 2

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

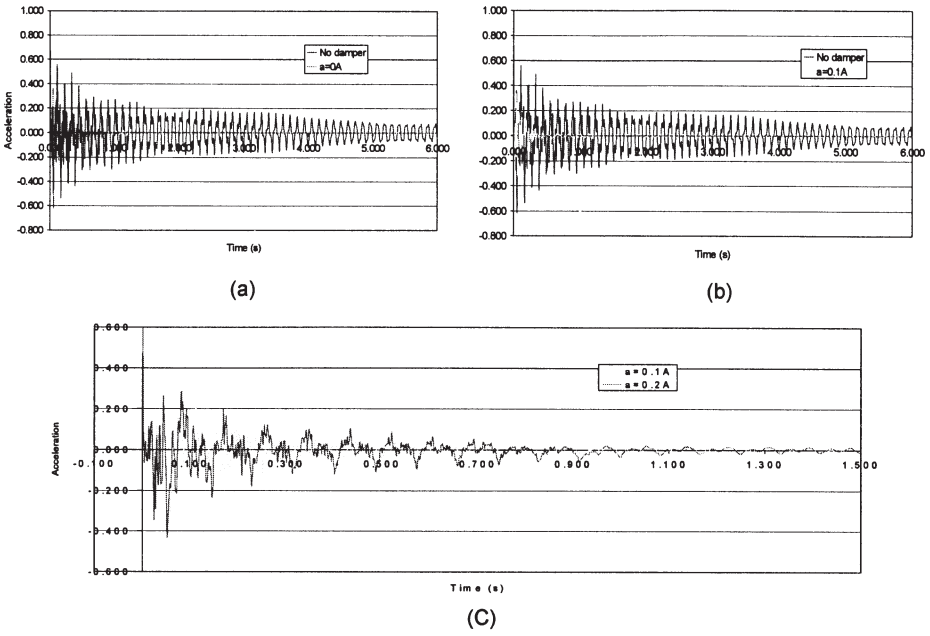

Figure 3

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 Center (TMC).

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 is based on solar power and rechargeable batteries.

Investigation

The project's objective was to design, develop, test, and document an Advanced Relocatable Traffic Sensor (ARTS) System for application to construction work zones and roadway incidents as shown in Figure 1.

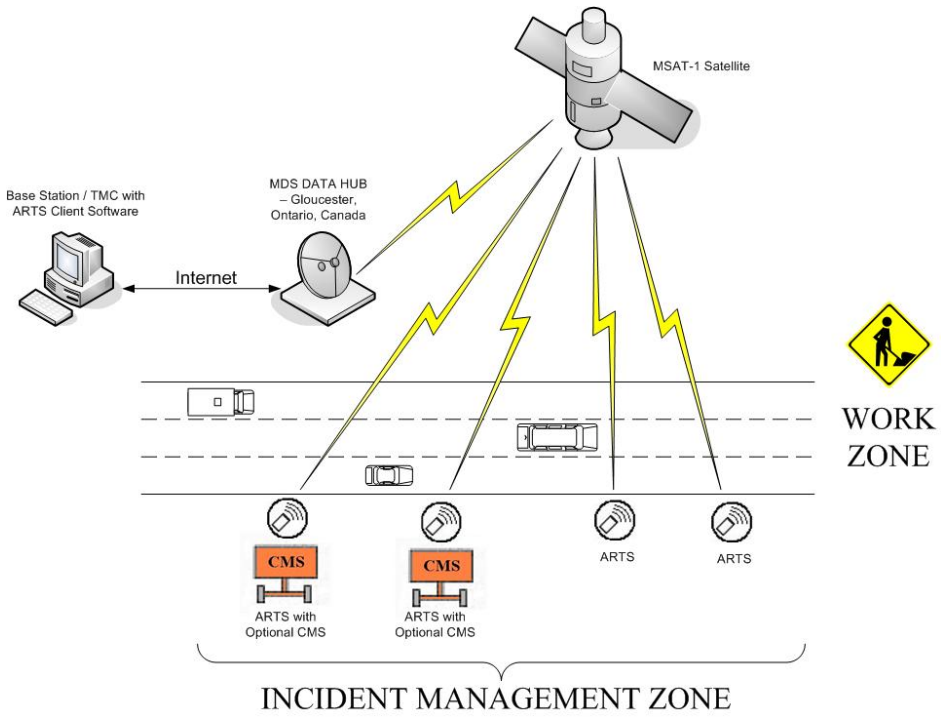

Figure 1

Advanced Relocatable Traffic Sensor for Work Zone and Incident Management Systems

The ARTS Prototype

Figure 2 shows the high-level design of the ARTS Sensor System. An electronics interface board integrates the major components of the system, consisting of a microwave radar sensor system, a digital compass, a solar portable power system, and an interface to the wireless communication system (PDT-100). The single-board computer houses software that will control operations of the ARTS system and thereby manage operation of the intelligent sensor system.

Technology literature and product information were researched and reviewed relative to project objectives in deciding specific hardware components for the ARTS System. The final selection of system components is documented below.

Microwave Sensor

The System Interface (SI-2D) manufactured by Decatur Electronics, Inc., is a radar sensor using a K-band antenna. The SI-2D processor board tracks target speeds from processed raw Doppler signals generated by the microwave transceiver. The SI-2D antenna is directional, meaning it can be set to track targets moving toward or away from it. The SI-2D antenna detects targets within the range of 5-200 mph (8-320 Km/h).

Single-Board Computer

Researchers preferred a small, single-board computer with low power consumption, that was able to withstand shock, vibration, and extreme temperature, and that would allow connectivity and expandability with the most commonly used input/output (I/O) interfaces. Octagon System's 6225 Palm-Size Single-Board Computer was selected to meet these requirements.

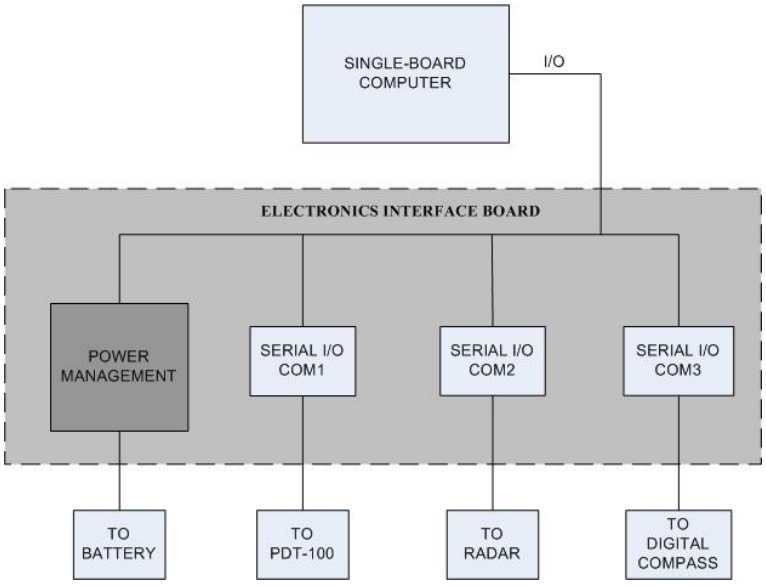

Figure 2

ARTS Schematic

Angle Sensor

The Honeywell HMR3300 Digital Compass was selected for the ARTS design as it is very compact, provides 3-axis support, and interfaces easily with the single-board computer. The Digital Compass provides the ARTS the necessary information to check whether it shifted from its original position. A certain shift angle threshold can be set and when exceeded, due to heavy winds or drafts caused by trucks on the highway or for any other reason, a warning can be sent to the host / base station computer that the ARTS may not be getting accurate speeds.

Electronics Interface Board

The Electronics Interface Board was designed and developed to integrate the major components of the ARTS System. It requires a 12 V DC input from which it provides a regulated 5V DC power to the single-board computer and a regulated 12V DC power to both the microwave radar and the digital compass. The PDT-100 Satellite Packet Data Terminal comes with a 7.5A fuse which was integrated into the cables extending from the fabricated outdoor enclosure and which directly draws its power from the Solar Portable Power System. The Electronics Interface Board has built-in fuses to protect system components from power surges and spikes. It was designed with three serial port interfaces, allocated for the PDT-100 Satellite Packet Data Terminal, the microwave radar, and the Digital Compass.

Solar Portable Power System

The Solar Portable Power System for the ARTS prototype consists of the XPower Powerpack 400 Plus and the SunWize OEM10 Solar Panel. It has an internal, sealed, 12V, 20Ah, AGM (Absorbed Glass Mat) lead acid battery and a battery charging controller system for the battery. Charging the batteries can be done by either plugging the AC charger to a standard AC outlet, or by plugging the DC charging cable into a vehicle's lighter socket or 12V accessory outlet or a generator's 12V DC outlet, or from a solar panel. It also has low battery protection, wherein an audible alarm sounds when the internal battery is nearly discharged (11.0 VDC) and the unit turns off at 10.5 VDC. Once the internal battery is fully charged, the charging current automatically reduces to a maintenance charge mode, and it may be left permanently connected to the AC charger or the solar panel.

Wireless Communications System

The particular satellite communication system selected for use with ARTS, the PDT-100 Satellite Packet Data Terminal, is from EMS Technologies, Inc. The system operates as a Specialized Services Mobile Terminal within the Mobile Data Services (MDS) satellite communication network operated by Mobile Satellite Ventures (MSV). One PDT unit consists of the antenna, transmitter, receiver, GPS, and RS-232 connection, all contained in a rugged 3lb enclosure.

