

Catalog of Practical Papers

2001 TRB Annual Meeting

Design and Construction of Transportation Facilities

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1. Bridge, Culvert and Tunnel Design and Performance

01-0378 “Development of Two TL-2 Bridge Railings and Transitions for Use on Transverse Glue-Laminated Deck Bridges”

The Midwest Roadside Safety Facility, in cooperation with the U.S. Department of Agriculture Forest Service, Forest Products Laboratory and the Federal Highway Administration, designed two bridge railing and approach guardrail transition systems for use on transverse glue-laminated timber deck bridges. The bridge railing and transition systems were developed and crash tested for use on medium service level roadways and evaluated according to the Test Level 2 (TL-2) safety performance criteria provided in the National Cooperative Highway Research Program (NCHRP) Report No. 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features. The first railing system was constructed using steel hardware, while the second railing system was built using glulam timber components. Four full-scale crash tests were performed, and the bridge railing and transition systems were determined to be acceptable according to the current safety standards in NCHRP Report No. 350.

Ronald K. Faller, Barry T. Rosson, Eric A. Keller, University of Nebraska-Lincoln, Midwest Roadside Safety Facility, 1901 Y St., Bldg. C, Lincoln NE 68588-0601, 402-472-6864, Fax: 402-472-0506, rfaller1@unl.edu; **Michael A. Ritter**, USDA Forest Service; and **Sheila R. Duwadi**, Federal Highway Administration.

01-0436 “Effective Use of Public Involvement in Aesthetic Quality of Bridge Design”

This Author relates his personal experience as the project manager in the replacement of four bridges in Columbus, Ohio that utilized public involvement to achieve aesthetic quality in the bridge designs. This paper outlines the successful use of public involvement in the design process by the Franklin County Engineer's office. Public involvement used as part of the design process has yielded a string of award winning bridges for the Franklin County Engineer's office and has added tremendous civic value to the community. The paper identifies the important aspects of public involvement and outlines the design process used and the efforts required by the County Engineer's office for the replacement of urban bridges having historical significance or civic importance. It also illustrates how engineers are able to maintain control of their projects throughout the design process.

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01-2754 “Use of Virtual Reality Images to Aid Public Involvement in Appearance of Roads and Bridges”

The UK Highways Agency have just completed a research project into the viability of using Virtual Reality technology to help communicate information about proposed new roads and bridges to the public, and to encourage their involvement in the design and appearance of roads and bridges. This paper considers primarily the bridge aspects. In the past there was a tendency to consult the public in two stages. Initially they were consulted conceptually about the route, with little detail about any major structures. Then a few years later they would be shown an artists perspective of the bridge, often out of context, and road layout plans of the route. A physical model emphasized psychologically that it was probably too late to change very much. This neither contributed to the elegance of the bridge nor particularly encouraged local support for the project. Using Virtual reality, the visual effects of a road or bridge in the specific location can be known at the very earliest stage. later, with high quality images, local people, as well as

the designers, can make real choices between viable structural options and can see the effect of different materials in the real context. The result will be more beautiful bridges, which because of public involvement and support, will be built sooner and without public objection. The Highways Agency is in the process of trialling this new approach.

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01-2801 “Fatigue Assessment of Traffic Signal Mast Arms Based on Field Test Data Under Natural Wind Gusts”

In recent years, several states including Missouri, Wyoming, California, Texas, etc. experienced fracture failures of signal mast arms. Almost all the failures are associated with the propagation of defects or cracks. It is therefore imperative to evaluate existing mast arms using a simple yet accurate procedure. In this paper, a statistical methodology is proposed to predict the fatigue life of signal mast arm structures based on field measured strain data. The annual occurrence of various stress levels is determined using the historical wind speed data in the vicinity of a mast arm structure and the strain readings of the structure under specific wind gusts. For each stress level, the crack initiation and propagation lives are estimated with the strain-life approach and the Paris crack growth rate model. They are combined to account for variable stresses by means of the Miner's rule and the Root-Mean-Square model, respectively. The stress concentration factor around the arm-post connection is determined using a finite element model. The parameters in the life prediction models are determined with the ASTM Standard flat tension and compact tension tests. The proposed methodology has been applied to a 12.8-meter-long (42 ft), octagonal arm and a 16.5-meter-long (54 ft), circular mast arm in Missouri. It is concluded that two signal structures will not crack under natural wind gusts in their service life. However, the 16.5-meter-long arm is likely vulnerable to the development of a crack while the 12.8-meter-long arm is safe unless a visible crack is developed.

