Transportation Research Board

2002 Catalog of Practical Papers

2002 TRB Annual Meeting research papers of immediate practical interest to State Department of Transportation professionals.

- **Bridge, Culvert and Tunnel Design and Performance**
- **Construction: General**
- **Construction: Pavements**
- **Facilities, Equipment Design and Performance**
- **Bituminous Materials**
- **Cement and Concrete**
- **Pavement Management and Rehabilitation**
- **Safety**
- **Soils, Geology and Foundations**

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Design and Construction of Transportation Facilities Group

Introduction

The 2002 Annual Meeting papers listed in this catalog contain information that has immediate application potential in state DOT operations. Technical committees within the Design and Construction of Transportation Facilities Group identified the papers during the paper review process.

Each entry in the catalog includes the abstract of the paper and information on the authors to facilitate direct interaction between the researchers and practitioners. Information regarding the technical session in which the paper is to be presented is also included.

The complete text of most of the papers in this catalog are on the 2002 Annual Meeting CD-ROM. Many may also later be published in a Transportation Research Record: Journal of the Transportation Research Board.

TRB is interested in hearing any comments about this catalog regarding its usefulness, additional information needed, etc. Email your comments to: fhejl@nas.edu, gjayapra@nas.edu, or smaher@nas.edu.

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8. Safety

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1. Bridge, Culvert and Tunnel Design and Performance

02-2022 Rehabilitation Study of Toutle River Tied-Arch Bridges

Session 182

The Toutle River tied-arch bridges (Br. No. 5/140 E & W) are located on Interstate 5 in western Washington State and were open to traffic in 1969. Approximately 33,000 vehicles a day cross these bridges. Twenty-two percent are trucks. Large deflections result with the passage of these trucks causing the bridges to vibrate in the first mode of vibration. This paper presents a strengthening and stiffening study to minimize deflection, vibration, and fatigue cracking. Several stiffening methods were analyzed. The addition of diagonal tension members between each vertical hanger and addition of compression members placed near the quarter points of the bridges are the most promising options. The bridges also experience fatigue cracking. The floorbeam webs have experienced cracks at most tie chord connections and at exterior longitudinal stringer connections. At the bridge bearings, there is extensive cracking at the fillet welds connecting the upper bearing blocks to the tie chord. Retrofit options are discussed which will alleviate the cracking. Stiffening the arches will also decrease the fatigue stress range in the tie chord. Retrofitting the floor system to accommodate thermal movements will minimize distortion-induced fatigue in the floorbeams. The paper recommends adding post-tensioning strands to the tie chord as a safeguard against sudden failure. Estimated retrofit costs are provided.

Amy C. Leland, **Nathan S. Brown**, and **John A. Van Lund**, Washington State Department of Transportation, Bridge & Structures Office, Washington State DOT, P.O. Box 47340, Transportation Building, Olympia, WA 98504-7340, 360-705-7204; 360-705-6814 –FAX, lelanda@wsdot.wa.gov.

02-2245 High-Performance Steels for Highway Bridges

Session 420

High performance steels (HPS) have improved strength, weldability, toughness, ductility, corrosion resistance, and formability for highway bridge design and construction. The first HPS bridge was completed and opened to traffic in October 1997. Since then, more than 30 HPS highway bridges have been completed and opened to traffic. Many more bridges are under design or construction. The design and fabrication experiences from these projects show that HPS can be used in combination with conventional structural steels to optimize design and economy. HPS allows the designers to use fewer lines of girders to reduce weight and cost, use shallower girders to solve vertical clearance problem, and increase span lengths to reduce the number of piers on land or obstructions in the streams.

M. Myint Lwin, Bridge Design Engineer, Federal Highway Administration, Western Resource Center, 201 Mission Street, Suite 2100, San Francisco CA 94105, 415-744-2660, 415-744-2620 –FAX, myint.lwin@fhwa.dot.gov.

02-2246 Effect of Diaphragms on Load Distribution of Prestressed Concrete Bridges

Session 356

Load testing results for six prestressed concrete bridges were used to evaluate analytical methodologies of the present study. These bridges had different span lengths, number of lanes, and skew angles. Maximum strains and load distribution factors predicted by finite element analyses and AASHTO Code Specifications were compared with those from measurements. This comparison indicates that the diaphragm stiffness of the bridges examined is uncertain due to possible concrete cracking and weakness of the diaphragm-girder connection. Ignoring or

considering low diaphragm stiffness gave better strain distributions across the bridge width than considering the full diaphragm stiffness. Sensitivity study reveals that the diaphragm stiffness has significant effects on bridge strains and their distributions. It is important, though difficult, to choose a reasonable diaphragm stiffness in the analytical analysis. Theoretically, full diaphragm stiffness can be achieved by post-tensioning the diaphragm across the bridge width. If the full diaphragm stiffness does exist, the maximum strain and load distribution factor can be significantly reduced.

Chun Cai, Louisiana State University, Civil and Environmental, 3502 CEBA, Baton Rouge LA 70803, 225-578-8640, 225-578-8652 -FAX, zhangcai@cs.com; **Mohsen Shahawy**, Structures Design and Rehabilitation; and **Robert J. Peterman**, Kansas State University.

02-2346 A Half Mile of Bridge without a Joint

Committee A2C01 meeting

The bridge on I-181 over the Holston River at Long Island in Kingsport, Tennessee was opened to traffic in 1981. This bridge consists of two almost identical structures, each of which is approximately 823 m (2,700 ft.) long. Each superstructure was tied into the piers such that the bridge is continuous over 29 spans with no interior joints. The bridge is too long to be constructed as a true jointless bridge; finger type joints were provided at the abutments to accommodate expansion and contraction.

The bridge was instrumented with strain gages, thermocouples, and displacement gages during and shortly after construction. Monitoring of this instrumentation continued through mid-year 1981. Then, in 2001, the writers reviewed inspection records and examined the bridge to assess the overall performance of the structure during its twenty year life.

The jointless, continuous construction of the bridge led to some cracking of piers near the ends of the bridge structures due to bending induced by thermal expansion and contraction. Also, there was cracking as early as 1981 in a diaphragm near the end of the northbound structure where the ends of five beams in the end span did not line up with the ends of four beams in the next to last span. Also, there were shrinkage cracks between the diaphragm and beam ends at a number of piers. None of the cracks just noted are of any structural concern. The successful performance of this bridge over a 20 year period provides strong support for the policy of minimizing the use of joints.

Edwin G. Burdette, **David William Goodpasture**, and **James Harold Deatherage**, University of Tennessee, Dept of Civil & Environmental Engineering, 220 Perkins Hall, Knoxville TN 37996-2010, 865-974-0724, 865-974-2669 -FAX, hdeath@utk.edu.

02-2535 A Simplified Method of Lateral Distribution of Live Load Moment

Committee A2C03 meeting

This paper introduces a simplified method, also called Henry's method, for the calculation of distribution factors of live load moment. Using the simplified method, all beams, including interior and exterior beams, will have equal distribution of live load effects. The method has been used in Tennessee for nearly four decades, and many bridges in Tennessee have been designed using this method. The simplified method offers advantages in simplicity of calculation, flexibility in application, and savings of expenses. In order to carefully examine the proposed simplified method, twenty-four actual bridges of six different types of superstructures were selected in the study. The selected types of bridges included steel I-beam, prestressed concrete I-beam or Bulb-Tee, concrete T-beam, multicell box beam, and steel open-box girder bridges. The distribution factors of actual bridges from Henry's method were compared with the

ones from the AASHTO LRFD, the AASHTO Standard, and Finite Element Analysis. In the comparison study, the effects of bridge superstructure types and key parameters that most affect calculation of distribution factors were discussed. Based on the results of comparison and evaluation, modification factors were introduced to Henry's method. With proper modification, the proposed simplified method can give very reasonable and reliable distribution factors of live load moment.

Xiaoming Sharon Huo and **Pingsheng Zhu**, Tennessee Technological University, P.O. Box 5015, Department of Civil and Environmental Engineering, Tennessee Technological University, Cookeville TN 38505, 931 372 3188, 931 372 6352 -FAX, xhuo@tntech.edu; and **Edward P. Wasserman**, Tennessee Department of Transportation.

02-2581 Grouted Connection Tests in Development of Precast Bent Cap System

Session 709

Test results are summarized from the first two phases of a research project that developed a design methodology, construction guidelines, and design details for connecting precast concrete bent caps to cast-in-place columns or precast concrete trestle piles in nonseismic regions. Three types of precast connections are addressed: grout pockets, grouted ducts, and bolted connections. The first phase of testing included thirty-two pullout tests of epoxy-coated straight and headed bars embedded in a grout pocket or grouted duct. The yield strength of the bars was developed in grouted connections at an embedment depth of 13 bar diameters or less. Pullout capacity of single and multiple headed bars in grout pockets is predicted closely by the Concrete Capacity Design Method equations modified by a cracking factor of 0.75 to account for grout pocket cracking. A development length equation based on a uniform bond stress model is derived for anchorage of straight bars in grouted ducts. The second phase of testing included a full-scale bent cap-to-column connection test for each connection type. Specimens in these proof tests exhibited minor levels of cracking and connector strain in the connection region at factored levels. Failure tests demonstrated adequate connector anchorage, large connector ductility, and negligible influence of shims and the grout bedding layer on response.

Eric Matsumoto, California State University, Sacramento, Department of Civil Engineerinng, 6000 J Street, Sacramento CA 95819-6029, 916-278-5177, 916-278-7957 –FAX, ematsumoto@csus.edu; **Michael E. Kreger**, University of Texas, Austin; **Mark Waggoner**, Walter F. Moore and Associates; and **Guclu Sumen**, Nelson Architectural Engineers, Inc.

02-2727 Precast Posttensioned Abutment System for Rapid On-Site Construction

Session 709

This paper presents details of a prefabricated bridge system designed to minimize on-site construction time. The system consists of a double-cell adjacent box beam superstrucure supported on precast post-tensioned abutment units on cast-in-place footings. The paper also describes the implementation of the design concept in a demonstration bridge replacement project. The structure is a single-span bridge crossing a creek in southwestern Pennsylvania. The construction project demonstrated the feasibility of the design concept as a means to reduce construction time by eliminating cast-in-place concrete for abutment walls.

Andrew Scanlon and **Alex Aswad** Pennsylvania State University, Department of Civil and Environmental Engineering, 212 Sackett Building, University Park PA 16802-1408, 814-865-5932, 814-863-7304 –FAX, axs21@psu.edu; and **James Stellar**, Patel Chen Associates, Inc.

02-2783 Econometric Model for Predicting the Deterioration of Bridge Deck Expansion Joints

Committee A2C01(1) meeting

Bridge deck expansion joints are an important element of bridge structures. When they fail to function properly, the performance of bridges can be seriously affected. Numerous research projects have been conducted to investigate the problems of the expansion joints and their causes. Some of this prior research was based on field observations while others utilized the in-house laboratory tests. However, a systematic approach to explore the relationship between the joint condition and the influence of the environmental factors does not yet exist. Also, while the Markov model is frequently used in the deterioration modeling, it cannot be applied when the condition data is discrete and ordinal. To address these two problems, this paper presents a methodology that uses the econometric model to predict the joint condition. The joint condition data has three rating levels, i.e., good, fair, and poor, and the ordered probit model is used to estimate the condition by the parameters, including age, traffic volumes, weather, skew angle, etc. Three joint types are investigated in the research: compression seal (B.S.), strip seal (S.S.), and integral abutment (I.A.). The source data is from the 1998 bridge inspection records provided by the Indiana Department of Transportation. The estimation results confirm the findings from the previous field studies as to the parameters' influence on the joint condition. In addition, the results show how the developed deterioration curves can be used for comparing the performance among different types of joints.

Luh-Maan Chang and **Yao-Jong Lee**, Purdue University, Div. of Const. Engrg. & Management, School of Civil Engineering, West Lafayette IN 47907, 765 494 2246, 765 494 0644 -FAX, changlm@ecn.purdue.edu.

02-2815 Creep Effect in Structural Composite Lumber (SCL) in Bridge Applications

Committee A2C01 meeting

Structural Composite Lumber (SCL) is a family of newly engineered wood products finding increasing use in highway bridge applications. The advantages of SCL are high strength, flexibility of sizes and shapes, stiffness and excellent treatability with preservatives. One of the main concerns in SCL bridge applications is the serviceability performance. The long-term creep behavior of SCL flexural members is not well known at present. In order to investigate creep effects, deflection monitoring of full scale SCL T-beam bridge members was performed under ambient conditions and accelerated aging process. A total of 16 beams were monitored under exposed weather conditions with frequent wetting and drying. Variables in the experiment were: lumber type (Douglas Fir and Southern Yellow Pine), SCL type (LVL and PSL), preservative type (CCA and Penta), and dead load intensity. It was found that creep behavior in SCL bridge members closely follow established theoretical models. LVL, Douglas-Fir and CCA treatment causes smaller creep deflections, as compared to PSL, Southern Pine and Penta treatment. NDS type creep multipliers for SCL vary between 1.9 to 2.45 for various sub-categories. A single average creep multiplier of 2.2 may be conveniently used for all treated SCL bridge beams.

Nur Yazdani and **Eric C. Johnson**, Florida A&M University-Florida State University, College of Engineering, 2525 Pottsdamer St., Tallahassee FL 32310-6046, 850-410-6125, 850-410-6659 -FAX, yazdani@eng.fsu.edu; and **Sheila R. Duwadi**, Federal Highway Administration.

02-2821 High-Performance Steel Cost Comparison Study

Session 420

In 1996, the American Iron and Steel Institute, the Office of Naval Research and the Federal Highway Administration (FHWA) introduced new High Performance Steel (HPS) grades with

superior strength, weldability and toughness. Since then, HPS-70W has been used successfully on bridges across the country and is increasingly gaining popularity with bridge design professionals. As HPS-70W steel becomes a more viable alternative, designers are faced with two basic questions: When is HPS-70W steel economical? What are the advantages of its use? To determine the economy of HPS-70W steel, a study was conducted to compare the relative cost of steel designs using HPS-70W and conventional grade 50W to investigate the conditions in which HPS-70W steel would offer economical advantages over grade 50W steel and present the advantages associated with its use. The study considered three 2-span continuous bridge arrangements with 45.75 meters (150 feet), 61 meters (200 feet), and 76.25 meters (250 feet) span lengths. Variable bridge cross sections were considered with 2.75 meters (9 feet) and 3.66 meters (12 feet) girder spacing. Forty-two girder designs were developed and compared for weight and cost and submitted to fabricators across the country to obtain relative costs for comparing the different steel grades. From this data, cost comparisons of designs using HPS-70W steel and conventional grade 50W steel are shown. Guidelines are also presented that will aid bridge designers in evaluating the economical use of HPS-70W steel and various hybrid combinations. The advantages of HPS-70W steel are discussed relating to its efficient use in design.

Richard Horton and **Edward Power**, HDR Engineering, Inc., 5700 Lake Wright Drive, Suite 300, Norfolk VA 23502, 757-222-1500, 757-222-1515 -FAX, epower@hdrinc.com; **Kristi Van Ooyen**, Nebraska Department of Roads; and **Atorod Azizinamini**, University of Nebraska, Lincoln.

02-2853 Forensic Investigation of Failed Mast Arms of Traffic Signal Support Structures
Session 628

In the state of Missouri, eleven traffic signal mast arms fractured at the arm-post weld connection during the past seven years. The latest incident occurred in October of 2000. Most of the failed arms lost their function after 1 to 2 years of service while others stayed in service for about 20 years. In an effort to reduce the fatigue failure of mast arms, the Missouri Department of Transportation developed a so-called ‘fatigue-resistant’ weld profile. The new weld profile basically increases the weld leg and reduces the slope of the weld at the toe. The purpose of this study was to investigate the causes of the failed arms and to compare the performance of new and old weld profiles. The scope of work included a metallurgical investigation of one failed mast arm retrieved from field, fatigue testing of five prototype mast arms in the laboratory (2 new and 3 old profiles), and failure analysis of one arm tested to cracking in the laboratory. Both metallographic and fractographic analysis indicated that the fatigue crack in a failed mast arm initiates near the weld toe of the arm due to undercutting, creating a sharp local toe angle. The location of the undercutting at the heat-affected zone of the base material, where the base material is softest, further contributed to early fatigue failure. The laboratory tests showed that the new weld profile does not consistently increase the fatigue strength of mast arms. The premature fracture surfaces of one tested arm indicated that the fatigue cracks initiate in an area at the weld toe as observed in the failed mast arm.

Genda Chen, **Michael Gray Barker**, **Christopher Ramsay** and **Lokeswarappa R. Dharani**, University of Missouri, Rolla, 307 Butler-Carlton Civil Engineering Hall, 1870 Miner Circle, Rolla MO 65409-0030, 573 341-4462, 573 341-4729 -FAX, gchen@umr.edu; **Joseph L. Alderson**, Missouri Department of Transportation; and **D. Scott Mackenzie**, Houghton International, Inc.

02-2931 Advantages and Limitations of Preformed Parallel Wire Strand Cables and Case Study Comparison with Aerial-Spun Cable

Session 224

The main cables of suspension bridges are formed from high tensile steel wires formed into strands and gathered together to form the cable. Currently two processes are used to construct the majority of these cables. One involves creating the strand in-situ and is termed aerial spinning; the second involves the erection of strands that have been formed offsite. This paper aims to describe the construction process for preformed strands, discuss the pros and cons of constructing cables with preformed strands and concludes with a case study comparing the two forms of construction.

John Justin Moran, Dorman Long Technology, United Kingdom, PO BOX 27, Yarm Road, Darlington DL1 4DE, United Kingdom, +44 (0) 1325 502279, +44 (0) 1325 502367 -FAX, john.moran@dormanlong.com; and **Simon Richard Hornby**, Cleveland Bridge, United Kingdom.

02-3000 Design of Discontinuity Regions in Structural Concrete Using a Computer-Based Strut-and-Tie Methodology

Session 314

The Strut-and-Tie Method (STM) is emerging as a code-worthy design procedure that has the potential to revolutionize the way that engineers design joints, pier caps, footings, and other regions for which engineering beam theory does not apply. This is of great significance as most structural deficiencies occur in these D-(Discontinuity) Regions due to shortcomings in traditional design provisions and detailing practices. The strut-and-tie design approach is to envision that an internal truss, consisting of concrete struts and steel ties, carries the loadings through the D-region to its supports or boundaries. To create this truss, reinforcing or prestressing steel is selected to serve as the ties while dimensions for struts and joints (nodal zones) are chosen so that they have sufficient strength.

The STM design process typically requires conducting multiple truss analyses, each of which involves the consideration of numerous geometric details. Completing this design process by hand or even with the aid of a truss-analysis tool can be prohibitively time consuming and thus discourage designers from using the STM. To overcome this problem, computer-based STM design tools are being developed that bring both efficiency and transparency to the STM design process; this includes the Computer Aided Strut-and-Tie (CAST) design tool. CAST provides a single graphical interface that enables the designer to sketch and analyze the idealized truss, to select member dimensions and tie reinforcement, to readily adjust all design variables, and to create a printout of the final design. This paper presents the STM, code provisions, and CAST design tool.