ARTS System Software

Software for the ARTS System consists of the client software that is run from a Traffic Management Center or host/base station computer and the embedded software for the single-board computer that provides first level control of the ARTS system components.

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,
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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. A preliminary design method and an example were developed as part of this project.

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 FRP-concrete bond strength with increase of strain rate. Bond strength is directly related to concrete strength and the strain rate effect seen in FRP/concrete interfacial bond is due to the sensitivity of concrete strength to strain rate. 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 conventional steel restrainers and was comparable to shape memory alloy restrainers in reducing relative hinge displacement.

Project Results

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 large-scale model of an in-span hinge (Fig. 1). The hinge model was tested with different FRP restrainers until failure of the restrainers. Artificial earthquakes replicating response spectra for soft soil were 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. Figure 2 shows the effectiveness of GFRP restrainers in reducing the relative hinge movement. In the proposed simple restrainer design method, bridge frames are combined into a single-degree-of-freedom system (Fig. 3). Using the response spectra and the period of the combined system the maximum displacement is found and from equilibrium the design restrainer force is determined. An illustrative example has been prepared to demonstrate the proposed method.

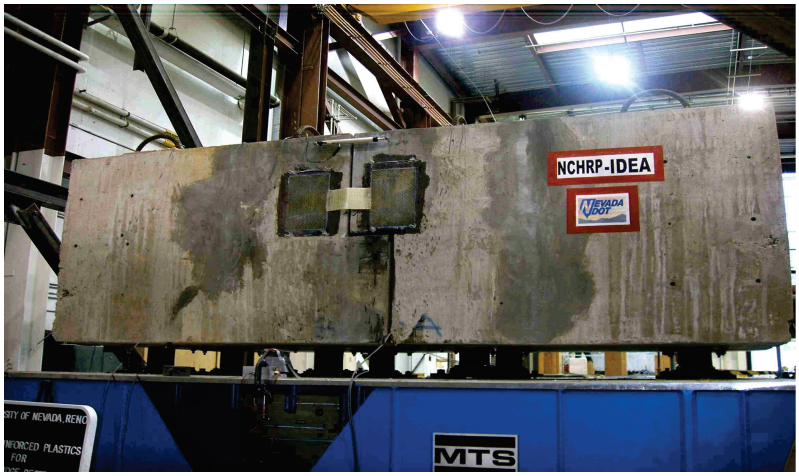

Figure 1

Full-scale model of in-span hinge

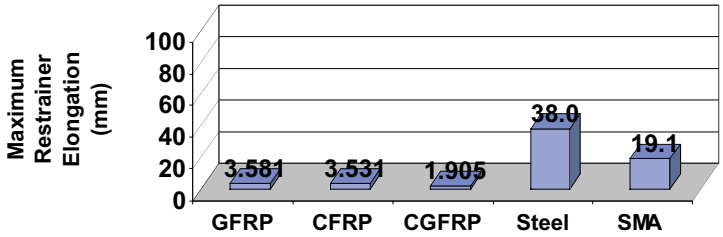

Figure 2

Measured elongation of different restrainers

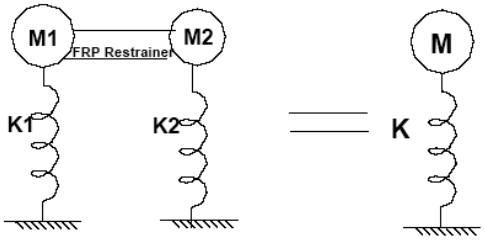

Figure 3

New restrainer design method

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 a worthwhile alternative to steel restrainers.

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 current study has explored 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, a simple new design method has been developed. An advisory panel consisting of bridge engineers from different state transportation agencies has been assisting the researchers by providing feedback. Suppliers of FRP fabric products provided input in better utilization of FRP restrainers. The final project report has been prepared and 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

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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.

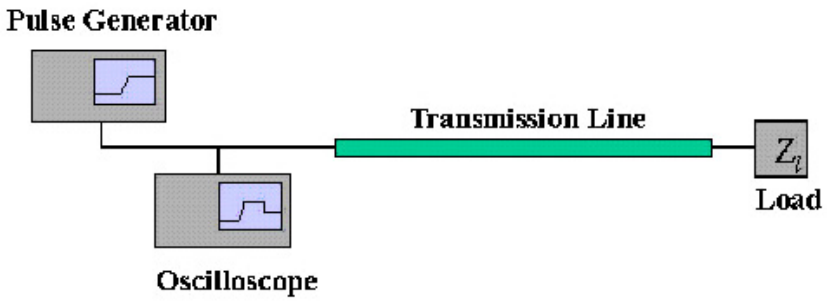

Figure 1

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.

Project Results

The research program is addressing the following questions:

1. Can TDR be used to effectively identify voids in grouted post-tensioning ducts?

2. How do 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).

3. How can the methodology be implemented successfully and economically in the field?

Detection of voids by using TDR with an internal sensor has been studied and evaluated. The basic possible geometries of the internal sensing transmission line have been studied, and the most applicable and flexible geometries have been identified. It has been confirmed that voids can be detected by using a single sensor wire in conjunction with an existing tensioning cable to form the two-wire transmission line. However, voids can also be detected by using commercially available transmission lines, such as lamp cord or 300 ohm TV cable as the sensor. These commercially available lines provide uniform geometry over their length and are relatively inexpensive. Detection of voids by using TDR with an external sensor has also been studied and evaluated. For external detection, the problem becomes more complex, because the reflected signal strength may be weaker and background noise reflections from other structural elements may make the signal difficult to measure. The methods used in internal detection must be modified for external detection. Possible variations include the change of the shape of the sensor wire, as well as the selective usage of single steel strands existing in the structure. The effects of different dimensions and geometry on signals measured externally were studied and evaluated. The effect of increasing the peak pulse voltage was also studied. Data indicate that transmitting a larger pulse voltage can be expected to improve the signal-to-noise ratio.

Factors that could influence the void detection signal have been identified and their effects on the signal have been quantified. The presence of sand, water, or moisture in the void tends to decrease the positive amplitude of the reflected TDR signal. However, in all cases tested, the void was still detectable. In fact, in the case of a water-filled void in concrete, the negative amplitude of the reflected pulse was larger than the positive pulse from an empty void, making the water-filled void easier to detect. Compared with water, which could be dissipated after a short term, moisture is a long-term factor that influences the void signal. The moisture could

come from water residue in the void or moisture penetration from outside the void. The moisture level appears to play a consistently significant role among the factors, while water, if it exists, plays a dominant role. This feature is illustrated by the data shown in Figure 2. The positive-going peak of the empty void is taken as 100%. Then the effects of sand, moisture and water filling the void are shown with the resulting reduction in the magnitude of the positive-going pulse that each produces. In the case of water, the 112% change means that a negative-going pulse results. Differential measurements would show a 212% change due to water.

In Stage 1 of this project the work was concentrated on detecting voids by TDR using an internal sensor. Stage 2 of this research concentrated on developing methods of void detection using an external sensor wire, such as would be necessary in the case of retrofitting existing structures. Data has been collected that indicates that voids can be detected with an external sensor, but the void signal is much weaker than that observed in internal detection. This weaker signal may be strengthened by use of a pulser with higher output voltage. Results have shown that, in the laboratory, 1 inch diameter voids can be detected with an external sensor spaced up to 3 inches away, using an output pulse voltage of 200-250 mV and a rise time of 40-100 ps. An ideal pulse generator for lab research also should have low-reflection connections and high data output resolution. In field practice, the situation is not necessarily more complicated; there can be mitigating factors. For example, when dimensions of the structure under test are much larger than the 1 meter size of laboratory samples, the situation actually becomes simpler, in that pulses of greater width can be used. Some commercially available TDR meters with peak pulse amplitudes of several volts, may be applicable to void detection in the field.

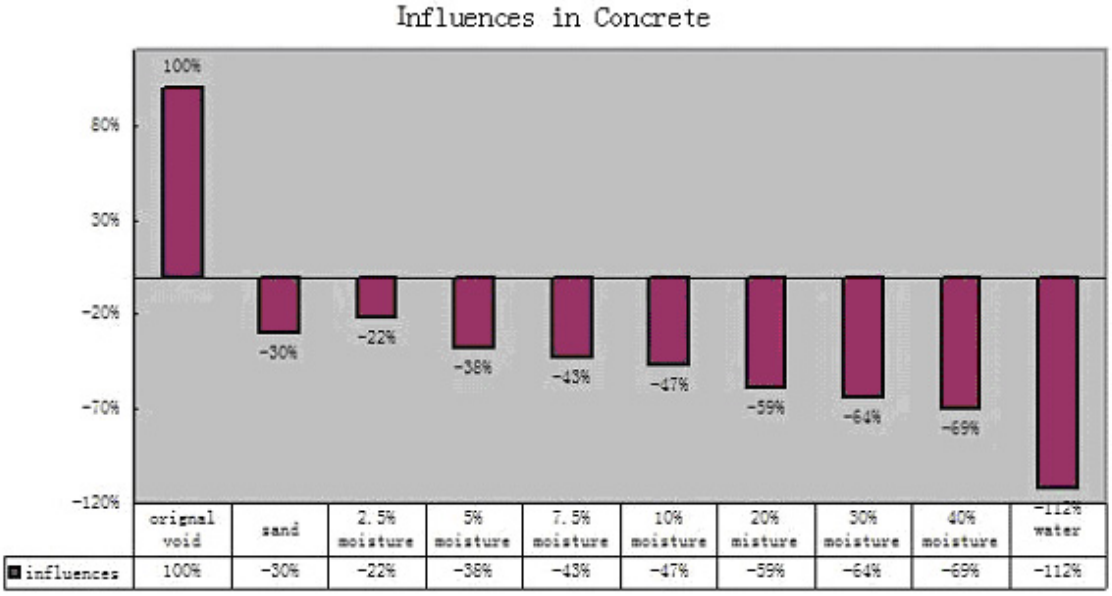

Figure 2

Comparison of different factors

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 and on others in Texas, as reported by M. Shadawy of SDR Engineering Consultants at the 2005 TRB Bridge Engineering Conference. 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 has demonstrated that TDR can be used effectively in this application.