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01-3016 “Long-Term Durability of Structural Composite Lumber in Bridge Applications”

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 effect of moisture, exposure to ultraviolet light and varying temperature/humidity effects on the long-term durability of the bridge members. In order to document these effects, 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), and preservative type (CCA and Penta). The moisture content of the SCL, ambient temperature, humidity and the general condition of the beams were monitored. The experiment concluded with the determination of an applicable SCL member for bridge applications. Although most of the members were found to be adequate, a Douglas Fir CCA treated LVL member was found to be most suitable.

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01-3384 “Ultrasonic Inspection of a Glued Laminated Timber Fabricated with Defects”

The Federal Highway Administration (FHWA) set up a validation test to compare the effectiveness of various nondestructive inspection techniques for detecting artificial defects in glulam members. The validation test consisted of a glulam beam fabricated with artificial defects known to FHWA personnel but not originally known to the scientists performing the validation tests. Ultrasonic inspection was effective for identifying voids within the glulam beam. The glulam was inspected across the width and through the depth. The inspections from each direction were combined to accurately detect and locate artificial voids in three dimensions. Wave travel time allowed identification of some of the voids, but signal amplitude parameters, such as RMS voltage and peak voltage, provided more precise location of the voids. The three-dimensional image provided valuable insight into the internal condition of the glulam. However, through-the-width inspection was able to locate voids in two dimensions along the length and depth of the glulam. For a field inspection, two-dimensional location of decay would provide sufficient information for judgments to be made on the future of the inspected specimen.

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01-0348 “High-Performance Concrete Bridges in Washington State”

The development of a superior and durable concrete capable of resisting environmental distress has been the focus of bridge engineering for many years and resulted in the development of High Performance Concrete (HPC). HPC is a concrete designed for a specific purpose, sometimes possessing a high strength and modulus of elasticity, but more often, a high durability under particular conditions of exposure. HPC has enhanced specific properties, such as workability, durability, strength and dimensional stability, resulting in long lasting economical structures. The durability of concrete is important because it determines the service life of the structures. HPC is a durable concrete, capable of resisting chloride diffusion and other environmental distress and has been increasingly used in bridge structures. Mineral pozzolanic admixtures have been incorporated into the BIPC mixes to increase concrete resistance to environmental distress. The chloride-induced corrosion can cause significant deterioration of concrete structures, resulting in costly repairs. This project helped the Washington State Department of Transportation (WSDOT) to better understand the performance of concrete bridges and factors affecting the durability of concrete. It focuses on the influence of mineral admixtures, entrained-air and curing on the durability of high performance concrete.

Chuck Prussack, Central Pre-Mix Prestress Co.; **David Jones**, and **Bijan Khaleghi**, Washington State Department of Transportation, Bridge & Structures Office, P.O. Box 47340, Olympia WA 98504, 360-705-7181, Fax: 360-705-6814, khalegb@WSDOT.gov.

01-0400 “Repair and Strengthening of Concrete Structures Through Application of Corrective Posttensioning Forces with Shape Memory Alloys”

Shape memory alloys recover deformations induced at lower temperatures upon heating above a transformation temperature; restraint of this shape recovery generates relatively large stresses. These stresses are used here to transfer corrective forces to structural systems for strengthening

and repair effects. For this purpose, shape memory rods are pre-elongated, anchored to the structure, and subjected to electrical resistance heating to transfer corrective forces to the structure. The project used iron-based shape memory alloys of relatively low cost; the alloy composition was selected to yield relatively high and stable levels of restrained shape recovery stresses. Laboratory tests verified the ability of pre-elongated rods anchored onto damaged structural systems to restore structural integrity through application of corrective forces. Subsequent damaging effects could also be overcome by electrical resistance re-heating of rods. A reinforced concrete bridge structure with beams lacking sufficient shear strength at longitudinal bar cut-off locations was selected for field demonstration of the technology. A design methodology was developed and verified through laboratory tests simulating conditions of the selected bridge structure. Subsequently, a detailed design was developed and the approach was implemented under field conditions. Application of corrective (post-tensioning) forces to structural systems using shape memory steel provides an efficient, rapid and convenient approach for repair and strengthening of damaged or deficient structures. The relatively large recoverable strains of shape memory alloys help reduce losses of post-tensioning forces. The approach suits application to diverse structures for corrective and strengthening effects.