Daniel A Kuchma and **Tjen N. Tjhin**, University of Illinois, Urbana-Champaign, Civil and Environmental Engineering, 2114 Newmark Lab., 205 N. Mathews Ave., Urbana IL 61801, 217-333-1571, 217-333-9464 -FAX, kuchma@uiuc.edu.

02-3086 High-Performance Steel: Research Front: Historical Account of Research Activities

Session 420

This paper provides summary of the major research studies conducted or being conducted in U.S., to address the design issues related to use of High Performance Steel (HPS) in bridge construction. Emphasis of the paper is on the work related to HPS-70W steel, which has specified minimum yield strength of 70 ksi. Design issues that are addressed in this paper

includes a) Flexural capacity of compact and non-compact HPS sections in negative sections, b) issues related to ductility of HPS composite girders in the positive sections, where concrete is in compression and bottom flange is in tension. In this section of the paper, a new criterion is introduced that simplifies the ductility check of the composite plate girders in general, c) Tensile ductility of HPS plates, d) Shear capacity of the hybrid steel plate girders and e) brief overview of the work that is underway to develop innovative bridge configuration capable of taking advantages, HPS has to offer.

Atorod Azizinamini, University of Nebraska, Lincoln, W348 Nebraska Hall, Civil Engineering Department, PO Box 880528, Lincoln NE 68588-0528, 402-472-5106, 402-472-6658 -FAX, aazizi@unl.edu.

02-3102 Prestressed Concrete Girder Bridges: From 2D to 3D Modeling

Session 314

Two Windows-based computer programs, WIN-PBEAM and VBDS are described in this paper. WIN-PBEAM is a two-dimensional (2D) prestressed/post-tensioned precast concrete girder analysis and design program. WIN-PBEAM performs a complete analysis of simple-span and multi-span prestressed/post-tensioned highway bridges in accordance with the 1996 AASHTO Specifications and 1998 AASHTO LRFD Specifications and their updated Interims to 2000. The WIN-PBEAM system contains features generalized to a level that allows universal usage. The program was developed using WINDOWS GUI and the latest numerical analysis techniques to accommodate general usage of strand patterns, arbitrary loadings, and user-defined girder members. The program computes and prints the results in tabular form for any defined points along the span with section properties for composite and non-composite; dead load and live load reactions; shears, moments, and displacements; stresses for various construction stages, prestressing losses and forces; ultimate moments provided and required; and cracking moments. A 5-span prestressed/post-tensioned girder bridge was adopted as the example of this program. On the other hand, VBDS, Visual Bridge Design System, a three-dimensional (3D) general-purpose bridge finite element analysis (FEA) program, is usually used for major or more sophisticated bridge structures. The embedded time dependent analysis of the concrete, following the AASHTO LRFD Specifications, is a perfect tool to analyze segmentally erected prestressed concrete bridges and other spatial frame structures. As the WIN-PBEAM program, VBDS can accommodate general usage of tendons, arbitrary loadings and girder members. Graphic output of an example segmental bridge is given for the demonstration purpose.

Chung C. Fu and **Shuqing Wang**, University of Maryland, College Park, Department of Civil and Environmental Engineering, College Park MD 20742, 301-405-2011, 301-314-9129 –FAX, sqwang@wam.umd.edu.

02-3128 Evaluation and Selection of Bridge Expansion Joint Using Fuzzy Logic Expert System

Session 628

The expansion joint system is an important part of a bridge structure. Today there are numerous expansion joint products available in the market. Many of these products are designed without specification or guidelines. Engineers and suppliers continue to develop new joint configurations and materials in an attempt to improve upon the poor record of joint serviceability. The performance and life span of a proper joint system depend on the material of the joint components, the water tightness of the joints, resistance to wear and tear, fatigue load, and the resistance to all other factors such as joint installation procedures and environmental problems.

Due to the uncertainty and extreme difficulty of measuring some or all of the factors that affect the function of a joint system, an expert system using fuzzy logic knowledge base from the joint properties and historical performance that were collected by industries and Department of Transportation was developed. This expert system will calculate the Serviceability Index (SI), Structural Mechanical Integrity (SMI), and Deterioration Rate (DR). These variables function as a fuzzy set to produce a computerized evaluation of joint systems for the user. Such a fuzzy logic expert system can be expanded to include more knowledge and subsystems as needed in the future. The results of this study concluded that the use of a fuzzy logic expert system is able to provide a comprehensive and accurate selection and evaluation process of an appropriate bridge deck joint system.

Shiou-San Kuo, University Central Florida, Dept of Civil & Environmental Engineering, PO Box 162450, Orlando FL 32816-2450, 407-823-2280, 407-823-3315 -FAX, kuo@mail.ucf.edu.

02-3282 Analysis of Reinforced and Prestressed Structures with Response-2000

Session 314

A new computer program for the rational prediction of reinforced and prestressed concrete behavior is presented. The program, called Response-2000, is a sectional analysis program that can predict the shear and flexural strength of concrete beams and columns in an easy to use manner. Examples are given in tutorial format for the use of the program, and statistical evidence is presented to indicate that the program does an excellent job at predicting experimental data. The program has been downloaded by 2300 engineers in 65 countries, and is currently freely available on the World Wide Web at the address: http://www.ecf.utoronto.ca/~bentz/r2k.htm.

Evan Charles Bentz, Assistant Professor, University of Toronto, Canada, Department of Civil Engineering, 35 St. George Street, Toronto M5S 1A4, Ontario, Canada, (416)-978-4608, (416)-978-6813 -FAX, bentz@ecf.utoronto.ca.

02-3302 I-95 and Okeechobee Boulevard Interchange: Design and Fabrication Issues of Curved Steel Box Girders

Session 182

Curved box girder bridges are not rare. Nevertheless, the challenges posed during design, fabrication and construction of such structures are not few. The analytical and design process can be complex, especially for fracture critical structures with medium to long spans coupled with sharp curves. Steel fabrication is labor intensive and detail oriented and therefore careful planning during the design stages can sometimes eliminate a lot of details that are unnecessary and expensive. The revisions in the design codes over the years have really paved the way for more simple and practical design and therefore implementation of recent codes can really lead to the elimination of tedious and cumbersome details of the past. Utilizing detailing and design methodologies that are slightly different from the traditional approaches can lead to easier fabrication and construction, saving construction time, cost and long-term maintenance. This article will address some of the interesting features that were incorporated in the structure including design and detailing issues for curved box girders that could ensure economy and ease of construction.

Gautom Dey, HDR Engineering, Inc., Transportation/Bridges, 2202 N. Westshore Blvd., Suite 250, Tampa FL 33607, (813) 282-2309, (813) 282-2449 -FAX, gdey@hdrinc.com.

02-3627 Intermediate Diaphragm Effects on Concrete Bridge Performance
Session 356

The objectives of this study were to determine the effects of intermediate diaphragms on bridge superstructure performance, combined with actual bearing stiffness and thermal changes. Some of the parameters studied included the presence of intermediate diaphragms, temperature rise and drop, and increase in bearing stiffness. A finite element model of a bridge superstructure containing Florida Bulb Tee 78 girders was created using ANSYS software. This model was subjected to HL93 truck load as suggested by the AASHTO LRFD. The results indicate that intermediate diaphragms have the positive effect of reducing the maximum deflections and stresses for the bridge system. The expansion of the bridge due to a positive temperature change was shown to decrease midpoint deflections, and vice versa. The combined effect of intermediate diaphragms and the temperature changes show an increase in the effect provided by the temperature changes.

Nur Yazdani and **Tanya M. Green**, Florida A&M University-Florida State University, College of Engineering, 2525 Pottsdamer St., Tallahassee FL 32310-6046, 850-410-6125, 850-410-6659 - FAX, yazdani@eng.fsu.edu; and **Sheila R. Duwadi**, Federal Highway Administration.

02-3666 New Details for Precast Concrete Girders Made Continuous for Deck Weight
Session 356

The use of prestressed concrete I-girders with cast-in-place (CIP) deck slab has started since 1950s. Currently, prestressed I-girders are approximately one-third of the bridges built in the U.S. each year. The prestressed girders are usually designed as simple spans due to their self-weight and the deck slab weight. Cast-in-place diaphragms and longitudinal reinforcement in the deck over the piers make the superstructure continuous due to super-imposed dead loads and live load. Nevertheless, the prestressed girders are made continuous for only about one-third of the total load. Besides, some of the bridges using this type of continuity have experienced cracking due to the positive time-dependent restraint moments at the piers, especially for the highly prestressed girders. This paper presents new details to make the precast girders continuous for deck slab weight using high-strength threaded rods, projecting outside the top flange at girder ends. The threaded rods are coupled before deck slab is cast. Two details, welded connection and bolted connection, are developed. Using the proposed details can reduce girder size and amount of pretensioned strands required at maximum positive moment section, and can increase the span capacity by 10% to 15%. The proposed details are simple for construction and does not need special contractor. The new details have been implemented in the plans of a two-span bridge in Nebraska. Construction of this bridge will commence in February 2002.

Sameh S. Badie, Assistant Professor, The George Washington University, Civil and Environmental Engineering, 801 22nd Street NW, Suite 638, Academic Center, Philips Hall, 202/949-8803, 202/949-0127 -FAX, badies@seas.gwu.edu; **Chuanbinbg Sun** and **Maher K. Tadros**, University of Nebraska, Omaha.

02-4024 Complex Steel Design and Fabrication: Newark Airport Monorail Extension
Session 725

For any traveler through the Newark International Airport, the monorail is a critical link between the three terminals, parking lots, and rental car lots. The Northeast Corridor (NEC) Extension of the monorail will connect the airport to the Amtrak and New Jersey Transit trains at a new Northeast Corridor Station.

The one-mile long curved steel structure presented many interesting design and fabrication challenges.

Fatigue governed the design of many of the steel components. A modified fatigue design approach was developed for the NEC Extension that accounted for the special live load characteristics of the people-mover trains.

The area of New Jersey in which the monorail is located is a Seismic Performance Category B region. Because of the complexity of the curved continuous spans, a multi-mode spectral analysis was performed. This analysis also included the mass of the live load.

The people-mover operation also imposed constraints to the guideway design. A heating system was provided to remove ice during severe weather conditions. This heating system, although not a structural component, is connected directly to the fracture critical girders. Therefore, all details of the heating system had to meet strict fatigue requirements, while also performing their de-icing function effectively.

The discussions of the special design and detailing considerations required for the Newark Airport Monorail NEC Extension provide valuable lessons learned for all design engineers that are faced with atypical steel structures.

Michael Hebor and **Kenneth Wright**, HDR Engineering, Inc., Structures Department, 3 Gateway Center, 3rd Floor, Pittsburgh PA 15222, (412) 497-6005, (412) 497-6080 -FAX, mhebor@hdrinc.com.

02-4063 Instrumentation Plan and Early-Age Monitoring of High-Performance Concrete Bridge Girders in Missouri

Session 709

The use of high performance concrete (HPC) for highway bridge structures has seen increased use in recent years due primarily to its extended service life, reduced maintenance requirements and flexibility for designers. In recent years bridges that combine high performance concrete with larger than standard large diameter prestressed strands have been constructed. Monitoring these bridges both at early-age and later-age to better understand the behavior of HPC structures will ultimately result in design guidelines that are more specific and appropriate for HPC bridges. This paper details the monitoring and instrumentation plan for such an HPC bridge in Missouri and presents the early-age results to date. On-going monitoring for this bridge includes concrete temperature, concrete strain, beam camber and deflection. These monitoring items will be used for determining the thermal gradients, prestress losses, beam curvatures, elastic responses of beams to prestress, and the time-dependent behavior of the members due to creep, shrinkage and temperature. The early-age monitoring plan has also included the use of match-curing technology to better access the mechanical and material properties of the concete. This paper aims to provide an applicable instrumentation procedure and demonstrate the benefits of match curing technology for early-age monitoring. Early-age instrumentation and QC/QA results to date are presented.

John J. Myers, **Yumin Yang** and **Ji Shen**, University of Missouri, Rolla, Center for Infrastructure Engineering Studies, 218 Engineering Research Lab, Rolla MO 65409-0710, 573-341-6618, 573-341-6215 -FAX, jmyers@umr.edu.

02-4166 Practical Effects of Load and Resistance Factor Design on Concrete Bridge Piers

Session 314

The new AASHTO LRFD Bridge Design Specifications bring to the bridge community changes and modifications compared to the previous AASHTO Standard specifications. In an effort to understand the similarities and differences between both sets of specifications, an "in-house" pier design study was performed on a multiple column concrete pier. The bridge width is 31'-6" and

is designed for two-lanes of traffic. The superstructure is comprised of continuous precast/prestressed concrete AASHTO Type 4 I-beams with three equal spans of 92-92-92 ft. Various foundation alternatives were investigated consisting of drilled shafts, spread footings, and combined footings on cast-in-place reinforced concrete piles. HS20 and HS25 AASHTO Standard and HL-93 LRFD live loads were used. For each of the foundation alternatives, pier quantities were estimated and unit prices were attached to provide a bridge pier cost summary using both sets of specifications.

A side-by-side comparison of the key design loads, load combinations, and live load reactions are summarized using both sets of AASHTO specifications. Each pier component (e.g., pier cap, column, drilled shaft, and footing) and design is compared using both sets of AASHTO specifications.

The underlying question that faces the bridge community is; can our existing substructures support the increased demand of the HL-93 live load under the AASHTO LRFD bridge specifications? And if not, what changes and/or modifications can be expected when; 1) designing new piers, 2) rehabilitating or analyzing existing piers previously designed for either HS20/HS25 live loads? As bridge owners continue to make the transition to LRFD design, understanding the potential bridge design impacts and knowing what to expect is a necessity for concrete bridge pier designs.

David A. Tomley and **Lee D. Tanase**, LEAP Software, Inc., PO Box 16827, Tampa FL 33687, 813-985-9170, 813-980-3642 -FAX, david@leapsoft.com.

02-4168 Thirty Years of Segmental Concrete Bridge Design and Construction Lessons Learned

Session 709

This paper presents the lessons learned in the past thirty years of designing and constructing segmental concrete bridges in the United States and other parts of the World. The range of discussions range from management organization for efficiently constructing segmental bridges, to reporting of some design details which have caused contractor problems and proper solutions, to incidents observed during construction leading to great expenses for contractors and owner alike. The layout of the casting yard for a precast segmental operation is particularly addressed. An in-depth discussion of geometry control procedures for both casting and erecting of precast segments are included.

There are no project names nor other identification of projects or individuals mentioned in the papers to protect the innocent and the guilty. All photos will be screened so that the identity of the project will be protected as much as possible. Some of the projects either are in litigation or could be in the future, The intent of this paper is to be positive and not influence any current project status an any manner at all.

James M. Barker, Vice President, HNTB Corporation, 213 Isle of Sky Circle, Orlando FL 32828, 407-716-0397, 843-853-4347 -FAX, jmbarker@hntb.com.

02-4172 An Innovative Aluminum Pedestrian Bridge System

Committee A2C01 meeting

Special extruded sections form standardized aluminum pedestrian bridges of various types. High quality shop welding and rapid erection through bolted connections in the field result in a flexible system for numerous applications with considerable free span lengths and very satisfactory life-cycle cost performance. Comparative design analyses with different national and international standards allow universal application.

Dimitris Kosteas, Technische Universitaet Muenchen, Institute of Structures, Arcis St 21, Section for Light Metal Structures & Fatigue, Munich D-80333, 49-89-289-22521, 49 89 2892 2522 -FAX, kosteas@lrz.tum.de.

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2. Construction: General

02-2223 Mathematical Modeling of Pavement Smoothness

Session 507

The vast majority of states, as well as many local agencies, now use statistical end-result specifications to encourage high quality construction by awarding payment in proportion to the level of quality received. Because many of these procedures were developed by intuition and guesswork, more recent efforts have been directed at converting them to true performance-related specifications, thus providing a rational and defensible basis for price-adjustment decisions. To develop practical and effective specifications of this type, it is necessary to have at least approximate quantitative (mathematical) models of the manner in which construction quality affects performance. Using pavement smoothness as an example, a method is presented by which empirical performance data can be combined with logical assumptions about mathematical form and boundary conditions to develop quantitative models sufficiently accurate for use with statistical construction specifications.

Richard M. Weed, New Jersey Department of Transportation, Quality Management Services, PO Box 600, 1035 Parkway Avenue, Trenton NJ 08625-0600, 609-530-5970, 609-530-5972 -FAX, richardweed@dot.state.nj.us.

02-2443 Procedure for Monitoring and Improving Effectiveness of Quality Assurance Specifications

Session 507

The development of quality assurance specifications is as much an art as a science. The specifications must be introduced and monitored in the field before it can be concluded they are providing the level of construction quality and performance that is desired. Even those specifications that have proven their adequacy must continue to be monitored in a changing construction environment. Little guidance currently exists on how a highway agency can objectively assess and monitor its quality assurance specifications. Presented is a procedure that responds to this need. The procedure can be used to assess how well a specification is working. A major benefit is that the procedure can identify inconsistencies that should be corrected if the specification is to be truly effective. Continuous quality improvement can thus be made possible. Emphasized throughout is the need for agencies to have good pavement or asset management systems and databases.

Sutharin Pathomvanich, Kasetsart University, Thailand; **Fazil T. Najafi**, University of Florida; and **Peter Andrew Kopac**, Federal Highway Administration, HRDI-12, 6300 Georgetown Pike, McLean VA 22101-2296, 202-493-3151, 202-493-3161 -FAX, Peter.Kopac@fhwa.dot.gov.

02-2842 Quality-Based Prequalification of Contractors

Session 135

This paper reports on the results of research performed for the Kentucky Transportation Cabinet (KyTC) on the development of a quality-based prequalification system for contractors desiring to

do work for the Cabinet's Department of Highways (DOH). Kentucky has had a formal contractor prequalification system for many years which establishes both the type of work that a contractor may perform for the DOH and the maximum dollar volume of work that the contractor can do, including work done for other clients, at one time. It was desired to strengthen the weight given to work quality in the prequalification analysis.

A new performance evaluation was developed for highway engineers to evaluate the performance of contractors on projects. This will be done annually for all projects or at the end of the project if it finishes prior to the end of a year. The contractor is given a copy of the annual evaluation and can appeal the rating. A summary rating of the performance rating on all projects worked on for the DOH during the year is calculated for each contractor and subcontractor. This overall rating is used in the prequalification process to determine the amount of work that will be allowed in the coming year. Lower quality work will reduce the allowable work volume, while high quality work will increase the allowable work volume. There is also an appeals process for the final work volume limit set each year.

A new performance evaluation was also developed to allow the contractor to evaluate the performance of the DOH on a project each year. This information will be used by the DOH to improve its processes and to develop training for its personnel.