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. Current plans include extensive use of TDR for monitoring post-tensioning cables in the soon-to-be-constructed Indian River Inlet Bridge in Delaware. Other applications are being considered.

DEVELOPMENT OF ASPHALT BINDER CRACKING DEVICE

NCHRP-IDEA Project 99

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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 surface-mounted resistance temperature detector is also installed inside of the tube to closely monitor the specimen temperature.

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 2 illustrates typical ABCD test results obtained in this study.

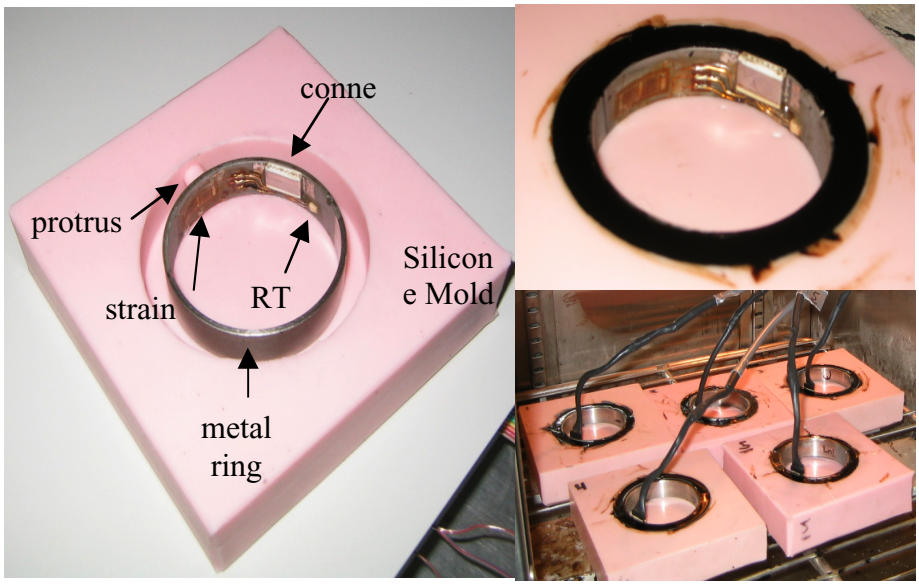

Figure 1

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

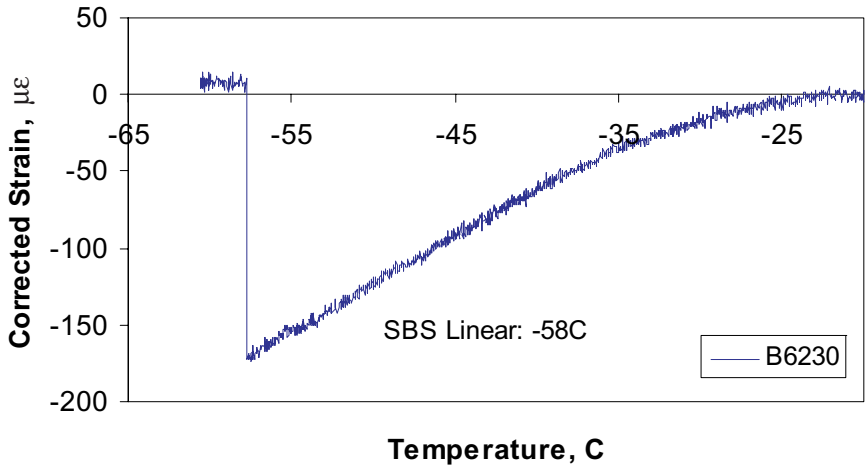

Figure 2

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 was 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. Recently, the ABCD rings were reconfigured to be sturdier and to provide accurate cracking temperatures. The repeatability of the ABCD tests performed on various asphalt binders is markedly improved with less than 1.0°C standard deviation.

In a comparison with the Thermal Stress Restrained Specimen Test (TSRST) using various modified and unmodified asphalt binders, ABCD results showed the strongest correlation; better than AASHTO M320 and MP1a.

ABCD results were further validated with the Pennsylvania Test Road. In 1976, six AC-20 asphalt binders from different sources were used to construct six test pavements at Traffic Route 219, Elk County, Pennsylvania to study low-temperature performance and durability. The project was well documented and the low-temperature performance of the pavements was measured using Cracking Index (CI). Samples of these six asphalts were saved for later studies. During SHRP, the saved asphalts were used to validate TSRST and later again used to validate M-320 specification. The remaining asphalts (from 100 to 400 grams) were used to validate ABCD. Four months after construction, T1 and T5 test pavements cracked with recorded minimum air temperature of -29°C. Four years after construction, T2, T4, and T6 test pavements cracked with the recorded minimum air temperature of -32.8°C. T3 test pavement never cracked during the seven-year test period.

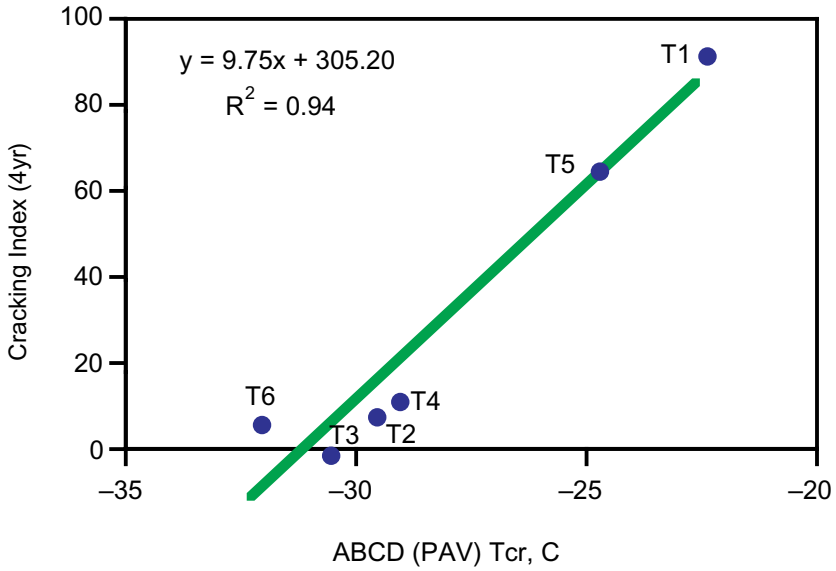

Figure 3

ABCD cracking temperature versus 4-year cracking index for Pennsylvania test pavement

Table 1

Properties of AC-20 asphalts used in Pennsylvania Test Road

Asphalt Type	Crude Sources	Method of Refining	Cracking Index after 4 years[1]	ABCD (PAV) (°C)	TSRST[2] Fracture Temp, (°C)	M-320[1] Critical Temp, (°C)	
						RTFO	PAV
T1	49% Sahara, 21% W. TX, 21% MT, 9% KS	Vacuum Distillation and Propane Deasphalting	92	-22.4	-19.3	-22	-18
T2	66.7% TX Mid-Cont., 33.3% Arabian	Steam Distillation	9	-29.7	-22.7	-28	-17
T3	85% Light Arabian, 15% Bachaquero	Vacuum Distillation	0	-30.7	-24.0	-28	-26
T4	75% W. TX Sour, 25% TX and LA Sour	Vacuum Distillation	12	-29.2	-25.4	-26	-23
T5	Same as T1	Vacuum Distillation and Propane Deasphalting	64	-24.8	-19.8	-24	-22
T6	Blend of Heavy Venezuelan and Middle East Crude	Vacuum Distillation	7	-32.3	-26.9	-30	-28

Data taken from
1. Kandhal et al (1996) AAPT 65
2. Kanerva et al. (1994) SHRP A-401

ABCD cracking temperatures for PAV residues showed very strong correlation with the 4th year Cracking Index with coefficient of determination, r^2, = 0.94. ABCD results of RTFO residues also showed strong correlation with CI with r^2 = 0.97.

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. Binders collected from 12 districts of Ohio DOT are being tested with ABCD. As the field performance data become available, they will be used to calibrate ABCD test criteria for specification purposes. After a successful completion of ABCD test validation, a pooled-fund study will be initiated.

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

NCHRP-IDEA Project 100

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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.

Project 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. A secondary production method whereby the Al-Zn-In alloy is thermally sprayed onto an aluminum mesh is also being investigated. Stage 2 is to install the anode on 1,000 to 2,000 square feet of a bridge deck surface to evaluate the anode performance. Approximately 550 sq ft of the thermally sprayed mesh was installed on a bridge deck on Interstate 44 in Cuba, Missouri, in July 2005. 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.

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

NCHRP-IDEA Project 102

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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

The current practice for Impact Echo testing was evaluated at the beginning of the project for reliability. This task extended the previous work of the principal investigator and the Olson research team in the development of the Impact Echo Scanner (See Figure 1).