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01-0417 “Effect of HPC, LFRD, and Advanced Construction Methods”

The race for longer bridge span lengths with low initial costs continuously forces engineers to consider innovative design and construction alternatives. This trend towards longer spans is driven by concerns regarding safety (reduced number of supports/piers), reduced maintenance costs of (elimination of deck joints), etc. Traditionally, regular prestressed/precast concrete girders were not considered viable alternatives in the 150 - 300 feet (30 to 90 meters) span range. Besides prohibiting girder/span ratios (girders were too deep), many states have restrictions regarding the maximum length of and weights of girders that can be transported on the highway system (usually not exceeding 130 feet (40 meters)). In response to these limitations, new construction techniques were developed by engineers, implementing greater concrete strengths and alternative construction methodologies, allowing girders to be spliced. This way, the girders may be fabricated and transported in sections, and spliced together at the job site. The resulting structure, with continuity between adjacent spans provides further economies, and extends the useful range of the bridge. The inherent benefits of prestressed/precast concrete, such as ease and speed of construction, quality control through certification, maintenance, aesthetics, durability, etc., have provided an excellent performance track record and a sustained growth during the last 50 years. Over the last 20 years, over 100 bridges have been constructed using precast spliced girder technology by champion states that have shown acceptance like AL, CA, FL, KY, NE, OR, PA, TX, WV and WA. The effects on span capability using material variations, design optimization, and alternative construction methods using splice girders has been researched and presented for high performance/high strength concrete (*HSC*) up to 10 ksi. A correlation between live load models using the LRFD (HL-93) and AASHTO standard *HS20* and *HS25* including *FWS* provisions is also presented. The construction method using splice girder technology is described and a numerical example is given for a two stage design process utilizing post-tensioning and *HSC*. This paper focuses on outlining some of the most cost-effective methods available today to stretch out the span length coverage and construction options by exposing the advantages of precast bridge girders and their new ability to comply with depth limitations and/or transportation limits.

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01-0420 “Field Investigation of High-Performance Concrete Bridge Decks in South Carolina”

A high performance concrete (HPC) mixture has been used on several bridge construction projects in the upstate region of South Carolina. The majority of these bridge decks, although not all, have experienced problems with early-age cracking occurring both before being opened to traffic and immediately thereafter. The cracking exhibited in these bridge decks presents a significant obstacle to the wide-spread adoption of high performance concrete materials for bridges in South Carolina. In an effort to determine likely causes of cracking experienced in these concrete bridge decks, sight inspections of nine bridges in the Greenville/Spartanburg, SC area and a thorough review of construction documentation from three of these sites was carried out. Additionally, a review of the SCDOT Concrete Specifications was conducted. It is concluded that observed cracking has two likely causes. Early-age shrinkage cracking resulted from a “rich” concrete mixture combined with poor curing practices. Load induced cracking, appearing shortly after the spans were open to traffic may result from the relatively stiff decks being placed on more flexible bridge superstructures. An improved on site quality control/quality assurance is recommended for all aspects of mixing, placing and curing when high performance concrete is used. It is also recommended to develop a more appropriate high performance concrete mix design for use in bridge decks. Such a concrete mix will have enhanced durability characteristics and should not be a high strength mix. The FHWA parameter characterization has to be adopted for the specification of high performance concrete mixes.