Donn E. Hancher and **Sean Eric Lambert**, University of Kentucky, Civil Engineering Department, 161 Civil Engr Transp Bldg, Lexington KY 40506-0281, 859-257-4857, 859-257-4404 -FAX, hancher@engr.uky.edu.

02-2876 Constructability Analysis for Asphalt Concrete Pavement Rehabilitation in Urban Corridors

Session 201

This paper presents the results of a constructability analysis for the Caltrans Long Life Asphalt Concrete Pavement Rehabilitation Strategies (LLACPRS). With the assistance of California asphalt concrete paving contractors, the analysis explored the effects on construction productivity of rehabilitation materials, design strategy (crack seat and overlay, full-depth replacement), layer profile, AC cooling time, resource constraints, and alternative lane closure tactics. Deterministic and stochastic constructability analysis programs were developed. A sensitivity study was performed that examined construction production within a 55-hour weekend closure. Weekend closures were also compared to continuous closures.

Demolition and AC delivery truck flow was the major constraints limiting the AC rehabilitation production capability. This study concludes that efficient lane closure tactics designed to work with the pavement profile can minimize non-working time to increase the construction production efficiency. The results of this study will help road agencies evaluate rehabilitation strategies and tactics with the goal of balancing the maximization of production capability and minimization of traffic delay during urban rehabilitation.

Eul-Bum Lee, **John T. Harvey** and **William C. Ibbs**, University of California, Berkeley; and **Jim St. Martin**, Executive Director, Southern California Asphalt Pavement Association, 13697 Hwy 94, #2000, Jamul CA 91935, 1-800-734-9996, jstmartin@apaca.org.

02-3004 Evolvement of Contractor's Construction Schedule to Meet Engineer's Satisfaction

Session 201

With the increasing complexity of construction projects, proper planning and control of project activities now represent key issues in the management function. Pretender planning leading to a

cost estimate is normally used as a baseline for project control in the following project stages. That is, construction planning and cost estimating go in parallel in order to reach a realistic cost estimate. However, not enough scheduling can be done at the tender stage since this requires a certain level of detail for the work items. It is proposed in this work that the misconception of the contractor being able to submit a full-fledged detailed construction schedule upon the award of contract, to be later followed by regular updates, be replaced with a rolling wave concept that permits work items with differing levels of detail to be shown simultaneously in any version of the schedule. A procedure for generating the first construction program and gradually developing it during the construction phase is proposed, aimed at allowing engineers and contractors the opportunity of understanding the intrinsic principles for properly administrating the construction schedule.

Mohamed-Asem U. Abdul-Malak and **Zeina A. Hassanein**, American University of Beirut, Lebanon, Engineering Management Program, P.O. Box 11-0236, Riad El Solh, Beirut 1107-2020, Lebanon, +961-3-888188, +961-1-744462 -FAX, mamalak@aub.edu.lb.

02-3215 Factors of Importance for Determining Daytime Versus Nighttime Operations in Oregon

Session 201

The State of Oregon is in the process of developing a decision model which will be used to improve the decision-making process concerning daytime versus nighttime construction and maintenance activities. In reviewing the literature, a comprehensive list of factors was available which was well defined and articulated. However, the literature did not provide information on the relative importance of the various factors. This paper provides the findings from the literature review, and results from an extensive survey. The survey details the views of 446 respondents from within the state of Oregon and 25 other states. Congestion, traffic control, and safety were the most important factors in making these decisions.

Kimberly D. Douglas and **Sang-Bin Park**, Oregon State University, College of Engineering, 118 Covell Hall, Corvallis OR 97331-2407, 541-737-3644, 541-737-5241 -FAX, kdd23@home.com; and **Kevin J. Haas**, Oregon Department of Transportation.

02-3226 Development of Quality Control/Quality Assurance Specification for Structural Concrete

Session 507

This paper describes the development of a Quality Control / Quality Assurance specification for structural concrete for the South Carolina Department of Transportation . The specification requires quality control sampling and testing to be performed by the contractor which is then verified by the Department on a less-frequent sampling schedule. Acceptance of in-place structural concrete is based on 28-day concrete compressive strength and percent air content in the concrete delivered to the site. Quality control tests required by the specification include mixture temperature, slump, unit weight, aggregate gradation and moisture content. Payment is based on the percent within limits and a pay factor applied to individual lots.

This paper also describes a recommended implementation plan for the State of South Carolina to gain acceptance throughout the state by developing a new technician certification program, conducting pilot projects to test the specification, and by conducting workshops to inform contractors and department employees of the new specification and its requirements for sampling, testing, quality control plans, control charts, and other changes.

W. James Wilde, The Transtec Group, Inc., 1012 E. 38 1/2 St., Austin TX 78751, 512-451-6233, 512-451-6234 -FAX, wjw@thetranstecgroup.com; and **Frank B. McCullough** and **David W. Fowler**, University of Texas, Austin.

02-3941 Contractor- Led Quality Control and Quality Assurance Plus Design-Build: Who Is Watching the Quality?

Session 135

This paper presents recent innovations by the Arizona Department of Transportation (ADOT) in the use of design-build procurement for highway construction. In response to explosive population growth, the Department spearheaded the passage of a pilot design-build law in 1996 aimed at completing public construction projects more rapidly than could be done using traditional methods. This paper describes an evaluation made of the material quality program used in the second design-build project in this program. The project reconstructed an extremely congested seven-mile segment of Interstate 17, a primary artery carrying 180,000 vehicles per day through the City of Phoenix, widening it from six lanes to ten. The A+B design-build contract, the largest ever awarded at the time, was won by a design builder who implemented a very aggressive schedule which required double shift work for nearly two years. In another contracting first, the Agency also assigned the design builder responsibility for the quality control and quality assurance functions on the project with ADOT providing verification sampling and testing only. This paper examines the project's concrete compressive strength and material density test data obtained from the project and compares them to state-wide averages of test results from traditional design-bid-build projects where ADOT performed the quality assurance function.

Analysis of the data shows that despite a highly compressed schedule, the material test quality on the project exceeded the project specifications and was similar in quality level to work completed for ADOT under traditional contracting methods with an ADOT operated quality assurance program.

James J. Ernzen and **Tom Feeney**, Arizona State University, Del E. Webb School of Construction, Box 870204, Tempe AZ 85287-0204, 408-965-0389, 408-965-1769 -FAX, james.ernzen@asu.edu.

02-4027 Issues Related to Use of Contractor Quality Control Data in Acceptance Decision and Payment

Session 100

Several agencies throughout the U.S. utilize contractor data as a means of acceptance. This is a permissible practice as long as certain safeguards are in place and that the functions of quality control (QC) and quality acceptance (QA) remain separate. The benefit to this type of procedure is a potential decrease in manpower and testing facilities for the state agency. However, there are inherent risks that also go along with this type of approach for acceptance.

In most cases, the changes required to implement a system where contractor data is used in the acceptance decision requires a more philosophical change rather than technical. In other words, the amount of testing the contractor will have to do to meet the requirements of the change will more than likely be about the same (or only increase slightly) as is currently undertaken in the current specification system. However, even though a state agency may see a drop in the testing required to support acceptance, they will now be faced with the fact that they must trust the contractor’s data for use in determining pay factors and ultimately acceptance of the work.

Thus, when the procedure of contractor testing used for acceptance is fully implemented, there will be two major impacts on a state agency. One is a psychological adjustment for agency personnel to assimilate the fact that contractor test results will be used for establishing the pay factor. Discussion is needed to address this adjustment and the state should plan training sessions to address the reasons for this decision and the importance of the steps that will be taken to implement it. The other impact is the need to implement and monitor the validation system.

Brian M. Killingsworth, Fugro-BRE, Inc., 8613 Cross Park Drive, Austin TX 78754, 512-977-1800, 512-973-9565 -FAX, bkillingsworth@fugro.com; and **Charles S. Hughes**, Consulting Engineer.

02-4055 Laboratory and Field Analysis of TransTech Model 300 Pavement Quality Indicator for Determining Asphalt Pavement Density

Session 545

The Pavement Quality Indicator (PQI), produced by TransTech Systems, Inc., uses principles of electrical impedance and dielectric constants of materials to determine the density of asphalt pavements. The Model 300 PQI device was recently evaluated in Illinois as a potential alternative to nuclear density gauges for quality control and quality assurance of asphalt pavement construction. Both laboratory and field testing were conducted to meet these objectives. The PQI has several appealing features relative to the nuclear density gage, including lightweight, rapid field operation, without the need for special licensing, handling or training.

The nuclear gauge generally exhibited a closer correlation with density determined from pavement cores, as denoted by significantly lower SSE values in the regression analyses performed. Also, while the Model 300 PQI has improved from earlier models to account for moisture and temperature, the data suggests that the device is still influenced by environmental conditions. On the other hand, the PQI proved to be more operationally convenient for the field technician, being significantly lighter and less time-consuming to operate in the field.

Based on analysis of the information obtained from these studies, IDOT has chosen to base acceptance and statistical pay factors on density values obtained from the T 166 method on pavement cores. At present, the nuclear gauge is still the specified device for QC/QA of asphalt pavement projects in Illinois.

John Joseph Hausman, ERES Consultants, Inc., 9030 Red Branch Road, Suite 210, Columbia MD 21045, (410) 997-6181, (410) 997-6413 -FAX, jhausman@ara.com; and **William G. Buttlar**, University of Illinois, Urbana-Champaign.

02-4102 Quality Management System for a Highway Megaproject

Session 135

Although the concepts of quality management have been successfully applied in many industries, primarily manufacturing and equally to the construction industry, highway mega projects especially those delivered through private-public partnerships (P3) arrangements present new challenges. The current movement from traditional method specifications to end-result specifications and the downloading of quality responsibilities to the developer/builder brings with it the need to verify quality performance. A quality information management system becomes a necessity given the volume of the information generated. This paper discusses the challenges of developing and implementing a quality information management system for a highway mega-project in New Brunswick Canada. The system developed addresses key needs including support for various levels of management (technical and executive), an open data structure and inter-operability, hierarchical information levels, integration with facility-wide

management information, and future scalability. The developed system addresses the needs of quality information management for a private project developer but can also be adapted to other project delivery mechanisms. The tool was implemented to support the entire project team including construction field supervisors and project's senior management. The paper offers a documented analysis of a generic implementation process that can be adopted in other projects to improve efficiency in quality information management in the highway construction industry in general, and in particular mega-projects delivered through P3 arrangements.

Donath M. Mrawira, **Jeff H. Rankin** and **A. John Christian**, University of New Brunswick, Canada, Civil Engineering, 17 Dineen Drive, POBox 4400, Civil Engineering, Fredericton, E3B 5A3, Canada, (506) 453-4976, (506) 453-3568 -FAX, donath@unb.ca.

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3. Construction: Pavements

02-2351 Online Tools for Hot-Mix Asphalt Monitoring

Session 248

This paper is used to demonstrate that it is feasible, realistic, and practical to develop and deploy, on a local or national scale, an online database to monitor hot mix asphalt (HMA) projects throughout their life cycle. Such a tool allows for the real-time acquisition and monitoring of mix design, field construction, and performance data, as well as archival of such data. Monitoring includes browsing, searching and analyzing data ranging from mix design and quality assurance/quality control (QA/QC) field data to performance measures such as roughness, cracking, and rutting. In particular, this paper demonstrates early implementation via Washington State's Superpave project data. The database includes quantitative design and construction data, field instrument readings, infrared and video images, and performance information. Analysis and search capabilities are provided, including a map-based front-end to support spatial searches and location based data entry. It is currently available online at http://hotmix.ce.washington.edu/.

George C. White, **Joe P. Mahoney**, **George M. Turkiyyah**, University of Washington, Civil & Environmental Engineering, Box 352700, Seattle WA 98195, 206-685-7198, 206-543-1543 - FAX, gcw@u.washington.edu; **Kim A. Willoughby**, Washington State Department of Transportation; and **E. Ray Brown**, National Center for Asphalt Technology.

02-2451 Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania

Session 372

Premature deterioration of multilane hot mix asphalt (HMA) pavements can occur at the longitudinal joints in the form of cracking and raveling. The National Center for Asphalt Technology (NCAT) initiated a national study of evaluating various longitudinal joint construction techniques in 1992 in an effort to select technique(s) which improve the performance of longitudinal joints. Test sections were constructed in Michigan, Wisconsin, Colorado, Pennsylvania, and New Jersey. This paper gives the 6-year performance evaluation of eight different techniques utilized on a paving project in Pennsylvania in 1995.

In Pennsylvania, longitudinal joint constructed using rubberized joint material gave the best performance closely followed by the joint made with cutting wheel. Test sections using rolling from hot side 152 mm away from the joint and the New Jersey wedge joint also performed reasonably well with no significant cracking. The remaining four test sections using

edge restraining device, joint maker, rolling from hot side, and rolling from cold side developed cracking at the longitudinal joint to different extents.

It has been recommended to specify minimum compaction level at the longitudinal joint to ensure its improved performance.

Prithvi S. Kandhal, National Center for Asphalt Technology; **Timothy Ramirez** and **Paul M. Ingram**, Pennsylvania Department of Transportation, Materials and Testing Laboratory, 1118 State Street, Harrrisburg PA 17120, 717-787-7150, 717-783-5955 -FAX, tramire@dot.state.pa.us.

02-2756 Precision Statements for Ignition Oven Using Plant-Produced Mix

Session 625

The current precision values given in Florida Method FM 5-563 for the determination of asphalt binder content by use of the ignition oven are based on laboratory fabricated specimens with known binder contents and gradations (1). This study was conducted to determine precision values for both asphalt binder content and gradation using plant produced mix. This approach would encompass the variability associated with: 1) differences in an asphalt mixture within the truck bed, 2) sampling the truck, 3) splitting the mix into sample size, 4) differences in ignition oven equipment, and 5) variability associated with the operator. The current precision values only include the variability associated with items four and five and the variability associated with batching and mixing laboratory prepared specimens. Twelve laboratories tested nine different mixtures containing a wide variety of gradations and aggregate types. The results of the study indicate that the allowable difference between two test results for asphalt binder content should be no greater than 0.32% within-lab and 0.44% between-labs. New graphs were developed for the within-lab and between-lab precision values for aggregate gradation. Separate graphs were developed for dense graded Superpave mixtures and open-graded friction course mixtures since it was determined that allowable tolerances differ significantly for each type of mixture.

Gregory A. Sholar, **Gale C. Page** and **James A. Musselman**, Florida Department of Transportation, 2006 NE Waldo Road, Gainesville FL 32609, 352-337-3278, 352-334-1649 - FAX, gregory.sholar@dot.state.fl.us.

02-3142 Construction and Performance of Ultra-Thin White Topping in Kansas

Session 201

This paper presents the results of a study of the effect of curling on as-constructed smoothness of concrete pavements (PCCP) in Kansas. Eight test sections on four newly built PCCP projects on I-70 and I-135 were selected. The test sections, varying in PCCP slab thickness from 280 to 320 mm, were on stabilized drainable bases and lime-treated subgrade. The effect of application of two coats of curing compound as opposed to commonly used one coat was investigated. Longitudinal profile measurements were done on each wheel path on both passing and travel lanes with a Dipstick and a South Dakota-type Profiler prior to opening to traffic. From these profile data, the International Roughness Index (IRI) values were calculated for both equipment types. Analysis of Variance (ANOVA) was performed to find out the effects of different variables on the calculated IRI values. For most cases, application of two coats of curing compound resulted in significantly different as-constructed IRI. On one project, the time of IRI measurement was found to be significant. In three out of four projects studied, IRI values calculated from the Dipstick data were significantly different from those calculated from the South Dakota-type Profiler data. A method has been developed to separate curling digitally from the actual profile assuming existence of uniform curling on each slab. The contribution of curling

to the measured roughness was very significant. The results also showed that 75 mm (3 in.) sampling intervals in profile measurement give the highest IRI for the currently used algorithms.

Zahidul Quadir Siddique, **Mustaque Hossain** and **John Devore**, Kansas State University, Dept. of Civil Engineering, Seaton Hall, Room 119, Manhattan KS 66506, 785-532-1576, 785-532-7717 -FAX, mustak@ksu.edu; and **William H. Parcells**, Kansas Department of Transportation.

02-3180 Evaluation of Concrete Pavement Construction Scenarios Under Performance-Related Specifications

Session 448

Performance-related specifications (PRS) specify the target quality level at which a pavement construction contractor would receive full payment for a job. PRS also specify minimum acceptable quality and maximum quality levels. At the minimum quality level, the pavement is deficient enough that a corrective action or 'remove and replace' is warranted. At the maximum quality level, the pavement is unnecessarily more conservative than the design so that no further pay increase will be applied. Thus, the contractor can be innovative in targeting various quality levels between the minimum quality level and the maximum quality level. Higher quality is likely to increase the initial construction cost, and lower quality is likely to reduce the initial construction cost.

The main objective of this paper is to provide a methodology for analyzing the risks and expected net gain or loss for various construction scenarios under PRS for a jointed plain concrete pavement (JPCP). The analysis is based on PRS that were developed for a JPCP project on I-295 in Jacksonville, Florida, and example relative initial construction costs. Contractors can run the analysis using their own relative cost data.

Risks can never be totally eliminated in pavement specifications because of the inherent variability in pavements and the use of random sampling. This paper focuses on quantifying the contractor's risk under the I-295 PRS.

Nasir G. Gharaibeh, **Joseph A. Stefanski** and **Michael A. Darter**, ERES Consultants, Inc., 505 West University Avenue, Champaign IL 61820, 217-356-4500, 217-356-3088 -FAX, ngharaibeh@ara.com.

02-3636 Importance of Concrete Temperature Control During Concrete Pavement Construction in Hot Weather Conditions

Session 448

The development of high concrete temperatures could cause a number of effects that have been shown to be detrimental to long-term concrete performance. High concrete temperatures increase the rate of hydration, thermal stresses, the tendency for drying shrinkage cracking, permeability, and decrease long-term concrete strengths, and durability as a result of cracking. Data from the Texas Rigid Pavement database was analyzed to reveal that there are an increased number of failures as the air temperature at placement increases. It was further shown that this was the case for both major coarse aggregate types: limestone and siliceous river gravel. The result of this analysis emphasizes the importance of concrete temperature control during concrete pavement construction in hot weather conditions.

Most states specify a maximum concrete temperature at placement, to mitigate the detrimental effects of hot weather placement. The specified limit remains the same irrespective of the type of mineral or chemical admixtures used. In order to produce specifications that encourage contractor innovation and the use of improved materials, modern specifications should account for these materials in order to ensure improved concrete performance under all

placement conditions. To provide improved performance for section paved under hot weather conditions, it is proposed that the CRC pavement reinforcement standards be re-designed to provide steel quantities for specific use during hot weather conditions, and that an end-result specification that limits the maximum concrete temperature during hydration be implemented.

Anton K. Schindler, University of Texas at Austin; and **B. Frank McCullough**, The Transtec Group, Inc., 1012 East 38 1/2 Street, Austin TX 78751, 512-451-6233, 512-451-6234 -FAX, bfm@thetranstecgroup.com.