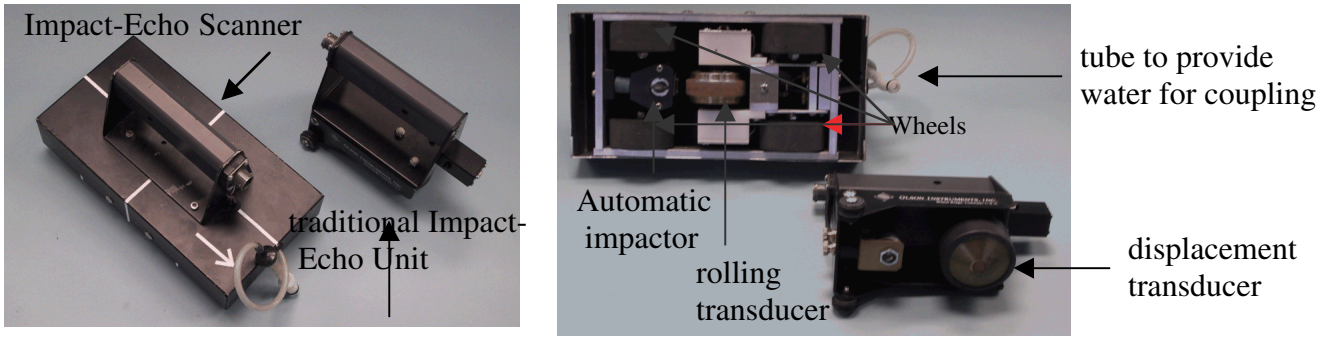

Figure 1

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

In the first stage, the sensitivity of the current Impact Echo was being studied on mock-up specimens with ducts and known defect sizes. To facilitate the analysis part of the IE scanning, the research team developed a software package for three-dimensional Impact Echo Scanning.

A full scale precast bridge girder with eight internal steel ducts (as shown in Figure 2) was used in the experiment. Styrofoam was cut in different sections and used to simulate voids inside the ducts. The IE results in a 3-D fashion from the South Wall with the actual defect design of the top duct placed above the IE results of the top duct are shown in Figure 2. The results are interpreted to indicate that the grout defect started to appear at a length of 1.93 m (76 in) and becomes clearly evident at a length of 2.92 m (115 in) from the west end of the duct. The location where the defect starts to appear corresponds to void with 11% depth lost or 20% circumferential perimeter lost. The location that the grout defect become more evident corresponds to void with 59% depth lost or 57% circumferential contact diameter lost. The dominant frequency of the fully grouted duct is approximately 6.4 kHz, resulting in an apparent impact-echo thickness of 28.37 mm (11.17 in.). The dominant frequency shifted to approximately 5.37 kHz for an empty duct, which corresponds to an apparent impact-echo thickness of 34.0 cm (13.4 in.). This is a relatively large thickness shift of over 30% compared to the nominal thickness of the wall. The interpretation of the impact-echo scanner results, however, shows a downshift in frequencies from lengths of 5.49 to 6.1 m (216 to 240 in), indicating voids at duct locations where no discontinuities were intentionally placed. It is likely that grout did not flow into the east end due to the big voids in front of it. Radiographic tests will be performed in the future to verify the design versus actual conditions of the simulated defects.

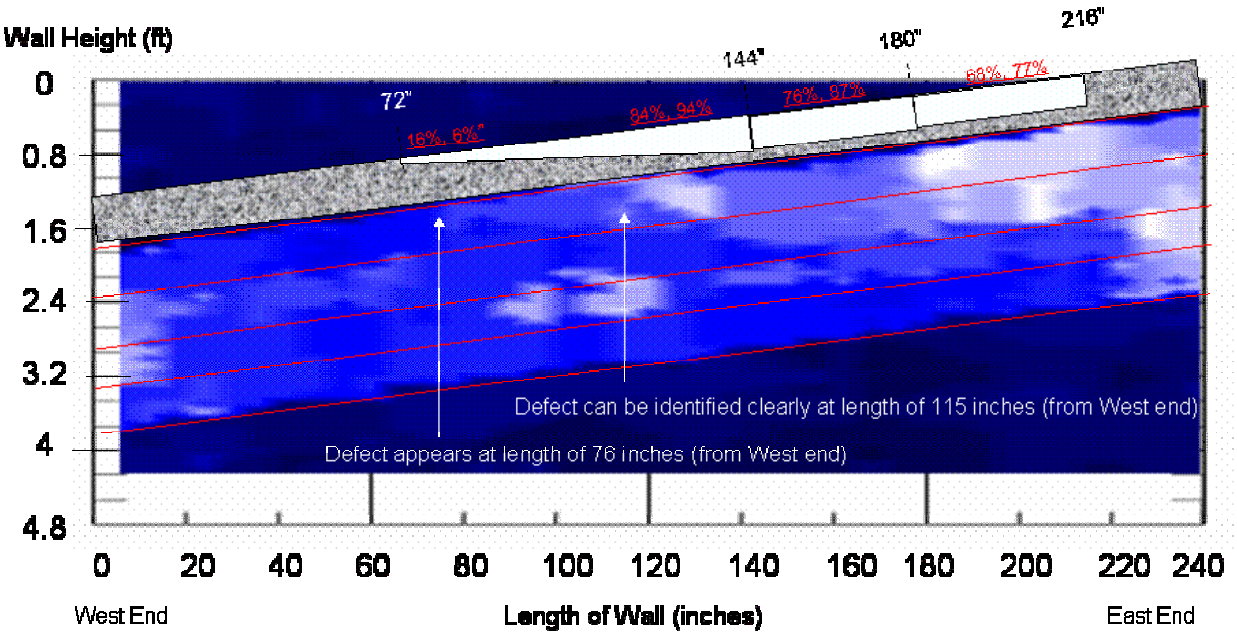

Figure 2

Impact echo scanning results in 3-D from the south wall with actual design defects of top duct

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.

Product Transfer

The benefits of this research will be immediately available to state DOTs and other bridge owners. 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

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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.

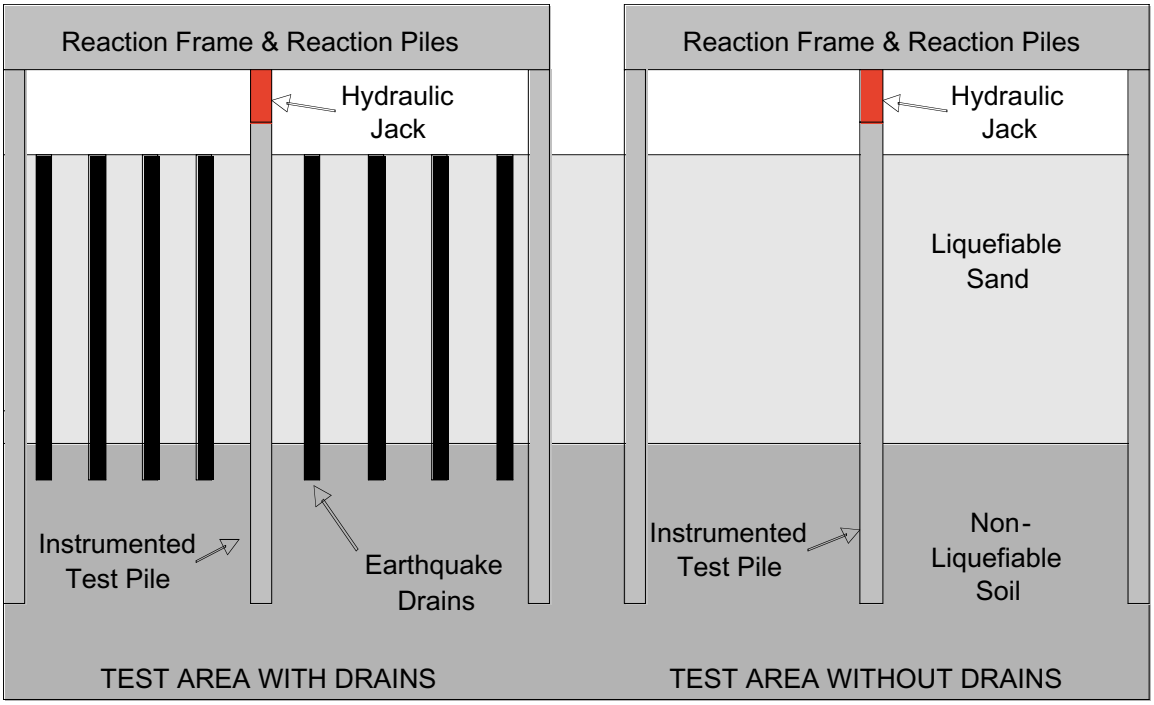

Figure 2

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.

IMPROVED LOW-TEMPERATURE AND FATIGUE PERFORMANCE GRADING OF ASPHALT BINDERS

NCHRP-IDEA Project 104

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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 products of this IDEA effort are four improved laboratory standard test methods for low-temperature and fatigue performance grading of asphalt binders. The new methods better recognize the importance of chemical and physical hardening as well as fatigue cracking as potential aggravating factors in low-temperature failure. An advantage of the methods is that no new equipment is required; all tests can be done with only slight modifications to the instruments originally purchased for the SHRP BBR and 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.

Project Results

To come to a definitive field validation of the proposed fracture mechanics-based specification system, it was imperative that new test sites be constructed with a number of carefully chosen binders. All binders should possess a similar 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 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.

In addition to the first pavement trial, the Ministry of Transportation of Ontario has now approved two additional trials. One will be located on Highway 417 just east of Ottawa while the other will be constructed just south of the first trial on Highway 655 north of Timmins.

Figure 1

Typical 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 deliverables from the proposed effort are as follows:

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

These four methods provide a practical and improved low-temperature and fatigue binder specification tests. 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 Highways 417 and 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

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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 involves the development of a novel 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 under development will achieve three key objectives: laboratory-quality precision, portability, and ease of use, 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.