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01-0132 “Superstructure Flexibility and Disintegration of Reinforced Concrete Deck Slabs: LRFD Perspective”

This paper examines the new deflection criteria of the AASHTO LRFD Bridge Design Specifications with respect to its potential impact on the serviceability and long-term integrity of deck-type highway bridges. This examination suggests that if the intent of this new criteria is implemented, the effective service life of reinforced concrete deck slabs may in some areas of the country become considerably less than 250,000 hours (30 years). Today, this is the age by which many deck slabs have disintegrated to the extent that they must be funded and programmed for replacement. Based on this examination, this paper urges that long-term superstructure flexibility research on aging reinforced concrete deck slabs be accomplished so that specification changes and bridge characteristics can be based on known consequences. Otherwise, unwary transportation administrators who adopt LRFD recommendations and abandon live load deflection limitations may find themselves owners of defective bridges that may have to be replaced rather than just being re-decked.

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01-0421 “Retrofitting to Correct Uplift of Curved Girder Bridge Through Field Testing and Analysis”

The Ramp C Bridge, at the New York State Thruway interchange with I-287 and New York State Route 17 in Rockland County near the New Jersey state line, is a continuous four-span bridge with a reverse horizontal curve alignment. It consists of five steel girders with radial abutments and skewed pier supports (61°). During construction immediately after the girders

were erected and the counter weights were poured, at low temperatures, it experienced unanticipated girder uplift at one corner of an end span. Physical testing and analysis were undertaken to investigate this behavior and to estimate the uplift forces. The data were used to design a tie-down system to correct the uplift problem, thus avoiding delays in opening the bridge to traffic.

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01-0467 “Health-Monitoring of Ironton-Russell Bridge for Rating Purposes”

The Ironton-Russell truss bridge spanning the Ohio River between the cities of Ironton, Ohio and Russell, Kentucky consists of a 3-span cantilever through truss, with a suspended truss in the center span, and a fourth span that is essentially a simple span through truss. Visual inspections of this bridge revealed that recent welded repairs and modifications to various truss members reduced their fatigue classification as well as modified original design and construction details. When the visual inspection team identified these details along with section loss at certain truss verticals and diagonals, it was their recommendation to reduce the allowable load on the bridge from 23.4 tons to 3 tons. However, a 3-ton load limit would hinder the transportation of heavy materials across the bridge and therefore have a severe impact on the local economy.

Consequently, a series of nondestructive field tests were organized and performed on the bridge to provide better assessments of load capacity and in-situ structural health. Controlled truck-load tests involving resistance-based strain gages were conducted and an instrumented monitor utilizing low-speed (vibrating wire) strain gages was installed at the site. The respective data recorded during these field efforts was used not only to evaluate environmental effects on the bridge, but also to compute the load-rating for each of the instrumented members. Resulting objective-based load-ratings and their corresponding allowable live loads greatly exceeded the recommended 3-ton load limit. Essentially, objective data identified/characterized in-situ structural mechanisms and therefore provided the basis for more sound and realistic load-ratings.

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01-2244 “Load Distribution for Heavy Equipment Transporter System”

The objective of this study was to determine the load effects of a loaded military heavy equipment transporter system (HETS) on typical highway bridges. The maximum moments due to this nine axle, 1009 kN (HETS) vehicle were compared to the design moments for typical bridges. This comparison was later used to determine passability of the HETS vehicle on typical bridges. Steel and prestressed concrete multi-beam bridges were of primary interest in this study. Approximately 100 typical bridges were selected to encompass the majority of the multi-beam type of bridges in the National Bridge Inventory (NBI). The bridge analysis program, SECAN, was used to determine maximum moments produced by the HETS vehicle in these typical bridges. These maximum moments were compared to the design moment assuming a HS20 design vehicle. In most cases the maximum moment resulting from the heavy equipment transporter load was less than twenty percent greater than the design moment. In cases where it was over twenty percent, the bridge was of uncommon dimensions and configuration.