02-3811 Construction and Performance of Ultrathin Whitetopping in Kansas
Session 201

A suburban city street in Kansas was rehabilitated with a 50 mm (2 in.) Portland cement concrete overlay, commonly known as ultra-thin white topping (UTWT). The construction and performance of this UTWT project have been described in this paper. The project, constructed in the Spring of 1995, incorporated the following design features: 0.9 m x 0.9 m (3 ft x 3 ft) panels versus 1.2 m x 1.2 m (4 ft x 4 ft) panels, plain versus fiber reinforced concrete, and sealed versus unsealed joints. The project has performed fairly well to date although some test sections needed periodic maintenance. Experience on this project shows that the UTWT overlay can be easily built with conventional equipment and locally available materials. UTW permits a skid-resistant finish to be applied. Excellent smoothness can also be obtained although the slab thickness is very small. Corner cracking appears to be the most dominant distress type, though it was observed that a strong bond existed between the concrete and asphalt layers even for the cracked panels. The bond appeared to degrade with time. Joint spacing has a significant effect on performance. The sections with smaller joint spacing appeared to perform better. The performance of the sections with fibers in concrete was inconclusive. Also, joint sealing did not appear to affect the performance.

Mustaque Hossain and **Nicolleta I. Dumitru**, Kansas State University, Dept of Civil Engineering, Seaton Hall, Room 119, Manhattan KS 66506, 785-532-1576, 785-532-7717 - FAX, mustak@ksu.edu; and **John B. Wojakowski**, Kansas Department of Transportation.

02-4150 Virginia's Experience with 9.5-mm Nominal Maximum Aggregate Size SMA
Session 248

This paper includes construction data from two 9.5 mm nominal maximum aggregate size (NMAS) (Superpave definition) Virginia SMA projects. The paper examines the effect of break point sieve size, rut resistance, design compactive effort, and permeability. Rut resistance and permeability results are compared to more conventional Virginia 19.0 and 25.0 mm NMAS SMA mixes produced by the same contractor and utilizing the same aggregate source.

The 2.36 mm sieve confirmed as being the appropriate break point sieve for 9.5 mm SMA. For this gradation, 9.5 mm NMAS SMA with both PG 70-22 and PG 76-22 was as rut resistant as previous Virginia SMA mixtures as tested by the Asphalt Pavement Analyzer. The data for these sections indicates that 9.5 mm NMAS SMA should be designed with 75 gyrations instead of the currently recommended 100 gyrations. 9.5 mm NMAS SMA was shown to be less permeable at the same air voids levels as more commonly used 19.0 and 25.0 nominal maximum aggregate size SMA.

Brian D. Prowell and **Alan Cooley**, National Center for Asphalt Technology, 277 Technology Parkway, Auburn AL 36830, 334 844 6228, 334 844 6248 -FAX, bprowell@eng.auburn.edu; **Richard J. Schreck**, Virginia Asphalt Association.

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4. Facilities, Equipment Design and Performance

02-2166 Influence of Vertical Alignment on Horizontal Curve Perception: Phase I: Examining the Hypothesis

Session 632

The importance of the driver receiving precise visual cues from the road environment cannot be overstated. If the visual cues are confusing or in any way cause the driver to incorrectly assess the approaching road environment, the crash risk of the driver may increase. Of particular concern are the perceptual problems induced by superimposing horizontal and vertical curves. To investigate the effect of overlapping vertical alignment on the perceived horizontal curvature, dynamic and static computer generated three-dimensional presentations of the driver's view of a road were created. Phase I of the experiment, presented in this paper, collected data to test the hypothesis that overlapping crest curves made the horizontal curvature appear sharper and overlapping sag curves made the horizontal curvature appear less sharp. The results of both presentation methods (dynamic and static) were in agreement with each other and showed that the hypothesis was valid. However, the hypothesis was more evident in the case of sag curves, which is more serious with respect to safety. The probability of erroneous perception, as influenced by vertical curves, increases as the sight distance increases, the horizontal curve radius increases, or the vertical curve becomes more pronounced. Driver characteristics did not seem to affect the horizontal curve perception.

Shaun Bidulka and **Tarek Sayed**, University of British Columbia, Canada; and **Yasser Hassan**, Carleton University, Dept. of Civil and Env. Eng., 1125 Colonel By Drive, Ottawa ON K1S 5B6, Canada, (613) 520-2600 X 862, (613) 520-2951 -FAX, yhassan@ccs.carleton.ca.

02-3487 Methodology to Calculate Sight Distance at Skewed Intersections Considering Driver's Position

Session 632

This paper describes a methodology of calculating sight distance available to drivers at skewed non-signalized intersections of which minor roads are controlled by stop signs. The methodology considers the fact that the sight distance may be variable depending on driving positions of the drivers and different types of vehicles can give the drivers different lines of sight. Through field observations, the factors affecting the sight distance available to drivers are found. The factors include intersection geometry, vehicle's dimension and driver's field of view. With sight triangle properly drawn, equations for calculating sight distance available considering the factors were developed. Values of sight distance were compared with stopping sight distance of vehicles on the cross roads by varying design speeds and intersection angles. Nomographs were developed which can be used by road designers or operators to check if a skewed intersection satisfies sight distance requirement.

YoungTae Son and **JinKak Lee**, Myongji University, Korea; and **SangGu Kim**, Korea Highway Corporation, Highway Research Center, 293-1 Keumto-Dong Sujeong-Gu, SeongNam-Shi 461-703, Kyunggi-Do, Korea, Republic of, +82-31-2230-4687, +82-31-2230-4182 -FAX, kimsg@freeway.co.kr.

02-3677 Three-Dimensional Visualization Approach for Illustrating Esthetic Concepts for Design of Highways

Session 632

The purpose of this study was to develop realistic and dynamic visuals that can be used in a teaching context for illustrating concepts that affect the appearance and fit of a highway alignment. The models consist of short video clips of the highway taken from the perspective of a vehicle's windscreen. These video images of the roadway are coupled with graphs showing the corresponding vertical and horizontal alignment of the roadway. The users of these models can simulate a drive over the selected highway segment and visually assess the appearance and continuity of the alignment. They can then study the accompanying alignment graphs to assess how different combinations of vertical and horizontal elements affect the appearance and continuity of the alignment. Each of the video clips was selected to illustrate either a good or bad example of a specific concept affecting alignment design. Some of the concepts discussed include the proper coordination of vertical and horizontal alignment and consistency in alignment development. In this paper, we also describe how the video clips where developed using images and data from the Connecticut DOT's photologging system.

Tomasz P. Janikula, Federal Highway Administration; and **Norman W. Garrick**, University of Connecticut, Civil and Environmental Engineering, 261 Glenbrook Rd. U-2037, Storrs CT 06269-3037, 860-486-2990, 860-486-2298 -FAX, norman.garrick@uconn.edu.

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5. Bituminous Materials

02-2205 Performance-Graded Binder Specification for Surface Treatments

Session 453

Surface treatments have been used by many government agencies as part of their maintenance and rehabilitation programs to improve surface quality and extend the service life of pavements. Traditional specifications for surface treatment binders failed to characterize materials across the entire spectrum of temperatures experienced during production and construction and in-service and required properties that were not directly related to performance. The Superior Performing Asphalt Pavements (Superpave) or performance-graded (PG) asphalt binder specification was developed in the 1990's to measure binder properties directly related to HMAC performance and included material characterization at low, intermediate, and high temperatures. Direct application of the PG binder specification to binders used in surface treatments is not appropriate due to differences between surface treatments and HMAC in terms of distress types, construction methods, and exposure to environmental conditions. The objective of this study conducted for the Texas Department of Transportation was to develop a performance-based specification system for surface treatment binders that maximizes the use of existing equipment required in the PG system for HMAC binders. This new surface performance grading (SPG) specification assumes appropriate design and construction practices and considers only binder properties after construction. The SPG was developed based on the identification of common distresses and analysis of physical properties at multiple temperatures of surface treatment binders that correlate to these distresses. The final SPG includes limiting values for high and low surface pavement design temperatures. Implementation of the SPG specification is recommended after a field validation experiment.

Roberto Barcena, Texas Transportation Institute; **Amy L. Epps**, Texas A&M University System, Room 503F, CE TTI Building, 3136 TAMU, College Station TX 77843-3136, 979-862-1750, 979-845-0278 -FAX, a-epps@tamu.edu; and **Darren Hazlett**, Texas Department of Transportation.

02-2361 Rutting Potential Evaluation of Asphalt Mixtures by Repeated-Load Creep Test

Session 342

Field or laboratory wheel tracking tests have been employed for the evaluation of the rutting potential of asphalt paving mixtures. Compared to field tests, laboratory wheel tracking tests are much less expensive and more manageable for most road projects. However, most test laboratories are not equipped to perform such tests because there does not exist any standard test procedure, and the required equipment is rather expensive. Furthermore, the size of test specimens and the relatively large quantity of test mixture required present difficulties for laboratory specimen mixing and compaction. This paper describes a project conducted to study the feasibility of replacing wheel tracking tests by a repeated-load creep test for rutting potential evaluation. Comparisons were made between the results of the two tests for different test temperatures, loading speeds and applied pressures. Three types of asphalt mixtures were studied in the test program. Favorable conclusions concerning the use of the repeated-load test for rutting potential evaluation were drawn based on the findings of the experimental test results. The correlation between the two types of tests was found to be good for all three asphalt mixtures. Adopting the repeated-load creep test would lead to cost savings since it employs standard test equipment already available in most laboratories. It would also result in substantial time savings due to the much smaller quantity of mix needed, and the ease in specimen preparation.

L.Y. Zhu, **Y. Liu** and **Tien F. Fwa**, National University of Singapore, Center for Transportation Research, Civil Engineering, 10 Kent Ridge Crescent, 119260, Singapore, 65-779-1635 -FAX, cvefwatf@nus.edu.sg.

02-2403 Coarse Versus Fine-Graded Superpave Mixtures: Comparative Evaluation of Resistance to Rutting

Session 700

Both coarse and fine-graded hot mix asphalt mixtures can be designed within the gradation control points recommended in Superpave mix design. However, some states have begun to specify only coarse-graded mixtures (below the restricted zone) whereas other states are specifying only fine-graded mixtures (above the restricted zone). This study was conducted to compare coarse-graded Superpave mixtures with fine-graded Superpave mixtures in terms of resistance to rutting so as to determine whether restrictions on gradations (either coarse- or fine-graded mixtures) are justified.

Fourteen mixtures comprising two nominal maximum aggregate sizes: 9.5 and 19.0 mm; two coarse aggregates: granite and crushed gravel; and four fine aggregates: sandstone, limestone, granite, and diabase, were tested. Resistance to rutting of both coarse- and fine-graded mixtures was evaluated using three test methods: Asphalt Pavement Analyzer, Superpave shear tester, and repeated load confined creep test.

Statistical analyses of the test data obtained by the three performance tests indicate no significant difference between the rutting resistance of coarse- and fine-graded Superpave mixtures. It has been recommended that mix designs should not be limited to designing mixes on the coarse or fine side of the restricted zone.

Prithvi S. Kandhal and **Larry Allen Cooley, Jr.**, National Center for Asphalt Technology, Auburn University, 277 Technology Parkway, Auburn AL 36830, 334-844-6228, 334-844-6248 - FAX, coolela@eng.auburn.edu.

02-2505 Use of Stiffness of Hot-Mix Asphalt as Simple Performance Test

Session 342

The objective of this study was to investigate if the stiffness of a mix could be used as a Simple Performance Test (SPT) parameter to complement the Superpave volumetric mix design. This was completed through a statistical analysis of the strength of correlation between different mixture stiffness parameters and field performance (rutting, thermal and fatigue cracking). A total of 30 mixtures were tested using laboratory-fabricated specimens. The measured stiffness parameters were compressive dynamic (complex) modulus (|E*|), Simple Shear Tester (SST) shear modulus (|G*|), and dynamic elastic modulus using ultrasonic wave propagation. Also, computed stiffness factors |E*|/sinf and |G*|/sinf for rutting and |E*|sinf for cracking were studied as analogous to the Superpave binder specification. Research indicated that the correlation to rutting varied based on test temperature and frequency, and it peaked at 54.4°C temperature and 5 Hz, and poorer correlations were found to develop at lower frequencies. At peak conditions, the |E*|/sinf had better statistical correlation to rutting than |E*|, but correlations reversed at lower frequencies. Although the |E*| and |G*| had similar correlation to rutting, analysis of test data indicated that the SST-shear testing gave lower mixtures stiffness values and higher phase angle values than the compressive dynamic modulus testing especially at high temperatures even when considering Poisson's ratio effects. Because of these and other reasons, the dynamic modulus |E*| was recommended as the SPT parameter for rutting, as well as for fatigue cracking. Non of the studied parameters turn out to be good enough performance indicators for thermal cracking.

Terhi Kristiina Pellinen, Purdue University, Civil Engineering, 1284 Civil Engineering Building, West Lafayette IN 47907-1284, 765-496-2513, pellinen@ecn.purdue.edu; and **Matthew W. Witczak**, Arizona State University.

02-2578 Impact of Different Types of Modification on Low-Temperature Tensile Strength and T-critical of Asphalt Binders

Session 114

Since the introduction of the Superpave asphalt binder specification, the asphalt industry has a useful guideline to choose appropriate materials to meet the requirements of a specific climatic locale. Acid, alkaline and polymer modification are just some of the ways to modify asphalt to meet the Superpave specification. The Direct Tension Test (DTT) technique was applied to study the low-temperature properties of modified asphalt in terms of DTT failure stress values and the critical cracking temperature (Tcritical). The Bending Beam Rheometer (BBR) usually failed to detect the improvement in low-temperature performance in polymer modified asphalt (PMA). The DTT results show that polymer modification improves the low-temperature performance of PMA. In some PMA, the failure stress value was higher than 9.5 MPa. The DTT technique for PMA is also discussed.

The effect of acid or alkaline modifiers on asphalt materials was also studied. It was found that acid or alkaline modification of asphalt is only temporary and can be reversed. Acid modification of asphalt can be reversed by reaction with alkaline materials such as lime or anti-stripping agents. Alkaline modification of asphalt can be reversed by reaction with acidic materials such as carbon dioxide. Alkaline can also be washed away by water. Even though BBR

suggested a slight improvement in the low-temperature performance in acid or alkaline modified asphalt, the DTT failure stress values and Tcritical did not confirm this improvement.

A relatively simple procedure allowing detection of acid or alkaline modification of asphalt materials is described.

Susanna Man Sze Ho and **Ludo Zanzotto**, University of Calgary, Canada, Civil Engineering, Bituminous Materials Laboratory, 2500 University Drive NW, Calgary T2N 1N4, 403-220-8077, 403-282-7026 -FAX, smsho@ucalgary.ca; and **Daryl MacLeod**, Husky Energy.

02-2779 Effect of Aggregate Structure on Rutting Potential of Dense-Graded Asphalt Mixtures

Session 580

Superpave mix design as the name suggests was developed to provide superior performing pavements for the transportation industry. However, researchers and designers in their quest to provide such mixtures have encountered problems with some design specifications such as the restricted zone. Superpave recommends that designers avoid grading through the restricted zone to eliminate tender mixes and gradations that may be too close to the maximum density line. But studies into the performance of the restricted zone have shown that dense graded mixtures that violate this requirement have provided good performance. It has also been reported that mixtures that are graded below the restricted (BRZ) have poor rutting performance than those that are graded above (ARZ) or through the restricted zone (TRZ). It is also known that the minimum VMA requirement, which was established to ensure durability, is very difficult to achieve and leads to over asphalting in BRZ mixtures thus compromising their resistance to rutting. The purpose of the paper is to examine the effect of aggregate structures on rutting performance of mixtures. Ten mixtures comprising seven whiterock and three granite mixtures were used. Of these, six were coarse-graded and four were fine graded. After investigating the behavior of the mixtures, it was concluded that BRZ mixtures developed different aggregate structures from ARZ mixtures and the performance of mixtures depended on their aggregate structures. It was observed the high VMA requirement caused over asphalting in BRZ mixtures hence their dismal performance as compared to ARZ mixtures.

Bensa Nukunya, **Reynaldo Roque** and **Mang Tia**, University of Florida, Department of Civil and Coastal Engineering, 124 Yon Hall, P. O. Box 116580, Gainesville FL 32611-6580, 352 392 9537 x1465, 352 392 3394 -FAX, bensa123@ufl.edu; and **Yusuf A. Mehta**, Rowan University.

02-2884 Simple Performance Test for Permanent Deformation of Asphalt Mixtures

Session 342

This research study had a primary objective: to recommend a fundamentally based laboratory Simple Performance Test (SPT) for permanent deformation evaluation to be used within the Superpave volumetric mixture design procedure. This SPT was intended to provide accurate correlation to field rutting performance. Two tests are discussed in this paper. These are the repeated load permanent deformation test, and the static creep / flow time test. The tests were evaluated using mixtures and performance data from three experimental sites: the Minnesota Road Project (MnRoad), the Federal Highway Administration (FHWA) Accelerated Loading Facility Study (ALF), and the FHWA Performance-Related Specifications Study (WesTrack).

Several parameters were evaluated from each test. Two tertiary flow laboratory response parameters stood out in the study as having excellent correlation with field rut depth data: the flow number from the repeated load test and the flow time from the static creep test. The two parameters were found to be repeatable, reliable in distinguishing between a wide range

of asphalt mixtures, and sensitive to different testing variables. Both of these parameters / tests were recommended for further evaluation and follow up validation testing.

Kamil E. Kaloush and **Mathew W. Witczak**, Arizona State University, Civil and Environmental Engineering, PO Box 875306, Tempe AZ 85287-5306, 480-965-5509, 480-965-0557 -FAX, kaloush@asu.edu.

02-2924 Simple Performance Test for Fatigue Cracking of Asphalt Concrete Based on Viscoelastic Analysis of Indirect Tensile Test and Its Validation Using WesTrack Asphalt Mixtures

Session 209

This paper presents the viscoelastic characterization of asphalt concrete in indirect tensile testing (IDT) and the development of a simple performance test for fatigue cracking. A 50 mm gauge length was adopted to measure the horizontal and vertical deformations using surface mounted LVDTs on an IDT specimen with a 100/150 mm diameter and 38 mm thickness. The effect of a concentrated load under loading strips on vertical displacement within the 50 mm gauge length was evaluated using the Digital Image Correlation method, a noncontact, full-field displacement/strain measurement technique. The theory of viscoelasticity was used to develop analytical solutions for creep compliance and center strain from displacements measured on the specimen surface. These solutions were verified by 3-D finite element viscoelastic analysis. Indirect tensile creep and strength tests were performed on fine and coarse mixtures from WesTrack with varying asphalt contents and air void contents, and various parameters determined from the analysis of these data were compared against the known fatigue performance of these mixtures from the WesTrack testing facility. Fracture energy obtained from the viscoelastic analysis of the indirect tensile strength test at 20°C correlated highly with the field performance of these mixtures at WesTrack.