Project Results

Stage I of the research involved a critical evaluation of several innovative methods for measuring the wcm of fresh concrete. Stage II of the project, now underway, involves the development of a functional prototype to implement the most promising of the methods evaluated during Stage I.

During Stage I of the project, the investigators experimented with various methods of quantitatively characterizing the amount of water and cement, or water/cement ratio, in a specimen of fresh concrete. Several mini-experiments were performed to identify the techniques having the highest potential. Of the techniques evaluated, the following techniques were of particular interest:

- Turbidity (via the prototype Kansas Water-Cement Meter),
- Standard-Addition & Fluorescence,
- Gamma Radiation Absorption, and
- Unit Weight / Specific Gravity.

Stage II of this NCHRP IDEA project will focus on the development of a device to consistently and reliably implement the Unit Weight / Specific Gravity method.

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 the intelliRock Concrete Quality Control System, which was jointly developed by Nomadics and Strategic Solutions International. 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

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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.
7. The system can process the images of the concrete and asphalt pavements automatically.

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

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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.

Project Results

The Caltrans projects originally selected for demonstration were delayed due to state funding problems in 2004 so it was necessary to seek new projects. By March 2005, the Donner Road Rehabilitation Project along I-80 (Figure 1) and the Cherry Avenue Four-Lane Project along State Route 119 were chosen.

The Donner Road project is already planned and at the specification/bid preparation stage, thus requiring only narrow application of the scoping technology. The Cherry Avenue project, in contrast, is at the early design stage of development, ideal for the broad scoping approach. These two projects are situated in very contrastive settings, high rocky mountainous terrain and low desert valley, providing an opportunity to demonstrate both the broad scoping and narrower capabilities of the technology while showing it's usefulness at different project stages. Equally important, these projects, while highlighting capabilities, will also be useful for identifying technological limitations.

Figure 1

Donner Road Rehabilitation Project

This road widening project is situated between Donner Summit and Truckee, along I-80 A four-mile long segment of the west-bound lanes was delineated for study, ranging from 6400 feet to 5945 feet in elevation. The primary concerns for this project are constructability and the desire to limit claims for conditions differing from contract specifications, especially for transverse drainage pipes. A secondary interest is in determining the usefulness of the technology for roughly mapping the geology, differentiating between reaches of glacial till, near-surface bedrock, and boulders in fill. Borelogs were used to groundtruth and assess the usefulness of the EM dataset produced.

Data processing includes combining aerial images of the project area with Caltrans construction details, geo-referenced geophysical transect data, and surface features (such as metal objects and overhead electrical lines) observed in the field which were tagged with GPS coordinates. First Order and Second Order levels of data analysis provided an overall depiction of the geophysical data, and specific details of selected areas respectively. Preliminary results provided first and second order data analyses of the geophysical survey data, incorporating data from drilling operations in the project area to delineate geological units. Third order data analysis included 3-dimensional subsurface imagery of the detailed study area to resolve oversized boulders.

Cherry Avenue Four-Lane Project

This bypass project around the towns of Dustin Acres and Valley Acres is in the beginning design phase. It is a 5-mile long, 400-foot wide corridor, ranging in elevation from about 400 to 320 feet above sea level. Several domains of interest have been identified where EM data might have potential to provide valuable information to design engineers. These included discrimination of soil texture/density differences across the corridor for assessing suitability of road subbase, identifying buried arroyos that would be of use for planning storm drainage layout, using EM data to more judiciously select geotechnical boring locations, identify anomalous areas or plumes that might indicate contaminated soils, as well as identifying anomalous areas that might be suggestive of buried archaeological sites. Groundtruthing/data interpretation will be conducted, assisted by using existing data collected during a geomorphic study by a contractor, who characterized the paleolandscape by excavating 30-45 trenches (30-meters long, about 1 meter deep).

The geophysical survey was completed and data processing commenced in the field, after the first day of data collection. Preliminary analysis involved identifying data points above and below the average range and noting their locations. With this information staff revisited the location, noting whether any surface feature might explain the high or low reading, and conducted photo and video documentation. Data processing for First Order analysis was completed and the results have been compared with the geomorphological trench data. Results will be presented to the Functional Managers of the project in a post-field meeting to determine areas of interest for Second Order analysis.

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 project 10-60).

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.

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

NCHRP-IDEA Project 108

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IDEA Concept and Product

Current practice of paper-based information transfer during the bridge design/fabrication/construction process is inefficient. The process is bogged down by repeated error-prone manual transcription of data, time-consuming approvals (e.g., of shop drawings), and insufficient format standardization for electronic data interchange (EDI) for information transfer. "Better, faster, more economical" delivery of steel and concrete bridges requires more complete integration of 3D modeling, computer-aided design (CAD), computer-aided engineering (CAE), and computer-integrated manufacturing (CIM). The key innovation here is that 3D product models, unlike 2D drawings, provide a single central repository for all shared project data. If something changes, it changes once in the central 3D model and the effects of that change are broadcast automatically to affected stakeholders with access to that model information. All design and construction documentation is managed coherently under one umbrella. The anticipated usable product from this investigation is a workable Bridge Information Modeling (BIM) approach, with documented guidelines for good 3D–centric practice, to integrated design and construction for improved quality, faster delivery, and more economical bridges.

Project Results

3D parametric modeling in bridge project documentation processes have been employed in modeling steel and concrete slab-on-girder bridges and are found to be radically different from the traditional 2D-based processes, as summarized in the following table:

2D CAD provides an electronic "drawing board"	3D CAD enables a parametric model
2D Drawings contain the information	3D model contains the information; drawings are only reports
2D Drawings intended to be human-readable; separate manual data entry is required for analysis	3D model is computer-readable, such that direct analyses are possible
Coordination is difficult; information is scattered among different drawings and specifications clauses	Coordination is automatic: 3D model is the single source for all product information
Manual checking	Automated checking
No support for production	Potentially full support for production (via CNC codes etc.)

Steel plate girder and prestressed concrete I-girder bridges have been modeled parametrically in 3D using Tekla Structures and Bentley MicroStation TriForma software together with the custom add-on programming capabilities provided by each of those two software platforms. There are two key aspects of this new paradigm: 3D parametric modeling of project information, and electronic data transfer and translation among the various "islands of automation" that have arisen to automate or semi-automate isolated pieces of the process.

The focus of this project is primarily the former (3D–centric processes applied to bridges). Aspects of the workflow addressed include the following: parametric data entry and management, line girder analysis under AASHTO LRFD (Load and Resistance Factor Design) loadings, AASHTO LRFD design checks, database maintenance and augmentation as the work progresses, 3D CAD modeling, selected contract plan and "shop drawing" generation, extraction of quantity takeoffs for cost estimating, material procurement and shop material management, and export of Computer Numerical Control instructions for automated fabrication by suitably configured shop equipment. Software used to implement all this includes Bentley MicroStation TriForma with Visual Basic for Applications, Microsoft Access including XML export, Washington State Foundation Libraries, MathCad, Tekla Structures with XML parser implemented in C++. Examples of generated bridge models are shown in Fig. 1.

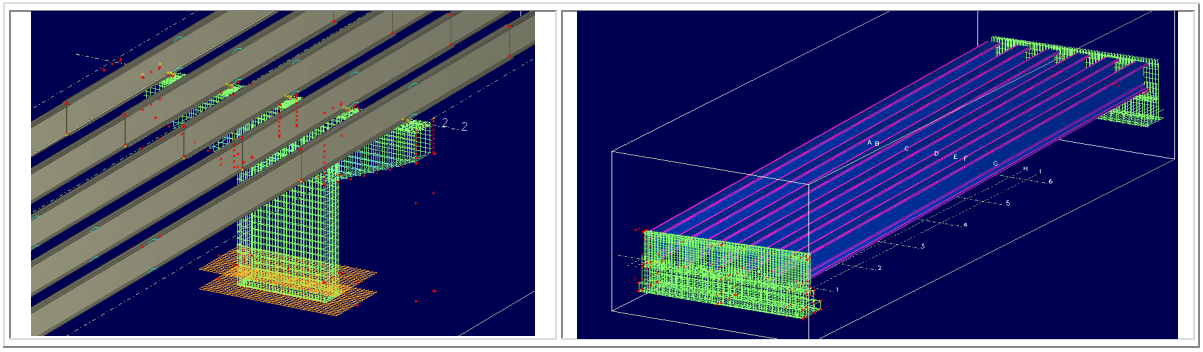

Figure 1

Portions of Steel and Concrete Bridge Models

From the single central 3D model can be extracted current project information relevant to a given project stakeholder (e.g., owner, designer, contractor, fabricator, detailer, precaster, erector) at any given time. A prestressed concrete bridge provided by PennDOT has been modeled parametrically in 3D and is currently being evaluated in conjunction with Arora and Associates, PC, to record lessons learned about how parametric 3D modeling should be conducted for a real bridge design and construction project.

Product Pay-Off Potential

The product of this research can change how an entire industry does business. Potential cost savings include the following: 10–15% reduction in field rework, up to 14% reduction in overall project schedule, and up to 40% reduction in fabrication schedule (see http://enr.construction.com/news/buildings/archives /030414.asp).

Product Transfer

Commercial-strength bridge-friendly parametric 3D-capable software, bridge owners friendly to and supportive of streamlined business practices, and stakeholders migrating toward 3D-centric collaborative ways of doing business are needed to transfer the results fully to highway practice. All are being cultivated via a resolution passed by the AASHTO Bridge Committee acknowledging the importance of and charging one of its technical committees with coordinating comprehensive integrated bridge project delivery through automation along with FHWA, software developer involvement and support, trial deployment using an actual bridge replacement project of an interested owner and bridge engineering consulting firm (Arora and Associates PC), and participation of industry groups such as the AASHTO/NSBA collaboration.