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01-2262 “Passability Program for Highways”

New Mexico State University (NMSU) was contracted by the Department of Defense via the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) through the Federal Highway Administration and the New Mexico State Highway and Transportation Department (NMSHTD) to study the impacts of the M1070/M1000 Heavy Equipment Transporter system (HETS) on public highway bridges. The goals of this project were to determine the potential effect of the HETS on public highway bridges and to develop a method to evaluate passability of the HETS on the nation's bridges using the National Bridge Inventory (NBI). The HETS is an army tactical vehicle that when used to transport the M1A1/A2 main battle tank has a gross vehicular weight of around 226,000 pounds which far exceeds the typical highway limit of around 80,000 pounds. However, the HETS has nine axles and a wide track on the trailer of 10.2 feet with four sets of dual tires per axle. A three pronged approach was used to accomplish the goals of the project: 1) an analytical study of typical bridge types and sizes to determine the effect of the loaded HETS compared to typical design vehicles; 2) field tests to verify the results of the analytical study; and 3) development of a computer program that would utilize the NBI to determine passability along a particular route. Analytical studies on bridges indicated that the forces in an individual girder or beam for the loaded HETS near the centerline of the bridge were, in general, no more than 20-30% greater than the design forces even though the total weight of the HETS vehicle was considerably greater than the design vehicle weight. The accuracy of the computer modeling techniques used in the analytical study were verified by field tests. The maximum predicted analytical live load stresses were slightly less than the maximum stresses from the measured strains for six of the tested bridges and within 3 percent in the other test. Six of the bridges could be crossed without exceeding the inventory rating (a common measure of capacity which is close to the design load). A computer program, BRGCKM, was developed using the above results to determine the passability of vehicles along a particular route utilizing the data in the NBI. The program determines an equivalent HS loading based on the maximum span as listed in the NBI and compares it to the operating rating as listed in the NBI. For particular types of bridges, the results of the above study is used directly to determine passability of the loaded HETS.

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01-2900 “Issues of Capacity Rating of Bridges from Field Measurement”

The paper discussed the principles of proof and diagnostic load tests for capacity evaluation. The rating formulas for both tests were presented. The rating factors calculated from measured live load moment, girder distribution factor (GDF), and linear extrapolation are proven the same, and are upper bounds in nature. The difference between load distribution factor (LDF) and girder distribution factor (GDF) was explained. A case study is conducted to clarify the discussions. The results indicate that the measured LDF, though calculated from measured strains, cannot fully reflect the capacity conditions of field bridges. It reflects only the relative load distribution among the girders.

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01-2923 “Field Performance of High-Performance Steel Bridge: Dodge Street over I-480 Bridge in Omaha, Nebraska”

As a result of a cooperative research program between the Federal Highway Administration (FHWA), the U.S. Navy and the American Iron and Steel Institute (AISI) High Performance Steel (HPS) with 70 (HPS-70W) and 100 ksi (HPS-100W) yield strengths was developed. During the past three years, several bridges in the U.S. have utilized this new grade of steel. One of the major bridges to use HPS-70W steel is the Dodge Street over I-480 bridge located in Omaha, Nebraska. This bridge was constructed using the stage construction approach where one half of the bridge is constructed while the other half is open to traffic. This bridge was heavily instrumented and monitored to comprehend the behavior of the bridge during and after construction. This paper provides an overview of the instrumentation plan, results to date and a summary of the live load tests that have been carried out. The paper also outlines the additional work that will be conducted.

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01-3297 “Diagnostic and In-Service Testing of Transit Railway Bridge”

The paper presents the results of a diagnostic load test and in-service monitoring of a steel through girder bridge. The bridge currently has a low load rating that is controlled by the flexural capacity of the steel deck trough. The diagnostic load test was conducted using the regularly scheduled transit trains, without any interruption to the daily service. A total of sixteen strain transducers were mounted to the bridge girders and trough; five dynamic train passes were recorded. The largest tensile and compressive stresses recorded in the edge girder were 33.5 MPa (4.86 ksi) and 23.4 MPa (3.39 ksi), respectively; the largest tensile and compressive stresses in the deck trough were 25.9 MPa (3.75 ksi) and 27.9 MPa (4.05 ksi), respectively. The test results showed the effective width of the deck trough to be 2.89 m (9.5 feet) for a single axle and 5.19 m (17 feet) for a 2.74 m (9-foot) spaced axle pair. An in-service monitoring system was also placed on the bridge to record the stress cycles experienced by the bridge over a one week period. During the in-service monitoring period, 163 trains crossed the bridge with an associated 1456 axles. The mean peak tensile stress in the deck trough due to locomotives crossing the bridge was 26 MPa (3.78 ksi) with a standard deviation of 1.8 MPa (0.26 ksi). The tests results are expected to result in a higher load rating for the bridge and consequently, a lifting of the current speed restriction.