Haifang Wen and **Y. Richard Kim**, North Carolina State University, Dept. of Civil Engineering, Campus Box 7908, Raleigh NC 27695, 919-515-7758, 919-515-7908 -FAX, kim@eos.ncsu.edu.

02-3144 Hot-Mix Asphalt Smoke and Emission Potential

Session 717

Gas chromatography was used to evaluate 10 binders from various regions of the country for odor producing volatile organic compounds (VOCs). A total of seven VOC groups were identified as being potential odor producers: polyaromatic hydrocarbons (PAHs), heterocyclics, alkanes, BTEX, mercaptans, phthalates, and chlorinated VOCs. A total of seven odor reducers were added to these 10 binders and the change in the VOC production evaluated. The ability of the odor reducers to mitigate a given VOC concentration depended on the quantity of the VOCs produced in the first place and the particular odor reducer.

Two odor reducers that were the most effective in reducing VOCs in the GC testing were used with a newly developed laboratory test for simultaneously measuring the mass loss and opacity upon heating. Results indicated that there is a good correlation between odor VOCs and both the mass loss rate and opacity measurements. However, these relationships appear to be specific to a given region of the country a single limit for the mass loss rate, and hence a total mass loss at a given time and test temperature, cannot be used to identify binders with potential emission problems. However, a combination of mass loss rate and opacity measurements have the potential for identifying critical temperatures above which smoke and emissions can be

expected when limits are set based on locally acceptable values. There is a fair correlation between visible emissions and the Penske-Marten flash point.

Mary Stroup-Gardiner and **Cliff Lange**, Auburn University, Dept of Civil Engineering, 238 Harbert Engrg Center, Auburn AL 36849, 334-844-6280, 334-844-6290 -FAX, marysg@eng.auburn.edu.

02-3301 Influence of Asphalt Tack Coat Materials on Interface Shear Strength

Session 717

Asphalt tack coat is a light application of asphalt, usually asphalt diluted with water. It is used to ensure a bond between the surface being paved and the overlying course. Normally hot asphalt cements, emulsified asphalts or cutback asphalts are used as tack coats. The objective of this study was to evaluate the practice of using tack coats through controlled laboratory simple shear tests, and determine the optimum application rate. The influence of tack coat types, application rates, and test temperatures on the interface shear strength was examined. Four emulsions, CRS 2P, SS-1, CSS-1, and SS-1h, and two asphalt binders, PG 64-22 and PG 76-22M, were selected as tack coat materials. The residual application rates considered were 0.00 (0.00), 0.09 (0.02), 0.23 (0.05), 0.45 (0.1), and 0.9 (0.2) l/m2 (gal/yd2). A simple shear test was performed to determine the shear strength at the interface at two test temperatures, 25°C (77°F) and 55°C (131°F). The results of this study showed that CRS-2P emulsion was identified as the best tack coat type and 0.09 l/m2 (0.02 gal/yd2) was determined as the optimum application rate at which a maximum interface shear strength was measured for both test temperatures, 25°C (77°F) and 55°C (131°F).

Louay N. Mohammad and **Md A. Raqib**, Louisiana State University, Baton Rouge, CEE and LTRC, LTRC Building, 4101 Gourrier Lane, Baton Rouge LA 70808, 225-767-9126, 225-767-9108 -FAX, louaym@lsu.edu; and **Baoshan Huang**, Louisiana Transportation Research Center.

02-3624 Round-Robin Study for Field Permeability Test

Session 168

Recently, a field permeability device and test procedure have been developed and tested by the National Center for Asphalt Technology (NCAT) that has shown the ability to identify pavement areas with high permeability to water. This device works by measuring the amount of water that flows into a pavement over a given time period using a falling-head approach.

Based upon work conducted by NCAT, the use of this field permeability device has many potential benefits to the hot mix asphalt (HMA) industry. The field permeability device can be used as an almost real-time estimate of mat density and may be a good indicator of longitudinal joint quality. Because of the success NCAT has had with the device to date, a study was needed to evaluate the repeatability and reproducibility of the test method.

Results of the round-robin study indicated that an estimate of permeameter/operator reproducibility was 10.0x10-5 cm/sec. An overall standard deviation on permeability measurements was found to be 24.4x10-5 cm/sec. Additionally, criteria were developed based upon the variability of test results to specify field permeability testing for quality control type testing to ensure impermeable pavements.

Larry Allen Cooley, Jr., National Center for Asphalt Technology, Auburn University, 277 Technology Parkway, Auburn AL 36830, 334-844-6228, 334-844-6248 -FAX, coolela@eng.auburn.edu; and **Saeed Magsoodloo**, Auburn University.

02-3629 Aggregate Blending for Asphalt Mix Design: The Bailey Method

Session 580

From the beginning of asphalt mixture design it was desired to understand the interaction of aggregates, asphalt , and the voids created during their compaction. In asphalt mixture design, guidance is lacking in the selection of the design aggregate structure and understanding the interaction of that aggregate structure and mixture volumetric properties.

This paper presents asphalt mixture design concepts that utilize aggregate interlock and aggregate packing to develop an aggregate blend that meets volumetric criteria and provides adequate compaction characteristics. The presented concepts rely on coarse aggregate for the skeleton of the mixture with the proper amount of fine aggregate to provide a properly packed aggregate structure. The objective is to utilize aggregate packing concepts to analyze the combined gradation and relate the packing characteristics to the mixture volumetric properties and compaction characteristics.

The new concepts presented for asphalt mixture design and analysis include an examination of aggregate packing and aggregate interlock, blending aggregates by volume, a new understanding of coarse and fine aggregate, and an analysis of the resulting gradation by volume.

The concepts outlined in this paper are the result of many years of field experience and are the backbone of the Bailey Method for Asphalt Mix Design. These methods are under continued development as the improved method for asphalt mixture design, which will assist with the transition to contractor mix design.

William R. Vavrik, Applied Research Associates, Inc., ERES Consultants, 505 W. University Ave., Champaign IL 61820, 217-356-4500, 217-356-3088 -FAX, wvavrik@ara.com; **William J. Pine**, Heritage Research Group; and **Samuel H. Carpenter**, University of Illinois, Urbana-Champaign.

02-3891 Target and Tolerance Study for Angle of Gyration used in Superpave Gyratory Compactor

Session 626

In the Superpave system, a gyratory compactor is used to obtain compacted specimens for asphalt mixture testing. Superpave gyratory compactors (SGC) from different manufacturers are commonly used, including the Pine, Troxler, IPC, Interlaken, and Rainhart gyratory compactors. The specified external angle of gyration under load (a) is 1.25 degrees. However, the measured dynamic internal angle (DIA) using the angle validation kit (AVK) has shown deviations from the external angle measurement. The different SGC models also produced different measured DIA's. The difference between the external angle and the DIA that the asphalt mixture sees is not as significant as the effect of the differences between the different SGC models on the hot-mix asphalt (HMA) properties including the bulk specific gravity (Gmb) of the mix. Differences between the angles at the top and the bottom of the specimen (aT, aB) have been also found for some gyratory compactors.

In order to determine a target and a tolerance for the internal angle measurement of the SGC, a comprehensive and complete testing program was used in this study. Pine and Troxler are the most predominate used models in the asphalt industry. Therefore, the testing program covered these two models in the study.

Ghazi G. Al-Khateeb, **Charles Paugh**, **Thomas P. Harman**, **Kevin Stuart** and **John D'Angelo**, Federal Highway Administration, Turner-Fairbank Highway Research Center, Asphalt Pavement Team, 6300 Georgetown Pike, McLean VA 22101, (202)-493-3093, (202)-493-6181 -FAX, ghazi.al-khateeb@fhwa.dot.gov.

02-3907 Evaluation of Measurement Techniques for Asphalt Pavement Density and Permeability

Session 626

The purpose of this project is to evaluate the PQI, Corelok, laboratory permeability and field permeability devices for their potential to improve Virginia Department of Transportation's (VDOT) current density specification or be used in a replacement specification. Fifteen samples were taken from 6 projects representing three nominal maximum aggregate sizes. Based on the project data, nuclear gage densities correlate well with core densities measured by AASHTO T-166 and the Corelok device. The Corelok densities produce slopes closer to 1 and may be better for calibration. PQI readings appear to be repeatable. However in this study they PQI densities did not correlate with either AASHTO T-166 or Corelok densities. A fair correlation was obtained for one project. Both laboratory and field permeability's correlate with pavement density. A good correlation was found between laboratory and field permeability's. The relationship appears to be linear in the range typically specified by agencies.

Brian D. Prowell, National Center for Asphalt Technology, 277 Technology Parkway, Auburn AL 36830, 334 844 6228, 334 844 6248 -FAX, bprowell@eng.auburn.edu; and **Michael C. Dudley**, Virginia Transportation Research Council & University of Virginia.

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6. Cement and Concrete

02-2136 Qualitative Study of Correlation Between Bridge Vibration and Bridge Deck Cracking

Session 112

In recent years, many New York State bridge engineers have suspected that bridge vibration induced by vehicular traffic significantly influenced deck cracking. Several remedial measures were considered, including modifying the deflection criteria recommended by AASHTO bridge design standards, which would have had a major impact on construction costs. The New York State Department of Transportation initiated a research project to systematically study the possible correlation between bridge deck cracking and bridge vibration. Vibration and cracking severities of most steel girder bridges with concrete decks, built in New York between 1990 and 1997, were obtained through a statewide survey and field inspection. Data were analyzed using statistical methods. Results indicate a strong correlation between bridge vibration and deck cracking. A recommendation to further study this relation, using quantitative data was made. Since this is an observational study, these correlations do not necessarily imply that bridge vibration is the primary cause of the bridge deck cracking.

Sreenivas Alampalli, **Frank T. Owens**, **Deniz Sandhu**, New York State Department of Transportation, Transportation R&D Bldg 7A, Room 600, 1220 Washington Avenue, MC 0869, Albany NY 12232-0869, 518-457-5826, 518-457-7535 -FAX, salampalli@gw.dot.state.ny.us; and **Jorge Haddock**, Rensselaer Polytechnic Institute.

02-2288 Mix Parameters Controlling Extended Freeze-Thaw Durability of Concrete Containing Cementitious Additives

Session 377

Use of fly ash and ground granulated blast furnace slag as partial portland cement replacement materials continues to grow, driven by recycling issues, occasional cement shortages, and simple initial cost economics. This laboratory study for the Wisconsin Department of Transportation examined the freeze-thaw durability of mixtures containing these additives with water-cementitious material ratios ranging from 0.30 to 0.45 and air contents ranging from no entrained air up to a target 7.0% air. ASTM 666 accelerated freeze-thaw testing in a sodium chloride solution with measurements of the dynamic modulus of elasticity and weight loss were the primary evaluation methods for the durability of the mixtures. Because of the latent hydraulic activity imparted by the mineral additives, specimens were allowed to cure for 56-days before the testing regime began. Freeze-thaw testing then proceeded for an extended period up to 1500 cycles. This paper examines the influence of air content, water-cementitious material ratio, rapid chloride ion penetration and compressive strength on freeze-thaw durability measured in the laboratory. Results showed that air content overwhelming determined the freeze-thaw durability of these mixtures and that w/cm had no identifiable influence for w/cm as low 0.30. Fly ash mixtures replacing 18.6% of the cement by weight displayed superior durability to a comparable ordinary portland cement mixture. The 50% granulated blast furnace slag mixes had durability comparable to the ordinary portland cement mixture.

Steven M. Cramer, University of Wisconsin, Madison, Dept. of Civil & Environmental Engineering, 1415 Engineering Drive, Madison WI 53706, 608-262-7711, 608-265-8213 -FAX, cramer@engr.wisc.edu.

02-3201 Using Epifluoresence Optical Microscopy to Identify Causes of Portland Cement Concrete Distress: Case Study

Session 602

Materials related distress (MRD) has affected many portland cement concrete pavements. Identifying a specific cause for an MRD is not always possible, but with the use of appropriate techniques and diagnostic approach, the cause can be determined in many cases. In a case studied as part of an FHWA project entitled, "Detection, Analysis, and Treatment of Materials Related Distress in Concrete Pavements," apparent MRD's were identified. In one case study, it was found that the determination of the "effective water-cement ratio (w/c)" using epifluoresence microscopy was the key to understanding the cause of distress. The effective w/c, which may not be exact for a given concrete on an absolute basis, was used to compare two concrete microstructures on a relative basis. Stereo optical microscopy, petrographic optical microscopy, and scanning electron microscopy were also used to identify the MRD diagnostic features present in the distressed concrete. As a result of this analysis, paste freeze-thaw and de-icer attack were identified as being present, but the principal cause of the distress was probably a high w/c in the distressed concrete.

Lawrence L. Sutter, **Thomas John Van Dam** and **Karl R. Peterson**, Michigan Technological University, School of Technology, 1400 Townsend Dr., Houghton MI 49931, 906-487-2268, 906-487-2583 -FAX, llsutter@mtu.edu; and **Kurt D. Smith**, Applied Pavement Technology, Inc.

02-3305 Effect of Curing Methods on Durability of High-Performance Concrete
Session 146

Many State Departments of Transportation are currently either using High Performance Concrete (HPC) or developing new mix proportions for the application of HPC to transportation structures with emphasis on bridge decks. However, many State Engineers have observed that curing methods and conditions in the field affect the behavior of HPC structures. Moreover, little is known about the effect of curing on the long term durability of HPC. Therefore, it is necessary to understand the behavior of HPC under various curing conditions and durations and the effect of pozzolanic material such as fly ash and silica fume on the Rapid Chloride Permeability (RCP).

This paper presents results that are part of an overall study for the New Jersey Department of Transportation (NJDOT) to develop and implement mix design and technical specifications for HPC transportation structures, such as pavements and bridges. An array of mixes is tested and the best mix is selected based on strength and shrinkage test results. The long-term durability is assessed by performing other tests such as the rapid chloride permeability, creep, and freeze-thaw behavior. Moreover, the effect of using four different curing methods on high-performance concrete is investigated. The curing conditions consisted of 1) Moist curing; 2) Air-dry curing; 3) Burlap; and 4) Curing compound.

Results show that moist cured cylinders performed best in comparison with other types of curing methods. Additionally, a minimum of 14 days is required for curing to allow HPC to attain its full strength. Final results will be in the form of a technical specification for the use of HPC in the State of New Jersey.

Hani Hamad Nassif and **Nakin Suksawang**, Rutgers University, Civil & Env., 98 Brett Road, 131 A-Wing, SOE Building, Piscataway NJ 08854, 732-445-4414, 732-445-0579 -FAX, nassif@rci.rutgers.edu.

02-3688 Influence of Key Parameters on Quality of Dry Shotcrete
Session 413

There exist two main types of shotcreting: the dry process and the wet process. In the dry process, all the components are mixed dry and then a jet of water is added to the mixture as it leaves the shooting nozzle. In the wet process, components are mixed wet and then shot through the nozzle. However, there is relatively little data pertinent to the factors that have vital effect on the shotcrete quality when the shotcrete is performed by a prepackaged (pre prepared) or on-site prepared.

The main objective of the work presented herein is to investigate the effect of parameters on the quality of dry shotcrete. Panels were shotcreted using conventional on-site mixes and prepackaged mixtures. The parameters investigated were the shooting distances, the water to cementitious materials ratio and the mix proportions. Cores were extracted from the surface and beams were sawed from the panels for testing. The concrete absorption, concrete unit weight, rebound losses, compressive strength, flexural strength and the Schmidt (rebound) hammer tests were performed on prepackaged mixtures as well as on-site prepared mixtures.

Results indicate that the prepackaged material has overall a superior quality compared with the on-site mix. It is also suggested that a shooting distance exists at which mechanical properties as well as losses may be at an optimum. This work strongly reveals that the traditional non-destructive tests such as the Schmidt hammer and the ultrasonic pulse velocity should be applied to shotcrete with some precautions due to changes in the nature of the concrete surface. Further work should be carried out to elaborate on the shotcrete parameters and investigate their impact when other parameters and techniques are implemented.

Mohamed Nagib Abou-Zeid and **Elrasheid M. Elkhidir**, American University in Cairo, Egypt, Construction Engineering, 113 Kasr El Aini St., P.O.Box 2511, Cairo 11511, Egypt, 011-202-797-5337, 011-202-795-7565 -FAX, mnagiba@aucegypt.edu.

02-3998 Investigation into Premature Deterioration of Concrete on USTH 169

Session 377

Premature deterioration of concrete on TH 169 near Hibbing, Minnesota triggered investigation to determine the potential cause for the distress. The deterioration manifested itself in the form of severe cracking and spalling in the upper 75 mm (3 in.) of the pavement in the vicinity of the transverse joints. Investigation of cores obtained from near-joint and mid panel locations indicated that the air-void system in the top 75 mm (3 in.) of the pavement was compromised initially (during construction) by over vibration of the concrete and later by in-filling of air voids with secondary products. This paper presents the results and analysis of the investigation conducted to determine the cause for the observed deterioration.

Prasad Rangaraju, Clemson University, Department of Civil Engineering, 208 Lowry Hall, Clemson SC 29634-0911, (864) 656-1241, (864) 656-2670 -FAX, prangar@clemson.edu.

02-4158 Influence of Cement Composition on AASHTO T 277 Rapid Chloride Ion Permeability: Recommended Changes to the Method

Session 573

The rapid chloride ion permeability test has received criticism as not being a valid test for the evaluation of permeability of concretes made with different materials or different proportions. It has also been criticized for inducing changes in some concretes through heating of the sample resulting from the prolonged test cycle. This study has demonstrated that the test cycle could be reduced from 6-hour to 30-minutes thus eliminating the heating effect. This recommendation is based on a survey of samples prepared with the same mix properties but only varying the cement component of the concretes and from data collected on concretes where all of the characteristics of the formulation remained the same, including the cement, but the pozzolanic admixtures were allowed to vary.

Barry Scheetz, **Della M. Roy**, **Paul J. Tikalsky**, **James L. Rosenberger**, **Tara L. Krize** and **Raafat Isaak Malek**, Pennsylvania State University, 201 Transportation Research Building, University Park PA 16802, (814) 865-3539, se6@psu.edu.

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Return to Index

7. Pavement Management and Rehabilitation

02-2458 Temperature Corrections of Multiload Level Falling Weight Deflectometer Deflections

Session 449

A new temperature correction procedure for multi-load level FWD deflections for flexible pavements in North Carolina is presented in this paper. In this procedure, the temperature correction factors are dependent on the radial offset distance from the FWD load plate. Temperature and FWD multi-load level deflection data used in developing this procedure were collected from 11 pavements in 3 different climatic regions of North Carolina. The effect of the FWD load level on this temperature correction procedure was investigated. Research efforts

focused on improvement of the accuracy of the current NCDOT temperature correction procedure.