SMART ARRAY ANTENNA FOR NDE OF FRP-WRAPPED CONCRETE BRIDGE MEMBERS

NCHRP-IDEA Project 109

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IDEA Concept and Product

This IDEA project will develop an innovative smart-array antenna concept into a high-performance nondestructive evaluation (NDE) system for in-situ condition assessment of fiber reinforced polymer (FRP)-wrapped (or jacketed) structural members of concrete bridges. The array consists of multiple tiny antenna elements actively controlled by sophisticated electronics and software to focus microwave (in a GHz range) to a point of inspection. Invisible damage, such as air voids, cracks, and debonding between FRP jackets and concrete, is detected by scanning the focused microwave beam and analyzing the scattered wave signals. The proposed smart-array antenna represents significant technological advancement and advantages over the currently available NDE technologies. First, the system uses focused microwave (vs. unfocused one commonly used in ground penetrating radars) and, as a result, substantially increases the signal-to-noise ratio as well as the inspection depth. Second, the wave focusing and beam scanning are performed electronically by software, making it possible to investigate a large area in real time (without mechanically moving the array). Such high performance, in addition to the portability, makes the proposed antenna system uniquely suitable for in-situ quantitative evaluation of damage in FRP-wrapped concrete members.

Project Investigation

Newport Sensors, Inc. has made significant progress in this IDEA project during the past eight months. Investigators performed extensive literature surveys and consulted with several potential users, including Caltrans, NY DOT, and Fyfe Co., and FRP experts in Aerospace Corporation and the University of California. Based on these studies, the technical specifications of the prototype have been determined.

Numerical simulations and experiments were performed in a systematic way in order to determine the design of the array antenna, including the number of antennas and their configurations. Based on the investigations, the angle of the incident wave and the reflected wave will be the same as the beam scans to minimize the measured unstable responses. In order to keep the same angle while scanning a large area, the system configuration consists of six phased-array antennas as shown in Figure 1. Each array antenna is connected with three phase shifters and switches, which activate one transmitting and receiving antenna at a time. By switching on and off these phased-array antennas and adjusting the wave angle by the phase shifters, the measurement line, which is 24cm long, can be scanned quickly without moving the antenna.

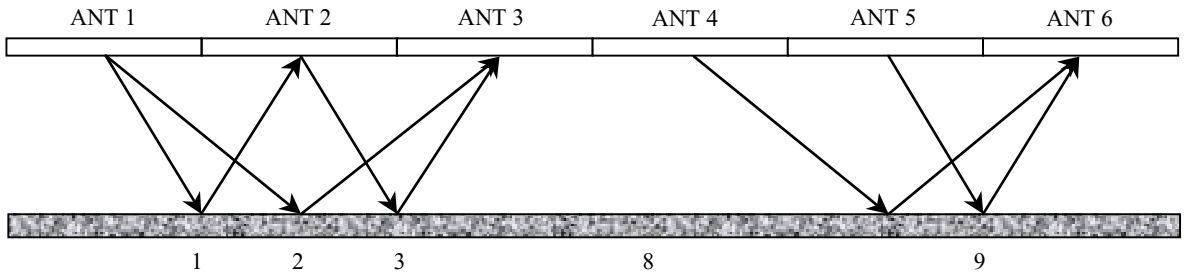

Figure 1

Scanning Mechanism of Smart Array Antenna System

The prototype smart-array antenna system consists of three modules including (1) a controller and a power supplier, (2) the transceiver (i.e., transmitter and receiver), and (3) array antennas including a feed network. For operational ease, the power supply is divided to support respectively the controller and the transceiver and feed network. In the transceiver module, the operation status can be reported to the controller in real time by using threshold detectors. By doing so, the operator is informed of any problem in real time as soon as an error occurs during the operation.

Product Pay-Off Potential

Due to aging and deterioration, the nation's highway transportation infrastructure is becoming increasingly vulnerable to natural and man-made disasters. Deployment of advanced materials, such as FRP composites, offers a cost-effective solution to the lack of funding for infrastructure rehabilitation. FRP composites can be effectively used to wrap (jacket) existing deficient concrete structure members, such as columns and cap beams, not only for seismic retrofitting, but also for strengthening and repairing. Despite their high performance and low lifetime overall cost, FRP composites have not been widely accepted by the bridge owners. A major concern is their long-term performance and durability, and most importantly, the unavailability of reliable NDE tools for field quality assurance and condition assessment of FRP-rehabilitated structures. Developing the smart-array antenna concept into an NDE device with a high signal-to-noise ratio, field portability and real-time evaluation capability will increase the confidence needed to quickly and widely deploy the FRP composites and to enhance the safety and integrity of the nation's transportation infrastructure. According to a market study, the proposed technology will contribute $21 billion to the U.S. economy over five years, from bridge inspection cost savings (due to the use of the smart-antenna array) and extending the life of the nation's bridge stock by an average of 10 years (due to the deployment of FRP).

Product Transfer

For the future commercialization, NSI has established an advisory board for the IDEA project that involves key representatives from transportation authorities, FRP composite manufacturers/suppliers, instrumentation manufacturers, and leading research institutions. The advisory board is helping the company forge strategic relationships, assess market opportunities, and define product positioning. The members of this board are potentially early adopters of the NSI products, and/or business partners in the future for manufacturing, marketing and distributing the smart-antenna array products and technology.

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

NCHRP-IDEA Project 110

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IDEA Concept and Product

Recent development in x-ray computerized tomography (XCT) imaging and computational simulation has made it possible to characterize the properties of asphalt concrete through reconstructing its three-dimensional (3D) microstructure and computational simulation based on the 3D microstructure. The digital representation of the real 3D microstructure (not a simulated 3D or 2D microstructure) of a physical specimen is named Digital Specimen. It is the digital counterpart of the physical specimen in every required detail. A digital specimen is usually represented as a 3D digital image and naturally includes scientific visualization of the initial/evolved microstructures and behavior related to rutting, fatigue cracking, and thermal cracking. Figures 1a and 1b are digital representations of a gyratory specimen with emphasis on its aggregate skeleton structure and its void structure, respectively. A digital specimen can be transferred through the Internet and shared by many researchers for use in multi-purpose studies such as model verification and behavior simulation. With detailed representation of the microstructure of asphalt concrete, modeling and simulation can be based on the real microstructure of the material; and experimental observation of the microstructure evolution can be compared with computational simulation to validate the models and the understanding of the fundamental mechanisms of strength and deformation of asphalt concrete.

Computational simulation of a mechanical test, which is based on digital specimens and considers every required detail of the microstructure and its evolution, is named Digital Test. It is different from conventional computational simulations that assume either a continuum model or a simulated microstructure. Figures 1c and 1d illustrate computational simulation of the digital specimen under axial loading and diametrical loading, or the digital counterparts of triaxial compression test and indirect tensile test, respectively. One can perform different digital tests on the same digital specimen, representing its multiple functional roles. The overall objective of this research is to develop Digital Specimen and Digital Test techniques and demonstrate their applications in performance evaluation of asphalt concrete.