The measured deflection and temperature data were also used to validate the LTPP temperature correction procedure. It was found that the effective pavement temperature prediction algorithm in the LTPP procedure is quite accurate and that the deflection correction procedure undercorrects the deflections at higher temperatures in pavements with an AC layer thicker than 242 mm. The main reason for this deficiency is that the LTPP procedure was developed from the national database and cannot fully consider the local variation in mixture characteristics.

Park Hee Mun and **Y. Richard Kim**, North Carolina State University, Dept. of Civil Engineering, Campus Box 7908, Raleigh NC 27695, 919-515-7758, 919-515-7908 -FAX, kim@eos.ncsu.edu; and **Park Sunwoo**, Federal Highway Administration.

02-2463 Colorado Department of Transportation's Transition to a Remaining Service Life-Based Pavement Management System

Session 134

The Colorado Department of Transportation (CDOT) has been working to implement a pavement management system since the late 1980's. CDOT has historically used a composite index, known as the overall pavement index (OPI), as the reporting criteria for the condition of the state highway network. OPI was comprised of a weighted combination of ride quality, rutting, and cracking.

Because OPI had a tendency to skew the apparent condition of the network towards ride and relied heavily on the apparent surface condition of the pavement, CDOT began shifting from a composite index to remaining service life (RSL) as the reporting criteria in 1999. For example, if a road element has 5 years of RSL, theoretically the pavement will reach the end of its serviceable life in 5 years, assuming no rehabilitation treatments are performed. It is believed the shift to RSL will provide a more accurate and understandable representation of the pavement network condition for both elected/appointed officials and engineers.

The shift to remaining service life has forced CDOT to completely revamp the pavement management system, starting with basic inventory information, through the candidate project identification process. CDOT selected Deighton Associates to provide the pavement management software and to act as a consultant during the system update.

The purpose of this report is to describe some of the technical details behind CDOT's system, as well as the intended use of the system when fully implemented. CDOT's pavement management system is comprised of four major sections. These include roadway data collection, calculation of RSL, identification of candidate treatments, and final treatment recommendation.

Mike Keleman, **Ali Farrokhyar**, **Stephen Henry**, **Richard Zamora** and **Mike Zaturenskiy**, Colorado Department of Transportation, 4340 East Lousiana Avenue, Denver CO 80222, 303-757-9246, moisey.zaturenskiy@dot.state.co.us; and **Rob Piane**, Deighton Associates Limited.

02-2516 Thirty-Three-Year Performance of Jointed Concrete Test Sections in North Carolina

Session 152

Eight test sections of jointed portland cement concrete(PCC) pavement were constructed in 1967 on interstate 95 in North Carolina. The test sections were "rediscovered" this year when six of the eight fell within the project limits of an interstate rehabilitation project. This report outlines the performance of those six sections and the control section using data collected in 2001 and

historic data found in an old research file. Performance was measured and ranked based on distress surveys, roughness reported as International Roughness Index (IRI), and joint faulting. All six sections were 9 inches thick with flexible paved shoulders and 30-foot joint spacing. The test section with the best overall performance consisted of undoweled PCC placed on bituminous base course. This section remains in fair to good condition after 33 years, resulting in the most favorable annual cost. Where direct comparison sections were available, dowels reduced faulting by 1-1.5mm over the 33-year period. Longitudinal, transverse and multiple break cracking were common in the sections having cement treated base or subbase, reducing their service lives and increasing their annual costs.

Clark S. Morrison and **Judith B. Corley-Lay**, North Carolina Department of Transportation, Pavement Management Unit, PO Box 25201, Raleigh NC 27611, 919-250-4094, 919-250-4098 -FAX, cmorrison@dot.state.nc.us.

02-2575 Closed-Form and Graphical Solutions

Session 145

Analysis and design of three-layered Portland cement concrete pavement systems incorporating a base layer have long been hampered by the scarcity of theoretically sound closed-form approaches. This study is focussed on verifying and extending the Method of Transformed Sections (MTS), a closed-form approach derived in 1992 on the basis of dimensional analysis and engineering mechanics. The applicability of the MTS to the dense liquid and elastic solid foundations is studied in detail using a wide range of numerical test data for all three fundamental loading conditions (interior, edge and corner). Both unbonded and bonded interface conditions between the two man-made layers are considered. To make the analysis easier, the MTS is incorporated into computer program WESTERX, a compendium of closed-form solutions for two- and three-layered concrete pavements. Maximum responses (bending stresses, deflections and subgrade stresses) predicted by plate theory MTS are compared with those obtained from finite element computer program ILSL2X. Formulae developed to apply a compressibility correction to these responses are verified using results obtained from layer elastic analysis (computer program DIPLOMAT). Critical responses from plate theory MTS are presented in the form of dimensionless charts, which can be used as an alternative to the closed-form approach with either of the two subgrade idealizations, for all three fundamental loading positions. Graphical solutions are also developed for maximum responses that account for the compressibility of the two man-made layers under interior loading conditions, for both foundation types.

Krishnakumar Sanjeevirao and **Anastasios M. Ioannides**, University of Cincinnati, Dept of Civil & Enviro Egngr, P. O. Box 210071, Cincinnati OH 45221-0071, 513-556-3137, 513-556-2599 -FAX, aioannid@uceng.uc.edu.

02-2615 Steel Reinforcing Netting Mechanism to Abate Reflective Cracking in Asphalt Concrete Overlays

Session 221

Hot-mix asphalt (HMA) overlays are usually used to rehabilitate cracked pavements. The cracks in the existing pavement move continuously due to thermal and traffic loadings, and hence propagate upward into the new surface causing reflective cracking. Steel reinforcing nettings have been successfully used in Europe for the past two decades to improve HMA resistance to reflective cracking. To investigate the potential of steel reinforcing nettings to mitigate the reflection of cracks, a theoretical approach is presented based on fracture mechanics and 3-

Dimensional (3D) finite element modeling. This 3D finite element model accurately simulates steel reinforcement as a non-homogeneous interlayer with openings. Based on the results of the finite element model, shear stress was computed at the crack tip for the reinforced and non-reinforced cases. The obtained shear stress was then used to calculate the number of cycles required for the crack to propagate into half the thickness of the overlay. Based on the this approach, results indicate that steel reinforcement increases the overlay service life by 20 to 40 percent depending on the original overlay thickness (50 to 100mm). This improvement is not dependent on the subgrade strength given that the compressive stress at the top of the subgrade is below 42kPa. The use of an intermediate low modulus layer appears to enhance the reinforced pavement system performance.

Imad L. Al-Qadi and **Mostafa A. Elseifi**, Virginia Polytechnic Institute and State University, 200 Patton Hall, Blacksburg VA 24061-0105, 540-231-5262, 540-231-7532 -FAX, alqadi@vt.edu; and **Thomas E. Freeman**, Virginia Transportation Research Council.

02-2782 Performance of Pavements Subject to Higher Truck Weight Limits in Virginia
Session 152

This paper presents the results of a study mandated by Virginia's General Assembly to determine if pavements in the southwest region of the state carrying vehicles operating under higher allowable weight limit provisions have greater maintenance and rehabilitation requirements than pavements bound by lower weight limits elsewhere. The study entailed detailed field surveys at 18 in-service pavement sites representing the range of roadway and traffic conditions typically found on primary and secondary highways in Southwest Virginia. Ten of the sites were located in counties afforded an increase in legal truck weight limits in accordance with the provisions of House Bill 2209, and the remaining 8 sites were located in counties that did not receive the higher weight loads.

Detailed traffic classification and weight surveys, an investigation of subsurface conditions, and comprehensive structural evaluations were conducted at all sites. These results were used to estimate the cost of damage attributed only to the net increase in allowable weight limits.

Consistent with the results of more comprehensive research conducted by and for other highway agencies, the authors found that pavement damage increased drastically with relatively small increases in truck weight for all vehicle classes influenced by HB 2209. The cost of structural damage to mainline pavements attributable to the net weight increase in the seven affected counties alone was estimated to be on the order of $28 million over a 12-year period. Costs associated with necessary improvements to roadway geometry, reduced service lives of bridges, increased motorist delays through work zones, and the safety implications of heavier vehicles operating in mountainous terrain were not included in the estimate.

Thomas E. Freeman, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville VA 22903, 434-293-1957, 843-293-1990 -FAX, freemante@vdot.state.va.us; and **Trenton Clark**, Virginia Department of Transportation.

02-2967 Maryland State Highway Administration's Project Selection Process
Session 181

The Maryland State Highway Administration is responsible for maintaining a 16,000 lane-mile pavement network. To maintain this network that Administration prepares a system preservation program annually that includes specific roadway locations to be improved. In recent years, the process to develop this program has improved considerably through the development of new

pavement management tools. These tools have provided the Administration the ability to evaluate multiple funding strategies to invest in the pavement network and the consequences, in terms of network health, for implementing the strategies. In addition, the development of new tools has provided a methodology to identify and select specific project locations for funding in an easier and more accurate manner.
The implementation of two of these tools is discussed in this report. These tools include an optimization process to create funding strategies and a computerized project selection tool to identify specific project locations. The approach to using each of these tools in Maryland is described in this report. The report includes discussion on how investment strategies are developed and approved, how projects are selected to match the investment strategy and how modifications are made to the plan throughout the year. Planned efforts to enhance the process in the future are discussed as well as conclusions on the implementation to date.

Peter J. Stephanos and **Paul Dorsey**, Maryland State Highway Administration, Office of Materials and Technology, 2323 W. Joppa Road, Brooklandville MD 21002, 410-321-3110, 410-321-3099 -FAX, pstephanos@sha.state.md.us; and **Adel Hedfi**, Axiom Decision Systems, Inc.

02-2978 Development of Pavement Management System for Municipality Roads in Saudi Arabia

Session 134

Simple engineering judgment was the only procedure followed by Dammam Municipality engineers for pavement evaluation and maintenance prioritization. By the end of 1997, the General Directorate for Operation and Maintenance decided to adapt an objective, systematic, and scientific evaluation procedure of their pavement network and to efficiently allocate the available limited funds to maximize their benefits. Therefore, they decided to develop a pavement management system (PMS). A methodology was developed to integrate different subsystems into a rational systematic pavement management system for Dammam Municipality road network, Saudi Arabia. These subsystems are (i) pavement features coding, (ii) visual pavement evaluation, (iii) equipment-based pavement evaluation, (iv) maintenance and repair strategy selection, (v) maintenance priority ranking, (vi) pavement condition prediction, and (vii) reporting. These subsystems were all integrated to form the Dammam Municipality Pavement Management System (DMPMS). The system is a customized computer software that is a knowledge-based Visual Basic Windows application. It has been designed to provide an easy-to-use PC product. It is a completely interactive menu-driven error-checking application, which is supplemented by a full active self-explanatory help facility. The DMPMS was tested and implemented for Dammam road network. The implementation activities included a review and evaluation of data collection procedures and a development of distress manifestation manual, preparation of the software documentation, and Dammam Municipality personnel hands-on training. It is hoped that the developed system will improve pavement performance and yield significant savings in pavement maintenance in the long term.

Hamad I. Al-Abdul Wahhab, **Rezqallah H. Ramadhan**, **Ibrahim M. Asi**, **Jaweed M. Yazdani**, King Fahd University of Petroleum and Minerals, Saudi Arabia, Civil Engineering, KFUPM Box 1064, Dhahran 31261, Eastern Province, Saudi Arabia, 00966-3-8604578, 00966-3-8602879 - FAX, asi@kfupm.edu.sa.

02-3100 Framework and Strategy for Implementing an Information Technology-Based Pavement Management System

Session 181

The advent of information and telecommunication technologies has significant impacts on the development and implementation of pavement management systems (PMS) for state departments of transportation (DOT) and also fosters great opportunities for improving states' highway pavement conditions through increased productivity and effectiveness in managing their highway pavement information. However, it still remains a challenge for state DOTs to successfully implement an integrated PMS due to the complexity of a PMS and many issues involved in the development and implementation that need to be resolved. This paper presents the development and implementation of an IT-based PMS by the Georgia Department of Transportation (GDOT). Based on the existing pavement management practices by GDOT, the needs and concerns for improvements are identified in light of the advent of information technology. The development of the conceptual IT-based PMS framework to meet GDOT's needs was first presented. The strategies for developing and implementing an integrated PMS were then presented, and the benefits of adopting the strategies were discussed. The need for incorporating a common spatial and temporal reference system to ensure system compatibility and integration for all the databases are discussed. Seven modules of this integrated IT-based PMS that have been implemented, including the computerized pavement condition evaluation system, historical pavement performance data conversion and filtering, network-level data management and analysis, GIS analysis and visualization, rehabilitation treatment decision, highway maintenance management system, and pavement distress causes diagnosing knowledge based system; four modules currently under development are also described in this paper.

Yichang (James) Tsai and **James S. Lai**, Georgia Institute of Technology, School of Civil and Environmental Engineering, 276 Fifth Street, Atlanta GA 30332, 404-385-0904, 404-385-0450 - FAX, yt7@prism.gatech.edu.

02-3111 Development and Performance of Interlayer Stress Absorbing Composite in Asphalt Concrete Overlays

Session 221

An 'Interlayer Stress Absorbing Composite (ISAC)' was developed and evaluated for the purpose of effectively alleviating/mitigating the problem of reflection cracking in an AC overlay. The ISAC materials and performance properties were carefully selected through comprehensive theoretical studies and laboratory evaluation programs. The ISAC system consists of a low stiffness geotextile as the bottom layer, a viscoelastic membrane layer as the core, and a very high stiffness geotextile for the upper layer. In order to evaluate the effectiveness of the ISAC layer to control reflective cracking, a laboratory pavement section with an AC overlay placed on a jointed PCC slab was constructed and tested in an environmental chamber. A mechanical device was used to simulate thermal strain in the slab and the joint was opened and closed at an extremely slow rate. The testing was conducted at -1.1° C and strain in the overlay was monitored using a sensitive LVDT device. The force required to pull and push the slab was monitored using a load cell placed between the slab and a hydraulic ram. Performance of ISAC was evaluated by comparing the cycles to failure of an ISAC treated overlay with a control section without ISAC and with two commercially available products. The base isolation properties of the ISAC system were demonstrated in the laboratory evaluation studies. The laboratory evaluation studies indicated that the ISAC system vastly outperformed the control

section and the two commercial products tested. Several years of field performance testing have shown that the ISAC system is highly effective for mitigating reflective cracking in AC overlays.

Barry J. Dempsey, University of Illinois, 1611 Titan Drive, Rantoul IL 61866, 217-893-0004, 217-893-0601 -FAX, bjdemps@uiuc.edu.

02-3125 Factors Affecting Rapid Roughness Progression on Portland Cement Concrete Pavements in Kansas

Session 355

Portland Cement Concrete Pavements (PCCP) with favorable as-constructed smoothness and lower rates of roughness progression are expected to have longer service lives. This study was done to quantify the effect of as-constructed smoothness and other design, construction, traffic, and climatic factors on the rate of roughness progression on concrete pavements in Kansas. Selected inventory, construction, climatic and annual roughness data were obtained for 21 PCCP projects constructed after 1992. From the annual roughness data in terms of International Roughness Index (IRI), collected by the South Dakota-type Profilometers, the rate of roughness progression was obtained by regression analysis. Multiple linear regression analysis was then done to find the functional relationships between the rate of IRI roughness progression and the independent variables selected. The results show that the concrete modulus of rupture, subgrade material, number of wet days, and initial IRI roughness significantly effect the rate of IRI roughness progression. Higher flexural strength tends to help retaining as-constructed smoothness longer. Pavements with high initial IRI roughness tend to become smoother as traffic passes over it presumably due to "smoothening" of minor surface irregularities and stabilization of subgrade soil moisture during early years of pavement life. Permeable subbase tends to decrease the rate of roughness progression. Finally, a trend analysis of annual IRI roughness data showed that the as-constructed smoothness tends to "wear" out in about 3 to 5 years, and thus does not effect future roughness development.

Mahmuda Akhter, **Mustaque Hossain** and **John Boyer**, Kansas State University, Dept of Civil Engrg, Seaton Hall, Room 119, Manhattan KS 66506, 785-532-1576, 785-532-7717 -FAX, mustak@ksu.edu; **William H. Percells** and Kansas Department of Transportation.

02-3150 Evaluation of Performance of Full-Depth Reclamation Mixes

Session 419

The Full Depth Reclamation (FDR), process consists of reclaiming all of the asphalt bound section along with a predetermined amount of underlying base, with some additive. FDR is particularly suitable for treating base problems related to deeper layers such as the base. The objectives of this study were to determine suitable compactive effort for designing FDR mixes, evaluate the benefits of using different types of additives in terms of improvement in the life of a pavement and determine suitable structural numbers for pavements recycled with different types of additives. The scope of work for this part of the study consisted of conducting Falling Weight Deflectometer (FWD), testing of an existing pavement before FDR, sampling of materials during FDR, determination of density of in-place material after compaction, compaction of loose mix in the laboratory, determination of density of compacted samples, conducting FWD on finished pavement, determination of resilient modulus of in-place cores and analyzing the data for determination of suitable number of gyrations, improvement in life of the pavement and structural numbers. From the results of comparison of in-place density and density of loose mix, and comparison of optimum fluid content and resilient modulus of laboratory samples compacted to 50 and 75 gyrations, it is concluded that samples be compacted to 50 gyrations during mix

design, and that a minimum of 98 % of density of in-place loose mix samples, compacted to 50 gyration, be achieved in the field at the end of compaction. Comparison of cost for a specific amount of increase in life of pavement showed that for the options considered in this study, recycling with emulsion (3.4 %) and lime (2 %) is the most cost effective option. A visual evaluation of recycled sections after one year showed no significant distress in any section, except in the water section where a moderate amount of edge cracking was noted.

Rajib B. Mallick and **David S. Bonner**, Worcester Polytechnic Institute, Department of Civil & Enviromental Engrg, 100 Institute Road, Worcester MA 01609, 508-831-5289, 508-831-5808 - FAX, rajib@wpi.edu; **Richard L. Bradbury** and **Jamie O. Andrews**, Maine Department of Transportation; **Prithvi S. Kandhal**, National Center for Asphalt Technology; and **Edward J. Kearney**, Gorman Brothers Inc.

02-3241 Implementation of Dynamic Segmentation for a Pavement Management Information System

Session 134

This paper describes how the dynamic segmentation capability of a Geographic Information System (GIS) is used to enhance a Pavement Management Information System (PMIS). Dynamic segmentation allows multiple attributes to be associated with linear features such as roadway pavements. These attributes can be stored and displayed without any redundant data storage. The data represented by dynamic segmentation also better reflects the actual conditions of pavement contained within the PMIS. This method produces better pavement management decisions since the actual street conditions can be better represented. The simplicity of data storage also allows the PMIS to be easily updated with minimal data manipulation. Defining a dynamically segmented street network requires that the PMIS must be properly configured from the start. A detailed procedure is given on how dynamic segmentation has been successfully implemented.