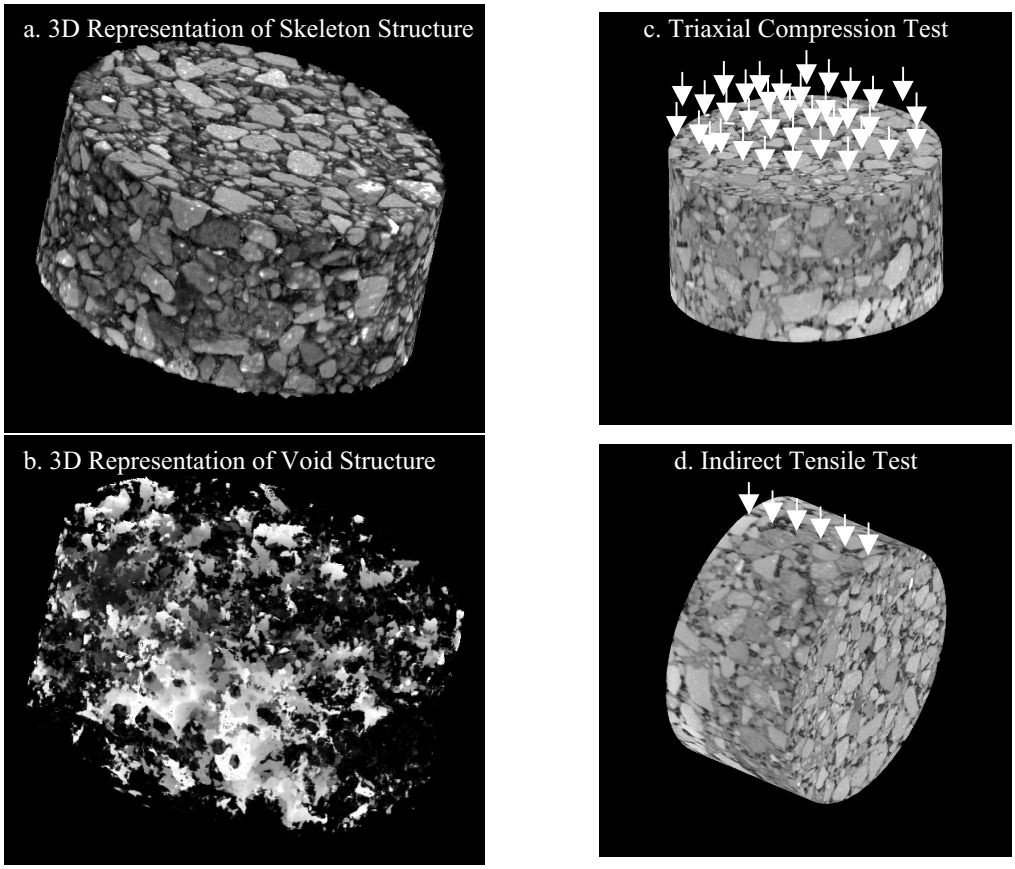


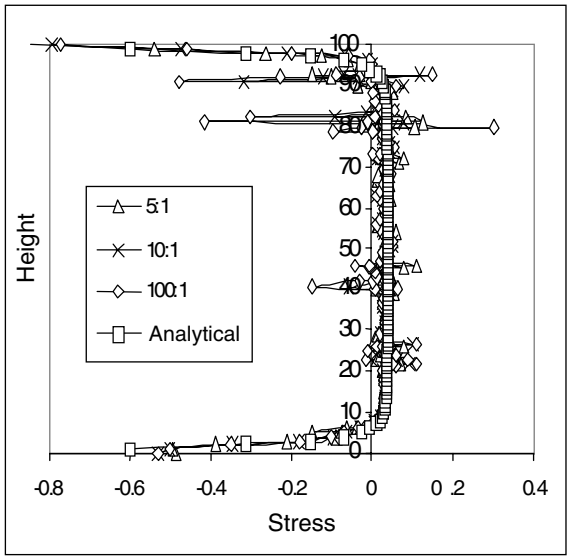
Figure 1

Illustration of the Concepts of Digital Specimen and Digital Test

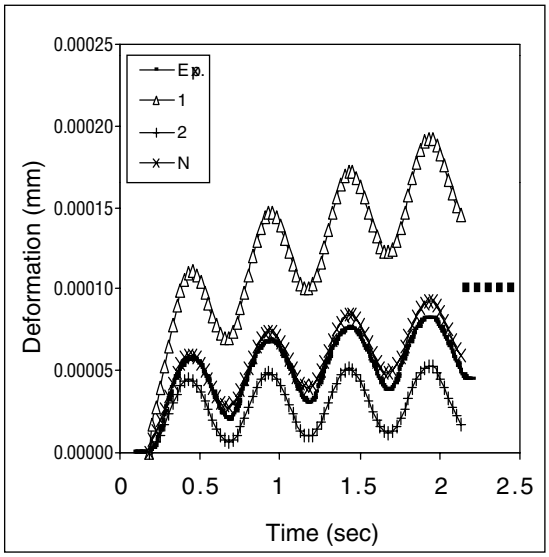
Project Results

This project consists of two phases. Phase I is research development and verification. Phase II is implementation. The Phase I objective is to develop a computer program to represent the microstructure of cylindrical specimens of asphalt concrete in a digital format (Digital Specimen), and modules to link the microstructure to a Finite Element Code for simulating the Indirect Tensile Test and Dynamic Modulus Test (Digital Test). The digital test will be verified through selecting mixes and coring specimens from the NCAT (National Center for Asphalt Technology) test track or the FHWA ALF (Accelerated Loading Facility) experiment, reconstructing the digital specimens of the cored or fabricated specimens of these mixes, and comparing the digital test results with results of actually conducted tests.

The Phase II objective is to implement the digital specimen and digital test techniques at the FHWA Turner-Fairbank research center through training and direct use of the newly developed techniques in its research projects. Digital representation of the microstructure of a specimen and simulation of indirect tensile test has been achieved. Figure 2a presents tensile stress distribution along the vertical axis of digital tests, where the aggregate, mastic, and void distribution are considered in the simulation. Compared with the analytical solution, which is adopted to analyze the indirect tensile test, stress distribution varies along the axis and is different for different mixes and the relative stiffness between aggregate and mastic. Using this analysis, the performance of the three mixes in the WesTrack project were successfully ranked. Figure 2b presents the experimental observation of the accumulative permanent deformation of the top plate during the indirect tensile test and simulated permanent deformation using a viscoplasticity model for the mastics. Generally, the simulation results vary with the material constants of the model. A down-hill optimization scheme has been developed so the material constants can be optimized through minimizing the sum of squares of the difference between the observed and simulated deformations.



a. Stress distribution along vertical axis



b. Accumulative permanent deformation

Figure 2

Simulation of Indirect Test and Optimization of Material Constants

Product Payoff Potential

Asphalt concrete is a very complicated engineering material in terms of its microstructure and behavior. Its quality service life is significantly affected by factors in mix design, construction, and maintenance. Any improvements in enhancing the quality service life of asphalt concrete would result in cost and materials savings. Although tremendous research efforts have been made on characterizing aggregates, asphalt binder and mixture, the fundamental mechanism governing the development of distresses such as rutting, fatigue cracking, low-temperature cracking, and moisture damage have not been well understood quantitatively. This situation arises due to the lack of an understanding of the fundamental mechanisms governing the complicated behavior resulting from the interaction among the three constituents (aggregates, asphalt binder, and air voids) that have drastically different physical, chemical, and mechanical properties. A new view to directly look at the microstructure of asphalt mixes and the interaction of constituents will enhance the understanding of these mechanisms in a coupled way as they actually behave under different loading and environmental conditions and therefore will result in larger potential to design better mixes. Accomplishment of the proposed research will potentially 1) enhance current practice in mix design by reducing the number of specimens required to test, and reducing needs for a wide variety of equipment, duration of design period, and manpower; 2) enhance the mix design procedure so that a mix would have a balanced capability to resist rutting, fatigue cracking, low-temperature cracking, and moisture damage; 3) reduce the potential of letting a problem mix be adopted and increase the potential of designing better mixes that last longer; and 4) improve the understanding of the mechanisms governing the various types of distresses.

Product Transfer

The final product is a computer program that reads processed XCT images of an asphalt concrete specimen, reconstructs them into its Digital Specimen, and performs the stiffness test on the digital specimen on the platform of a Finite Element Code. The verified program will be implemented at the FHWA Turner-Fairbank research center for its research projects. With more successful applications, the techniques can be implemented at other research agencies including NCAT, Virginia Transportation Research Council (VTRC), Louisiana Transportation Research Center (LTRC), other universities and DOTs.

AUTOMATED PAVEMENT DISTRESS SURVEY THROUGH STEREOVISION PHASE II

NCHRP IDEA Project 111

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University of Arkansas

IDEA Concept and Product

This research is the continuation of a previous IDEA project (NCHRP-88). Stereovision has been applied in various industries for visualization and inspection. Photogrammetry in highway engineering is a good example. With rapid advances of computing power and digital camera technology, application of stereovision in automated pavement distress surveys became a research topic. The purpose of this research is to validate findings of the previous research and produce a working device based on stereovision techniques for pavement distress surveys.

Project Investigation

Two research tasks have been conducted to date. The first task is the construction of a new research vehicle, the platform of which is to be used for this research. Figure 1 illustrates the new vehicle and proposed setup for the stereovision camera pairs. The four cameras to the rear of the vehicle were mounted in September 2005.

Figure 1

New platform and two pairs of cameras for surface stereo modeling

The second task is the development of a more robust calibration procedure to correct camera distortion for 3D surface reconstruction. 3D camera calibration is a necessary step in 3D reconstruction; its purpose is to decide the relationship between 2D image planes and object space coordinates. In this report, a new algorithm, 3-D Modified DLT (Direct Linear Transformation) method, is proposed. This method is different from the one used during the prior phase of the research. The advantage of the algorithm is that it is more accurate because it considers optical errors and improves the accuracy by using an iteration method to extract a stable set of parameters.

The calibration procedure reported here is based on the modified DLT equations. Two cameras are used to take photos for the same calibration board simultaneously. Figure 2 shows the images from the left and right cameras. There are 22 control points in the calibration board. The coordinates of the 22 points in the object space and image space can be measured and substituted with the DLT method. The parameters are then obtained by iteration and least square method.

It is anticipated that before the end of calendar year 2005, the newly equipped vehicle will be able to collect and analyze pavement data through 3D reconstruction at driving speed. Preliminary rutting information will be obtained during this time frame.

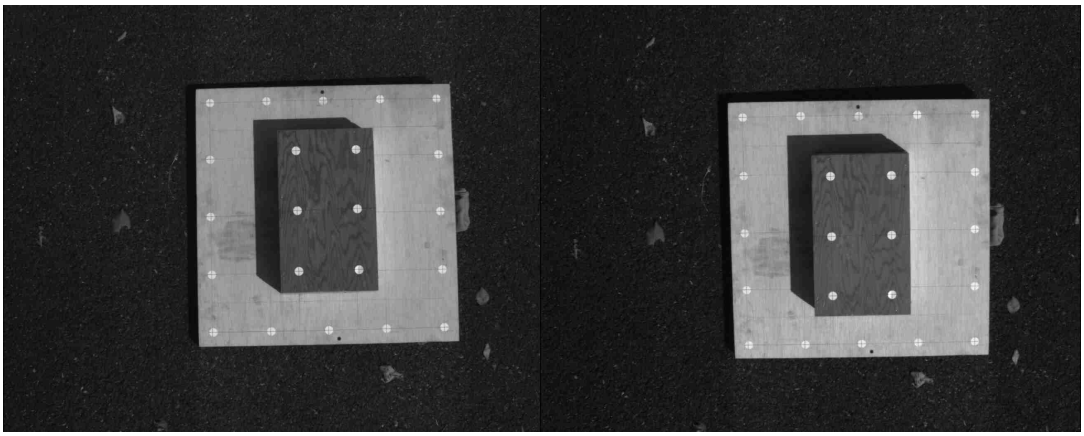

Figure 2

Left and right images with calibration mode

Product Pay-Off Potential

Pavement distress survey is the method for evaluating pavement condition and most of the data for the survey are still collected manually. A primary goal of this research is to use high-resolution digital cameras to reconstruct the transverse profile of pavement with necessary 3D characteristics. When the system's resolution is sufficiently high and accuracy is acceptable, it is possible to establish more than one thousand height points in the transverse direction of a pavement. The current setup of four digital cameras will provide 2600 pixel resolution across the pavement. When this new system is developed and verified, it can substantially reduce the cost of rutting surveys. Presently, a laser-based rutting device with an adequate number of lasers would cost $100,000 or more without the consideration of the vehicle cost. The hardware cost of the camera based stereovision is only several thousand dollars.