Y. J. Eddie Chou and **Chenchen Wang**, University of Toledo, Dept. of Civil Engineering, Toledo OH 43606, 419-530-8120, 419-530-8116 -FAX, ychou@uoft02.utoledo.edu; and **Joey L. Mathias**, Finkbeiner, Pettis & Strout, Inc.

02-3266 Why (Not How) Kansas Department of Transportation's Pavement Management System Works and How Preventive Maintenance Actions Are Integrated

Session 134

The Kansas Department of Transportation uses a Pavement Management System (PMS) to track pavement condition and to provide measures for Performance-Based Budgeting and Asset Management, but most importantly, KDOT uses the system to help program reconstruction, rehabilitation, and maintenance of pavements. KDOT PMS is streamlined to allow data collected in the spring with reporting in the summer, analysis in the fall, programming the following spring and implementation (construction of rehabilitation projects) the following summer. The system is theoretically sound and based on principles that naturally incorporate the wide variety of choices for timing and scope of pavement rehabilitation projects. This means the system balances between preventative maintenance and more significant rehabilitation or reconstruction alternatives by evaluating short and long term costs and benefits within budget and performance constraints. The system produces a strategy that meets the constraints as an optimal solution; however, this solution must be converted into a practical solution for use in programming. Applying some feasibility rules to the optimal solution and then supplying rehabilitation program managers with mileage allotments and three years of candidate project locations and tentative scopes accomplish this conversion. An implementation agreement then specifies how closely the

program managers must follow the candidate project locations from the system. Program managers have had substantial latitude with scope refinements from those recommended out of the system. For many years the scopes selected were typically more extensive than those recommended by the system, but as the condition of the highways have improved more of the lighter, preventative maintenance scopes recommended by the system have been accepted by program managers. Because KDOT has a way to implement a PMS that supports timely application of preventative maintenance and other rehabilitation and reconstruction activities, the condition of the highway system has substantially improved in Kansas. KDOT will continue to use PMS to help determine how best to manage our highway assets. Further, PMS will continue to supply a measure of system performance that incorporates many of the aspects associated with maximizing the benefits from dollars spent on pavements.

Richard W. Miller, Kansas Department of Transportation, Materials & Research, 2300 Van Buren, Topeka KS 66611-1195, 785/291-3842, 785/296-2526 -FAX, rick@ksdot.org.

02-3296 Index for Evaluating Initial Overlay Smoothness Using Measured Profiles

Session 607

An index for evaluating the acceptability of initial overlay smoothness based on surface profile measurements is presented. The proposed index predicts the change in overlay service life due to differences between the target surface profile assumed in the design and the as-built profile. From theoretical considerations, the change in overlay life, based on reflection cracking, was found to be a function of the fracture characteristics of the overlay mix and the variability in vehicle dynamic loading due to uneveness in the surface profile. The application of the index for evaluating initial overlay smoothness is illustrated using profile data from actual overlay projects. The illustration provided is based on the final surface profile and is applicable to projects where the overlay thickness is more than 64 mm or where surface preparations such as milling to grade or in-place recycling are used to correct or remove existing surface distress. Implementation of the proposed index in a smoothness specification will require the use of surface profilers and the simulation of vehicle dynamic loads from measured profiles.

Emmanuel G. Fernando, Texas Transportation Institute, Texas A&M University, Materials & Pavements Division, TTI/CE Bldg, Suite 508, College Station TX 77843-3135, 979-845-3641, 979-845-0278 -FAX, e-fernando@tamu.edu.

02-3522 Ride Quality Assessment Using Pavement Profiling Devices, Part 2: Profile Analysis

Session 607

The Massachusetts Highway Department (MHD) is developing and implementing ride quality specifications as part of their construction Quality Assurance Program. To achieve their goal, MHD, in cooperation with the Federal Highway Administration (FHWA), sponsored this research project to identify suitable profiling devices with adequate precision and bias for implementing construction Quality Assurance specifications. The purpose of this research project is to evaluate precision and bias of profiling devices based on ASTM E950. In 1999, this study was conducted where 16 profiling devices including highspeed, lightweight and walking profilers performed 10 repeat runs on eight sites. This paper summaries the test program and presents precision and bias results for profile analysis and profile leadin effect. Part 1 presents precision and bias data using IRI summaries.

Tahar El-Korchi and **Jason Bacon**, Worcester Polytechnic Inst, Civil Engineering Department, 100 Institute Road, Worcester MA 01609, 508-831-5518, 508-831-5808 -FAX, tek@wpi.edu; and **Matthew Turo** and **Mike Ecmecian**, Massachusetts Highway Department.

02-3721 Long-Term Performance of Fast-Track Full-Depth Repairs
Session 419
This paper presents the results of 5-year monitoring of field performance of the fast-track full-depth repairs placed under SHRP C-206 project. The objective of SHRP C-206 full-depth repair experiment was to demonstrate and validate the technologies that allow early opening of full-depth PCC pavement repairs to traffic and to document the information needed to apply this technology. The experimental factors included material type, strength at opening, and repair length. A total of 11 different high-early-strength concrete mixes with opening times ranging from 2 to 24 hours were evaluated at 2 field sites (I 20, Augusta, Georgia and SR-2, Vermilion, Ohio). The long-term performance of these test sections was evaluated under a follow-up FHWA study. The monitoring program consisted of conducting annual visual distress surveys to monitor the development of cracking, faulting, and spalling. The results of long-term monitoring showed that full-depth repairs made with high-early-strength PCC can provide good long-term performance; however, adverse temperature conditions during installation can cause premature failures. The study also showed that the fatigue damage due to early opening is negligible, especially for repairs 3.7 m (12 ft) or shorter. Based solely on fatigue considerations, full-depth repairs could be opened to traffic at lower strengths than those typically recommended; however, opening at strengths much less than previous recommendations is not advisable because of the risk of random failures caused by single heavy load at early age. Therefore, no changes to the opening criteria suggested in the SHRP C-206 manual of practice are recommended.
H. Thomas Yu, **Jagannath Mallela** and **Michael I. Darter**, ERES Consultants, Inc., 505 West University Ave., Champaign IL 61820, 217-356-4500, htomyu@hotmail.com.

02-3745 New Condition Assessment Procedure for Asphalt Pavement Layers Using Falling Weight Deflectometer Deflections
Session 609
This paper describes the development of nondestructive condition assessment criteria to be applied in conjunction with the condition evaluation indicators that are estimated based on Falling Weight Deflectometer (FWD) deflections, which is described in the companion paper (1). Data obtained from state DOTs and DataPave 2.0 were used in developing these criteria. To account for the effects of pavement structure and temperature on FWD deflection analysis, structure and temperature correction procedures based on synthetic databases were applied. Also, a deflection prescreening procedure is established to identify and correct any irregular deflection basins potentially arising from measurement errors. All the calibrated predictive procedures, structure and temperature correction procedures, and prescreening algorithms are incorporated into the user-friendly deflection analysis program with graphical interface, APLCAP 1.0 (Asphalt Pavement Layer Condition Assessment Program), written in MS Visual Basic (6.0) for MS Windows-based computing platforms.
Bing Xu, **Ranji Ranjathan** and **Y. Richard Kim**, North Carolina State University, Dept. of Civil Engineering, Campus Box 7908, Raleigh NC 27695, 919-515-7758, 919-515-7908 -FAX, kim@eos.ncsu.edu.

02-4029 Deflection-Based Analysis Techniques for Jointed Concrete Pavement Systems
Publication in TR Record only.
This paper presents techniques based on the dense-liquid foundation model for analyzing deflection data obtained at center slab, slab edge, and slab corner positions to provide indications

of the quality and uniformity of support beneath jointed concrete slabs. Deflections obtained at central slab positions are used to quantify a baseline foundation k-value for each slab tested. Edge and corner deflection data is used to establish the foundation edge and corner k-values of each slab. Adjustments for slab size and temperature curling during testing are discussed. Slab support ratios are determined on a slab-by-slab basis using the ratio of edge and corner k-value to center of slab k-values, ke/ki and kc/ki. Where non-uniform support exists, the foundation support ratio will typically be less than 0.75. Example and field results are provided to illustrate the analysis techniques and the interpretations necessary to distinguish between poor support due to slab curling or foundation voids.

James A. Crovetti, Civil Engineering, Marquette University, Haggerty Hall Room 267, P O Box 1881, Milwaukee WI 53201-1881, 414-288-7382, 414-288-7521 -FAX, james.crovetti@marquette.edu.

02-4032 Repairing Ultrathin Whitetopping: Minnesota Experience

Session 382

Thin and ultra-thin whitetopping overlays are becoming a more common method of pavement rehabilitation. It is important to gain information on the types of distresses that occur in the overlays and effective repair techniques. In 1997, the Minnesota Department of Transportation constructed several thin and ultra-thin whitetopping test cells at the Minnesota Road Research (Mn/ROAD) facility. The test cells varied in overlay thickness from 76-mm to 152-mm. The joint spacing of these cells ranged from 1.2-m by 1.2-m to 3.1-m by 3.7-m. Over 3.5 years of existence and 4.7 million ESALS, both temperature- and load-related distresses were observed on the 76-mm and 102-mm thick sections. There were no noticeable distresses in the 152-mm sections. Typical distresses included corner breaks, transverse cracks, and reflective cracks. The finite element program ISLAB2000 was used to investigate stress patterns and their relation to the distresses.

Different techniques for repairing ultra-thin whitetopping were investigated. It was determined that using a milling machine with tungsten carbide teeth to remove the concrete greatly reduced the time required per repair. Various techniques were also used to deter reflective cracking. This included the use of various bond-breaking materials and full-depth sawing at strategic locations along the longitudinal joint to prevent cracks for propagating into adjacent panels at misaligned transverse joints.

Four of the six sections had PSIs greater than 3.5 before the repairs showing a good level of performance has been maintained after 4.7 million ESALS. The two sections that exhibited the largest drop in PSI were the overlays with 1.2-m x 1.2-m (4-ft x 4-ft) panels. The repairs made in sections containing 1.2-m x 1.2-m (4-ft x 4-ft) panels have brought the PSI back up to an acceptable level (PSI>3).

The thin and ultra-thin whitetopping test sections at Mn/ROAD have shown that whitetopping is a viable rehabilitation alternative for asphalt pavements. The importance of choosing an optimum panels size was exhibited. It has also been shown that, when necessary, it is easy to repair ultra-thin whitetopping sections and various techniques for repairing each type of distress have been summarized.

Julie M. Vandenbossche and **Aaron James Fagerness**, Minnesota Department of Transportation, Off of Materils & Road Res., 1400 Gervais Ave., Maplewood MN 55109, 651 779 5565, 651 779 5616 -FAX, julie.vandenbossche@dot.state.mn.us.

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8. Safety

02-2531 Box-Beam Burster Energy-Absorbing Single-Sided Crash Cushion

Session 151

This paper presents the design and crash test results of a new box-beam burster energy absorbing single-sided crash cushion (herein referred to as BEAT-SSCC). It is an energy absorbing crash cushion designed for shielding a rigid hazard, such as the end of a concrete safety shaped barrier. The energy absorbing capability of the BEAT-SSCC is based on the bursting tube technology, similar to that used with the box-beam burster energy absorbing terminal (BEAT).

Four full-scale vehicle crash tests were conducted to evaluate the impact performance of the BEAT-SSCC in accordance with guidelines set forth in NCHRP Report No. 350: test designation 3-31 - pickup truck head-on test; test designation 3-38 - pickup truck critical impact point test; test designation 3-39 - pickup truck reverse direction test at mid-point of crash cushion, and modified test designation 3-39 - pickup truck reverse direction test at connection to the concrete barrier. The crash cushion performed as designed and it is concluded that the BEAT-Single-Side Crash Cushion meets all evaluation criteria for a Test Level 3 (TL-3) crash cushion set forth in NCHRP Report No. 350. The BEAT-SSCC is being evaluated by FHWA for approval to be used on the National Highway System (NHS).

John D. Reid, **John R. Rohde** and **Dean L. Sicking**, University of Nebraska, Lincoln, Midwest Roadside Safety Facility, Mechanical Engineering, N104 WSEC (0656), Lincoln NE 68588, 402-472-3084, 402-472-1465 -FAX, jreid@unl.edu.

02-2909 Flared Energy-Absorbing Terminal Median Barrier

Session 151

This paper presents the design and crash test results a median barrier version of the FLared Energy Absorbing Terminal (FLEAT), known as FLEAT-MT. It is an energy absorbing terminal designed for use with a W-beam, strong-post median barrier. The FLEAT-MT terminal utilizes two standard FLEAT terminals, one for each of the two W-beam rail elements. The energy absorbing capability of the FLEAT-MT terminal is based on the sequential kinking concept, similar to that used with the SKT and FLEAT guardrail terminals.

Three full-scale vehicle crash tests were conducted to evaluate the impact performance of the FLEAT-MT terminal in accordance with guidelines set forth in NCHRP Report No. 350: test designation 3-35 - pickup truck redirection test (test no FMT-1); test designation 3-31 - pickup truck head-on test (test no. FMT-2); and test designation 3-39 - pickup truck reverse direction test (test no. FMT-3M). The terminal performed as designed and it is concluded that the FLEAT-MT terminal meets all evaluation criteria for a Test Level 3 (TL-3) median barrier terminal set forth in NCHRP Report No. 350. The FLEAT-MT terminal is being evaluated by FHWA for approval to be used on the National Highway System (NHS).

John D. Reid, **John R. Rohde** and **Dean L. Sicking**, University of Nebraska, Lincoln, Midwest Roadside Safety Facility, W328.1 Nebraska Hall, PO Box 880531, Lincoln NE 68588-0531, jrohde@unl.edu.

02-3157 Development of the Midwest Guardrail System

Session 116

A revised guardrail system has been developed that should provide greatly improved performance for high center of gravity light truck vehicles. The barrier incorporates W-beam

guardrail and standard W6x9 steel posts. Primary changes to the design include raising the standard rail height to 635 mm, moving rail splices to mid-span between posts, increasing blockout size, and increasing the size of post bolt slots. All of these changes are designed to improve the barrier's performance with high center of gravity vehicles. One full-scale crash test has been conducted to verify that the guardrail performs adequately with mini-size automobiles when raised to a height of 660 mm to the center of the rail. This test proved that the barrier can provide satisfactory performance when mounted at heights ranging from 550 mm (standard guardrail height) up to 660 mm. Hence, the new guardrail design provides approximately 110 mm (4.4 in.) of mounting height tolerance. When installed at the nominal mounting height of 635 mm, a 75 mm pavement overlay could be applied to the roadway without requiring adjustments to the barrier's height.

John D. Reid, **John R. Rohde** and **Dean L. Sicking**, University of Nebraska, Lincoln, Midwest Roadside Safety Facility, W 328.1 Nebraska Hall, P. O. Box 880531, Lincoln NE 68588-0531, 402-472-9332, 402-472-2022 -FAX, dsicking@unl.edu.

02-3675 Crash Testing and Analysis of Work Zone Sign Supports

Session 116

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside nor in the traveled way outside of the work zones. These devices are used to enhance the safety of the work zones by controlling the traffic through these areas. Due to the placement of the traffic control devices, the devices themselves may be potentially hazardous to both workers and errant vehicles. The impact performance of many work zone traffic control devices is mainly unknown and to date limited crash testing has been conducted, under the criteria of National Cooperative Highway Research Program (NCHRP) Report No. 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features.

The objective of the study was to evaluate and analyze the results of full-scale crash testing of flexible panel work zone sign stands to quantify the features that successful devices shared, as well as common features of those devices that failed salient safety criteria. Parameters considered include sign base and upright properties, sign height, cross-member properties and ancillary details. Results of the analysis point to three fundamental design issues that are problematic, these include 1) combinations of base and upright stiffness and strength that generally lead to significant windshield damage, 2) cross-members that lead to windshield damage in the end-on (90 degree) impact orientation, and 3) appurtenances that have an impact on performance. While there are a significant number of variables that control the performance of a given device, these generalizations offer a basis for evaluation of the fundamental design elements.

Karla A. Polivka, **John D. Reid**, **John R. Rohde** and **Dean L. Sicking**, University of Nebraska, Lincoln, Midwest Roadside Safety Facility, 1901 'Y' Street, Bldg. C, Lincoln NE 68588-0601, 402-472-9070, 402-472-0506 -FAX, kpolivka2@unl.edu.

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9. Soils, Geology and Foundations

02-2140 Filter Paper Technique for Measurement of Total Soil Suction

Session 147

Non-contact filter paper testing is an economical and reasonably reliable technique for measuring total soil suction in the laboratory. This paper presents the results of an experimental program that was conducted to investigate two issues related to the technique. First, calibration curves for seven different batches of Whatman #42 filter paper are obtained to investigate variation in the calibration characteristics from one batch to another. Second, a series of tests using salt solutions for controlling total suction is conducted to statistically evaluate the uncertainty in non-contact filter paper measurements as a function of total suction.

It is shown that the calibration curves for seven batches of paper can vary significantly from batch to batch. Depending on the magnitude of total suction, this variation can be as much as 11% in terms of filter paper water content, resulting in as much as 92% error in terms of total suction. The statistical evaluation shows that the standard deviation in measured suction increases as total suction decreases. At relatively high values of suction (e.g., 32,000 kPa), the standard deviation for five independently determined measurements is as much as 11.6% of the mean. At relatively low values of suction (e.g., 270 kPa), the standard deviation increases to as much as 23.2% of the mean. One hundred total suction measurements obtained over a wide range of values for a typical clayey soil confirm the observation that the scatter in the measurements increases as total suction decreases.

William J. Likos and **Ning Lu**, Colorado School of Mines, Engineering Division, 1500 Illinois St, Golden CO 80401, 303-273-3679, 303-273-3602 -FAX, wlikos@mines.edu.

02-2400 Field Investigation: Precracking of Soil-Cement Bases to Reduce Reflection Cracking

Session 251

This paper describes a new approach to minimize the amount of shrinkage cracking in newly constructed soil-cement (S-C) bases. The approach, called microcracking, is demonstrated on three city streets constructed in October 2000 in a new subdivision of College Station, Texas. The bases on these streets were designed to meet TxDOT's specification 272 (1) requiring an unconfined compressive strength of 500 psi after 7 days moist cure. The base aggregate available in this area is a sandy gravel. To meet the TxDOT strength requirement requires a high cement content typically 6 - 8%. However with this cement content the City has experienced substantial shrinkage cracking.

In an attempt to mitigate this problem the microcracking approach was evaluated. Based on research from Austria (2) this requires a maximum of four passes of a steel wheel vibratory roller applied a few days after finishing. This introduced a network of hairline cracks into the base early in its life with the idea that these "micro-cracks" will minimize the major shrinkage cracks associated with S-C bases. Furthermore, as this is performed only a few days after placement, the microcracking will not impact the pavements overall structural capacity as the cracks will re-heal and the base will continue to gain strength with time. During this study the base stiffness was monitored with both the Humboldt Stiffness gauge and the Falling Weight Deflectometer. Large reductions in stiffness were monitored immediately after microcracking, but after 2 days recovery the base regained most of its initial stiffness. After 6 months a visual inspection was made and the structural strength was measured with a Falling Weight

Deflectometer. The base was found to be very stiff and only minor amounts of cracking was found in each of the three monitor sections.

Based on this study draft specifications have been developed for incorporating microcracking in future projects. The S-C sections described in this report were all six inches thick and the work was completed in the fall with an air temperature ranging from 75 to 80 degrees. More work is needed to determine what changes will be required in the draft specifications when working with thicker bases, lower strength bases and or when construction occurs in either hot or cold weather.

Tom Scullion, Texas A&M University, Texas Transportation Institute, CE/TTI Building, Room 501E, 3135 TAMU, College Station 77843-3135, 979-845-9913, 979-845-1701 -FAX, t-scullion@tamu.edu.

02-2871 Condition Assessment of Buried Metal-Tensioned Elements

Session 254

This paper describes application of nondestructive test (NDT) methods for condition assessment of metal-tensioned elements in geotechnical engineering applications including rock bolts, ground anchors and soil nails. Electrochemical tests, such as measurements of half-cell potential and polarization, are used to detect the presence of corrosion and evaluate the integrity of corrosion protection systems. Mechanical wave propagation techniques, such as impact and ultrasonic tests, are used to locate features along the length of an element including loss of cross section from corrosion. Interpretation of test results requires knowledge of the electrical continuity between elements being tested, and knowledge of the details associated with the installation of the system being evaluated.

The utility of the NDT's are evaluated under controlled conditions on bench scale specimens in the laboratory, and on buried specimens at a specially developed insitu test facility. However, given the numerous variables inherent to field installations that may have an effect on the measurements, it is necessary to study performance of the NDT technologies in the field.

Results from condition assessment employing NDT technologies of tie-backs for a quay wall in Buffalo, New York, and of rock bolts along a highway cut in Dresden, New York are described. Background information is given for each site including a description of the aggressiveness of the environment relative to corrosion in terms of results from chemical analysis of native soil samples.

Results from NDT correlated well with features of the tieback and rock bolt installations. Electrochemical test results indicated that corrosion was occurring, but the wave propagation tests did not indicate any significant loss of cross section. NDT measurements should be archived to serve as a baseline against which future NDT results may be compared.

Kenneth Lawrence Fishman, McMahon & Mann Consulting Engineers, P.C., 2495 Main Street, Suite 432, Buffalo NY 14214, 716-834-8932, 716-834-8934 -FAX, kfishman@mmce.net.

02-2872 Temperature Monitoring and Compressibility Measurement of a Tire Shred Embankment in Manitoba

Session 202

A shredded tire road was constructed to provide access to a gravel pit near the city of Winnipeg, Manitoba, Canada. This paper discusses the results of temperature monitoring and strength and compressibility testing on shredded rubber tires

The thermal behavior of the tire shreds is established by a long term on site automated temperature measurement. Which has shown that the thermal coefficient of the tires is 0.312 W/m-0C.

Three sizes of shred minus 300 mm, minus 150 mm and minus 50 mm are examined. The elastic modulus of the shredded tires is determined as a function of the bulk density of tires. A model is used to predict and verify the compressibility of the tire embankment based on the laboratory testing of tire compressibility.

Ahmed Shalaby and **Riaz Ahmed Khan**, University of Manitoba, Canada, Civil Engineering, 15 Gillson Street, 342 Engineering Building, Winnipeg R3T 5V6, MB, Canada, 1-204-474-6818, 1-204-474-7513 -FAX, shalabya@cc.umanitoba.ca.

02-2891 Control and Monitoring of Bridge Abutment Stabilization Project

Session 722

The eastern abutment of the Inner Belt Bridge (CUY-90-15.24, the Central Viaduct), Cleveland, Ohio, experienced excessive slope movements that became more noticeable and threatening by 1994 in both rate and magnitude. Accordingly, a stabilizing system was designed to improve the stability of the slope employing many slope stabilizing techniques, including driven piles, drilled shafts, and rock anchors.

Due to the significance and nature of work, it has been the concern of the Ohio Department of Transportation to ascertain design criteria, efficiency of the selected stabilizing system, prevention of any unforeseen risk due to construction works and procedure, as well as to assure the long term stability of the stabilized slope. Thus, representative elements of the accomplished, complex structured slope have been instrumented to enhance our current understanding of the behavior and relative contributions of each element of the stabilizing matrix, as well as their interactions and possible shortcomings.

This paper presents real time instrumentation measurements, showing construction sequential attributes to the success of the slope stabilization works. It aims to provide some practical insights on the compatibility of the selected instruments and the instrumented elements, and issues regarding the constructability and design input parameters for similar geotechnical structures.

Robert Y. Liang, University of Akron, Department of Civil Engineering, Center for Infrastructure Materials and Rehab, 431 ASEC Building, Akron OH 44325-3905, 330-972-7190, 330-972-6929 -FAX, rliang@uakron.edu; and Gene Geiger and Jawdat Siddiqi, Ohio Department of Transportation.

02-3110 Comparison of Measured Hydraulic Conductivity with Predictions from Aggregate Gradation Specifications

Session 401

A method for estimating the lower limit of saturated hydraulic conductivity for a gradation specification is demonstrated. Past studies have indicated a relationship between the porosity of the compacted fill, the percentage of particles finer than 0.075 mm, and the sieve size through which ten percent of the material will pass. A gradation specification proposed for Illinois highway edge drain envelopes was tested by fabricating two samples theoretically having the lowest permeability within gradation limits. The samples were tested for saturated hydraulic conductivity using a large permeameter and compared with the results for a well draining sample, also within gradation specifications. The test results indicated that the two laboratory samples had much lower saturated hydraulic conductivity coefficients than the well draining sample, although all were within gradation limits. The conclusion is if gradation specifications

are used to control drainage performance, the specifications need to be correlated with laboratory hydraulic tests.

Jeffrey Stanley Stein, **Andrew Wright** and **Barry J. Dempsey**, University of Illinois, Civil and Environmental Engineering, 1611 Titan Drive, Rantoul IL 61866, 2178930302, 2178930601 - FAX, j-stein1@uiuc.edu.

02-3161 Effect of Wet-Dry Cycles on Resilient Modulus of Class C Fly Ash Stabilized Aggregate Base

Session 251

The laboratory study undertaken in this research focused on investigating the effect of wet-dry (W-D) cycles on low quality aggregates chemically stabilized with Class C fly ash (CFA). Resilient modulus (Mr), unconfined compressive strength (UCS), and modulus of elasticity (E) were the only properties used to evaluate this effect. Cylindrical samples stabilized with 10% CFA, cured for 3 and 28 days, and subjected to different W-D cycles were tested. The Mr values of 28-day cured samples increased as W-D cycles increased up to 12, beyond which a reduction was observed. As for 3-day cured samples, the resilient modulus increased with the number of W-D cycles. Wetting and drying action produced more detrimental effect on 28-day cured samples than on 3-day cured samples. The resilient modulus values of 28-day cured samples subjected to 30 cycles were approximately 5% lower than the corresponding Mr values of samples without W-D cycles. The Mr values of 3-day cured samples, on the other hand, increased approximately 55% compared to the corresponding Mr values of samples with no W-D cycles. Also, it was found that beyond 12 and 30 cycles, the W-D action started to have a noticeable negative effect on 28- and 3-day cured samples, respectively. Additionally, it was observed that the positive effects of curing time were more dominant on 3-day cured samples, and the detrimental effects of W-D cycles were more influential on 28-day cured samples.

Naji Najib Khoury and **Musharraf M. Zaman**, University of Oklahoma, Civil Engineering and Environmental Science, 202 West Boyd Street, room 334, Norman OK 73019, 405 325 5911, 405 325 4217 -FAX, naj@ou.edu.

02-3314 Performance of Lime Cement Stabilized Soils for I-15 Reconstruction Project, Salt Lake City, Utah

Session 346

This paper describes the application and performance of lime cement stabilization for the I-15 Reconstruction Project in Salt Lake City, Utah. Lime cement columns were used to support a mechanically stabilized earth (MSE) wall that was constructed adjacent to a commercial business. This wall was constructed over weak, compressible, lacustrine deposits that are susceptible to a large amount of consolidation settlement and potential shear failure. The soil properties, design of the lime cement stabilization and the construction and post-construction settlement performance of the system are described herein.

Steven Bartlett, University of Utah, Civil and Environmental Engineering, 122 S. Central Campus Drive, Salt Lake City UT 84112, 801-587-7726, 801-585-5477 -FAX, bartlett@civil.utah.edu; and **Clifton Farnsworth**, Utah Department of Transportation.

02-3485 Using Tiltmeters to Monitor Pier Movement: Case Study

Session 722

In December 2000, the Illinois Department of Transportation began the staged replacement of dual Interstate 55 bridges over Lake Springfield. As part of the construction, bi-axial tiltmeters were attached to one existing bridge to monitor pier movement during the construction of a

causeway around and through existing pile bents. The instrumentation provided IDOT with the ability to ensure the safety of interstate traffic during construction. The instrumentation was removed after causeway construction beneath and adjacent to the bridge was completed. Although the tiltmeter system achieved the overall objective of monitoring pier movement due to rockfill placement, the system did not work as anticipated. This was partially due to a combination of unrealistic expectations of system capabilities, greater than expected variability in background movement, and increased data collection frequency over that planned.

Kenneth Monroe Berry, URS Corporation, 2318 Millpark Drive, Maryland Heights IL 63043, 314-429-0100, 314-429-0462 -FAX, kenneth_berry@urscorp.com; and **Gregory B. Heckel**, Illinois Department of Transportation.

02-3683 Quality Management of Base and Subgrade Materials

Session 627

The acceptance criteria for compacted geo-materials (such as base and subgrade) are typically based on adequate in-place density. Unfortunately, the design of a given project is based on the engineering parameters, such as strength or stiffness. A procedure based on seismic techniques to measure the modulus layer-by-layer shortly after placement is presented. The major advantage of seismic methods is that similar results are anticipated from the field and laboratory tests as long as the material is tested under comparable conditions. This unique feature of seismic methods in material characterization is particularly significant in quality control and quality assurance for ground treatment prior, during and after construction.

Simplified field and laboratory tests are suggested that can be rapidly and nondestructively performed and interpreted so that problem materials can be identified before construction and in order that any problems during the construction process can be adjusted. The field and laboratory methods are incorporated in a manner in which the results can be readily reconciled without any scaling or simplifying assumptions. The simplified laboratory tests can be used to develop the ranges of acceptable properties for a given material. Nondestructive field tests are performed to determine whether the contractor has achieved the minimum specified stiffness.

This paper provides a concept on using seismic nondestructive testing technology in the evaluation of compacted materials and describes the equipment and setups that have been developed for implementing the technology in both field and laboratory tests. The methods have shown promise as practical tools for use by highway and construction industry. Currently the procedure is being implemented on the trial basis by the Texas Department of Transportation.

Soheil Nazarian and **Deren Yuan**, University of Texas, El Paso, Engineering Building, Room E201, 500 West University Avenue, El Paso TX 79968, 915-747-6911, 915-747-8037 -FAX, nazarian@utep.edu; and **Miguel Arellano**, Texas Department of Transportation.

02-3698 Theory of Acceptance Sampling for Production Piles

Session 446

When a contractor places a large number of piles according to certain design and construction criteria, how many of those piles should the inspecting agency load test to assure that the set of piles meets acceptable quality levels, and what performance criteria should be used to decide upon the suitability of individually tested piles or groups of tested piles? This is a traditional problem of acceptance sampling in quality assurance and quality control, and the methods of those fields offer insights which complement the reliability-based provisions of the load and resistance factor design (LRFD) methodology now enjoying increasing use in geotechnical

engineering. An overview is pre-sented of principles of acceptance sampling for deep foundations, with examples of its use in practice.

Gregory Baecher and **Bilal Ayyub**, University of Maryland, Dept of Civil and Environmental Engineering, 1173 Martin Hall, College Park MD 20742, 301 405 1972, 301 405 2585 -FAX, gbaecher@eng.umd.edu; and **Bjorn Birgisson**, University of Florida.

02-3707 Innovative Soil Moisture Probe for In Situ Subsurface Investigations

Session 380

Accurate determination of subsurface moisture is important to the transportation sector for improving pavement performance and longevity and mitigation of contaminated property. An innovative soil moisture resistivity temperature (SMRT) capacitance probe was studied for its potential to improve in situ moisture measurements.

Response of the probe in six different soil types (fine sand, alluvial sand, Upshur clay, fine sand/bentonite, fine sand kaolinite, and fine sand/organic mix) with low to saturated moisture content was investigated. The study included the effect of soil characteristics, temperature, resistivity variability and air gap around the probe.

The probe's response varied slightly under variable temperature conditions (from 5°C to 40°C) for low to moderately high moisture contents (3% and 15%). At high moisture content (23%) an observed effect was the dependency of dielectric constant of water on temperature. A study of insertion/reinsertion of the probe indicated an apparent air gap effect, which has been observed with other conventional capacitance probes, but is circumvented with this probe, since it is pushed into the subsurface. The probe was relatively insensitive to large variations in soil resistivity. A calibration equation appropriate for a broad range of soils was determined based on the variation of volumetric moisture data determined by the gravimetric method versus the probe readings of moisture. A 5th order fit of data within a +/- 4% envelope and a correlation of 97.4% was achieved. The study illustrated the utility of the capacitance probe for determination of in situ moisture, which could be beneficial to future transportation projects.

Gayle F. Mitchell and **Kwame Adu-Gyamfi**, Ohio University, Dept. of Civil Engineering, 143 Stocker Center, Athens OH 45701, 740-593-1465, 740-593-0625 -FAX, gmitchel@bobcat.ent.ohiou.edu; and **James Shin**, Applied Research Associates, Inc.

02-3756 Stabilization of Silty-Sand with Nontraditional Additives

Session 222

A laboratory experiment was conducted to evaluate the stabilization of a silty-sand (SM) material with nontraditional chemical or liquid stabilizers. Silty-sand soil specimens were mixed with various stabilization products and compacted using a gyratory compaction machine to approximate American Society for Testing Materials (ASTM) D 1557 moisture-density compaction. Each specimen was subjected to "wet" and dry testing following the designated cure period. Twelve nontraditional stabilizers were evaluated in this experiment including acids, enzymes, lignosulfonates, petroleum emulsions, polymers, and tree resins. Additional specimens were stabilized with an asphalt emulsion, cement, and lime to provide a comparison to traditional stabilizers under the same mixing, compaction, and curing conditions. The analysis of the test data consisted of determining the average strength, in terms of sustained load, of three replicate specimens of each mixture. The average strength of the three replicates was compared to each additive's strength, the traditional stabilization results, and a series of control specimens that were not stabilized. The results of the experiment indicate increased strength of some nontraditionally stabilized specimens when compared to both the control series and the

traditional stabilization alternatives. Some of the nontraditional stabilizers did not demonstrate significant increased strength over the control series for the conditions of this experiment. Many of the stabilized specimens were highly moisture susceptible indicating the potential for poor performance when exposed to adverse environmental conditions, while a few specimens demonstrated excellent performance when exposed to moisture. Specific products are recommended for stabilizing silty-sand soils.

Rosa L. Santoni, **Jeb Tingle** and **Steve L. Webster**, U.S. Army Corps of Engineers, Engineer Research and Development Center, GSL-APB (CEERD-GM-A), 3909 Halls Ferry Road, Vicksburg MS 39180-6199, (601)634-3379, (601)634-4128 -FAX, rosa.l.santoni@erdc.usace.army.mil.

02-4026 Road Stabilization, Reconstruction, and Maintenance with Combined Mechanically Stabilized Earth and Secant Pile Wall, Zion National Park

Session 304

A 1995 landslide diverted the North Fork of the Virgin River, in Zion National Park, Utah, causing complete erosion of 180 m (590 ft) of the Valley Floor Highway, the park's main access road. Buried utilities were damaged and 450 people were left stranded. Road reconstruction and maintenance has been ongoing in many phases since 1995 and has proved to be difficult because of environmental and physical constraints imposed by the river, and steep slopes of recent and historic landslide debris on both sides of the valley. In an effort to limit disturbance to the landslide slope while maintaining a two-lane access road adjacent to the river, a compound retaining wall was designed and constructed through the narrow reach of the valley. The lower part of the wall consists of cantilevered secant piles, providing 3.6 meters (12 feet) of scour protection, and the upper part of the wall is a mechanically stabilized earth wall. Intermittently spaced foundation piles reduce the lateral loads on the secant piles, making cantilever support practical.

Scott A. Anderson and **Jennifer L. Williams**, URS Corporation, Geo/Civil, 8181 E. Tufts Avenue, Denver CO 80237, (303) 694-2770, (303) 694-3946 -FAX, scott_a_anderson@urscorp.com.

02-4183 Cold In-Place Recycling and Full-Depth Strengthening of Expansive Subgrade Soils Using Cementitious Waste Products in Northern Climates

Session 251

Over recent years, Saskatchewan has witnessed significant increases in commercial truck traffic due to grain transportation rationalization, consolidation of the rural grain elevator system, rural economic diversification and expansion of resource industries such as oil and gas, mining and forestry. Although increasing truck traffic has long term implications for the primary pavement system, significant increases in commercial truck traffic hold immediate implications for thin paved roads because many thin pavements were not originally designed to accommodate significant numbers of heavily loaded commercial trucks. The detrimental impact of increasing commercial trucks is already being witnessed by the accelerated, and often catastrophic, deterioration of many Saskatchewan thin pavements. Therefore there is a clear need to strengthen many Saskatchewan thin pavements, however, conventional structural strengthening typically involves building up with granular subbase-base overlay systems which are often too expensive because of costly aggregate hauls and narrow grade widths often require regrading in order to provide adequate substructure width to build up. As a result, Saskatchewan Department of Highways and Transportation (SDHT) is investigating the use of cold in-place recycling and full depth cementitious stabilization to strengthen Saskatchewan thin pavements with an innovative

"build down" approach. To this end, industrial waste co-products such as flyash, bottom ash and kiln dusts are being investigated as structural cementitious soil stabilizers. This study presents the results from laboratory characterization and field test section performance of alternative cementitious stabilization soil systems and road structures constructed on Highway 19-06 near Elbow, Saskatchewan. Field performance of the Hwy 19-06 test sections after two years show cold in-place recycling and cementitious stabilization to be a technically and economically feasible solution for strengthening Saskatchewan thin paved roads built on clay-till subgrades. This paper presents a summary of the per-construction site investigation methods, laboratory materials characterization, and field quality control and quality assurance methods being developed to support cold in-place recycling and full depth strengthening of Saskatchewan rural roads.

Curtis F. Berthelot, University of Saskatchewan, Canada, Transportation Centre, 57 Campus Drive, Saskatoon S7N 5A9, SK, Canada, (306) 966-7009, (306) 477-4090 -FAX, berthelot@engr.usask.ca; and **Ron Gerbrandt**, Saskatchewan Highways & Transportation.

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