Product Transfer

The University of Arkansas has a contractual relationship with a university affiliated business, WayLink Systems Corporation, to commercialize technology of highway information systems. It is anticipated that the new technology developed in this project will be licensed to WayLink so that it will be available to highway agencies.

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

NCHRP-IDEA Project 112

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Case Western Reserve University

IDEA Concept and Product

This project will develop a low cost, mobile, and robust unit of cone penetrometers equipped with piezoelectric sensors that can quickly measure stiffness and Poisson's ratio of subgrade materials of a pavement under construction or an existing pavement. It offers an automated, accurate, and economical system for monitoring and controlling construction quality and evaluating performance of pavement systems. The concept has been validated in the laboratory and several papers have been published. This proposal will explore the application of the concept to real field situations by improving the design of the device and conducting tests at several pavement project sites. During a test, the cone penetrometers will be pushed into the base and subgrade materials and the velocities of P and S waves will be measured using piezoelectric sensors, from which the moduli and Poisson's ratio of soils can be determined. The penetrometers can be pushed into the soil as far as 4 feet deep and the profiles of shear modulus, elastic modulus, and Poisson's ratio in the soils can be measured in just a few minutes. The test is quick and economical enough that it can be conducted at many locations during construction.

Project Investigation

The cone penetrometers were fabricated in the laboratory and the system was tested on two types of soil, a fine-grained Nevada sand and a coarse-grained sand. The new system has the piezoelectric sensors mostly within the penetrometer and the sensors have good contact with surrounding soils. Small wedges made of steel were placed just above and below the bender elements (which are used to measure the velocity of shear waves). They can protect the sensors when they are pushed into or pulled out of the foundation soil. The extender elements (which are used to measure the velocity of primary waves), stay inside the penetrometers and just touch the outside soils. The penetrometer with the sensors is shown in Fig.1.

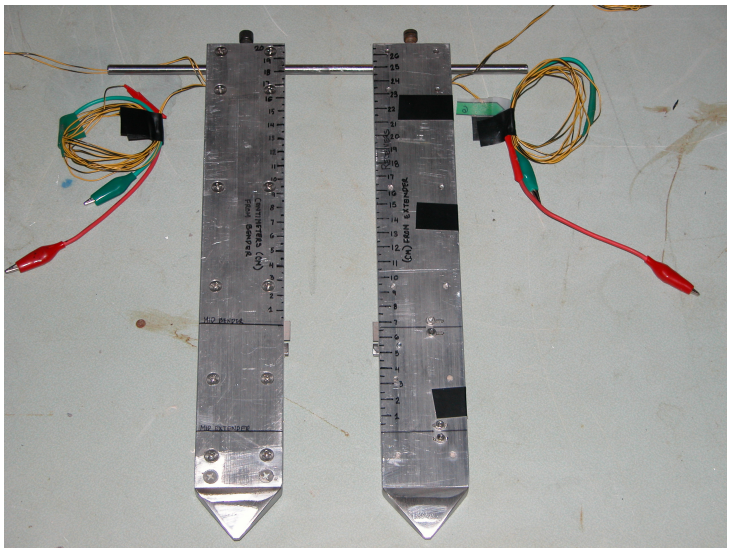

Figure 1

Cone penetrometer equipped with piezoelectric sensors

Tests were carried out on two types of soils. The first soil is Nevada sand—a fine-grained soil, while the second one is a coarse-grained sand. For each type of soil, one dense sample and one loose sample was prepared for testing. In addition, each test was repeated at least once and very good repeatability was achieved, suggesting the performance of the system is reliable. Example results are shown in Fig.2. As shown in the figure, the stiffness of sand increases gradually with depth as confining pressure increases. Based on the measured constrained modulus and shear modulus, it is possible to calculate the Poisson's ratio of the soil. In the test, the Poisson's ratio measure varied between 0.3 to 0.4, which is typical for sand. Also shown in the figure is the value of shear modulus calculated by a widely used empirical equation, the Hardin and Richards equation, which estimates shear modulus of soil based on in-situ stress and density of soil. As can be seen from the figure, the test results agree very well with that of the empirical equation. This was true for all the soil samples tested. In comparison with results on the same soil using other methods, the agreement is very good, proving that the new device is accurate in determining the stiffness and Poisson's ratio of soils.

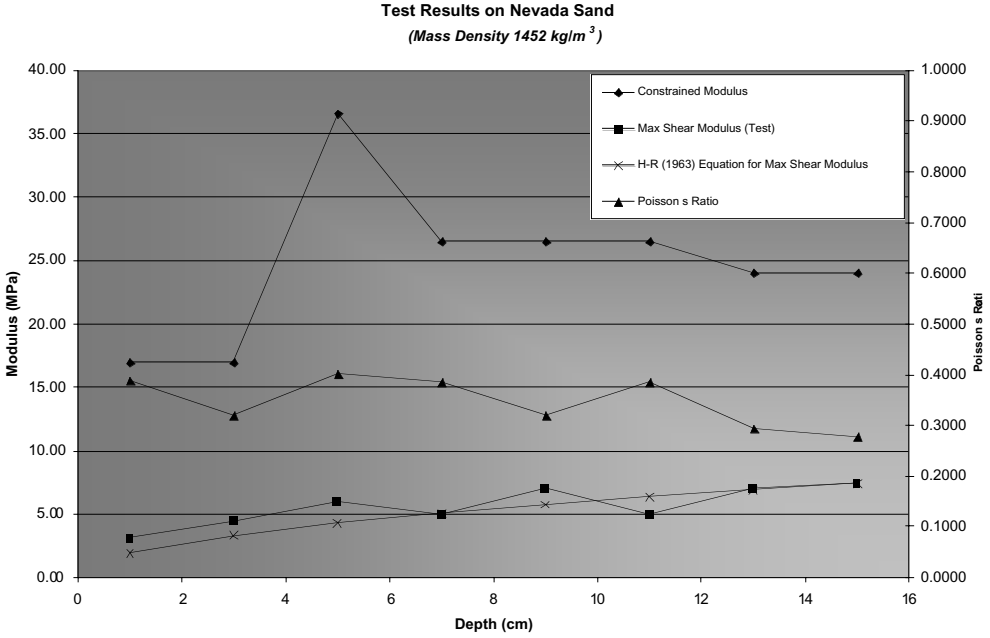

Figure 2

Test results of stiffness and Poisson's ratio of dense Nevada sand

Product Pay-Off Potential

Low cost, mobile, and automated equipment for quickly measuring stiffness and Poisson's ratio of base and sublayers in the field is very useful for design and for construction quality assurance. When the project is finished, a system based on a proven advanced technique will be developed and tested in the field, with the support of and in collaboration with the Ohio Department of Transportation (ODOT) and a leading civil engineering equipment company. Investigators plan to provide ODOT with several sets of the system for statewide testing. Pile Dynamics Inc. will start to produce commercial units. The payoff in terms of improving design and construction quality of highway pavements will be significant.

Product Transfer

When the system is developed and proven through this project, researchers will provide the Ohio Department of Transportation with several units for statewide pilot applications. After that, Pile Dynamics Inc. will start to produce commercial units for sale to highway construction companies and state DOTs. Researchers anticipate that the system will be widely available within a few years.

SECTION 3
NSF/NRC-IDEA COOPERATIVE PROJECTS

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

CONTROL SYSTEM FOR HIGHWAY LOAD EFFECTS

NSF/NCHRP-IDEA Project 1

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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.

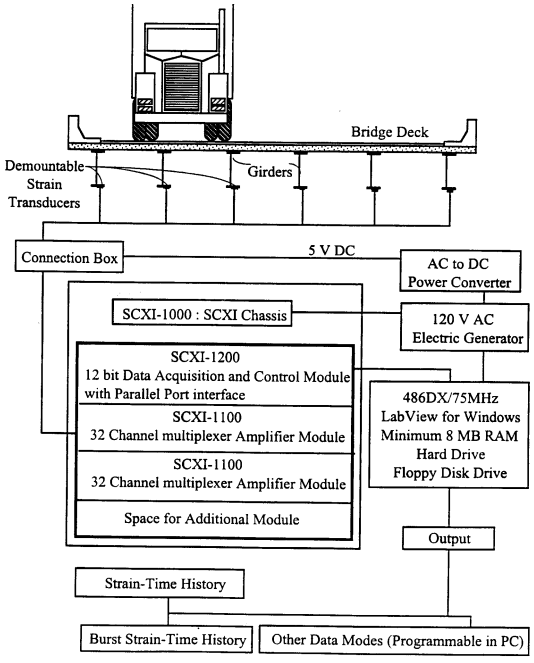

Figure 1

Data acquisition and control system.

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

NSF/NCHRP-IDEA Project 2

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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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