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2. Construction: General

01-0364 “Derivation of Equation for Cost of Premature Pavement Failure”

With the continuing interest in performance-related specifications, and the development of software packages to compute the appropriate level of payment associated with variable levels of quality, there is need for a simple, easily understood method to validate the output of these computer programs. A standard validation procedure is to create realistic hypothetical cases that can readily be calculated by hand, and then compare the results to the output of the procedure under test. An equation is derived that can serve two extremely useful purposes; it can be used as

a validation tool for software currently under development, or it can be used directly to establish pay schedules that award payment appropriate for the level of quality received.

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01-0405 “Statistically Based Methods for Verification Testing”

State Highway Agencies are currently using split-sample and independent-sample verification procedures for the purpose of comparing test results or verifying the contractors overall construction process in Independent Assurance (IA) programs and Quality Assurance (QA) construction specifications. The purpose of this paper is to review both sampling procedures and present new statistically-based methods for developing comparison procedures in both IA programs and QA specifications. The statistically-based approach determines an appropriate mean difference between either split-sample test results or independent-sample verification results by recognizing sample size, field variability, and inherent risks. A practical application is given using collected field data from hot-mix asphalt construction projects. This paper will benefit State Highway Agencies and contractors by providing an understanding of the statistical concepts involved with split-sample and independent-sample comparison procedures, and what information an agency needs in order to determine if a contractor’s overall test results are accurate. The concepts and procedures in this paper can be applied to all areas of highway construction involving split-sample and independent-sample verification tests, such as base materials, concrete structures and pavements, and hot-mix asphalt pavements.

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01-2933 “Examination of Operator Variability for Selected Methods for Measuring Bulk Specific Gravity of Hot-Mix Asphalt Concrete”

The ability of different operators to obtain repeatable results when performing laboratory testing on the same material is a very important part of producing accurate testing results. Different operators, using the same materials and equipment and following the same procedures ideally should be able to obtain similar results. By conducting trials in triplicate for each of three different testing methods, a measurement of the bulk specific gravity (G_{mb}) of compacted Hot Mix Asphalt Cement (HMAC) cores was obtained. An analysis of the variability between operators was investigated using a total of almost 1300 test results, using hot-mix asphalt concrete sampled from six projects in Arkansas. Three methods were used to determine the bulk specific gravity of compacted HMAC samples, including SSD (as per AASHTO T-166), height / diameter (as per AASHTO T-269), and vacuum sealing (using the Corelok vacuum sealing device). In almost all cases, G_{mb} values determined using the height/diameter method were statistically different from those determined using the SSD and Corelok methods; further, the SSD and Corelok values were not statistically different. The Corelok method exhibited a lower degree of variability than the other two methods used, based on the standard deviation of test results obtained by different operators. In a direct comparison between the Corelok and SSD methods, the Corelok exhibited a lower variability (standard deviation) in 82 percent of the cases. Overall, the Corelok method appears to offer a viable alternative for determining the bulk specific gravity of compacted hot-mix asphalt concrete.

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01-0273 “Nighttime Construction Issues”

This paper summarizes the findings of the Kentucky Transportation Cabinet (KyTC) study KTC-00-16, Night-Time Construction Issues. The current state of night-time construction is examined through a survey of night-time construction practitioners. In order to determine the feasibility of performing a project at night the factors that affect night operations are discussed as well as a night-time project evaluation form. As lighting is a crucial element of any night project, a new form of lighting technology is briefly discussed. An idea which is slowly beginning to gain favor with transportation departments is outlined, the contractor supplied work plan. Finally, ideas for improvements in public relations as well as recommendations for overall night-time project improvement are discussed.

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01-2944 “Lessons-Learned System for Highway Constructability”

A nine-mile stretch of the North Central Expressway (NCE) in Dallas was reconstructed to increase capacity and improve the geometric design of the freeway. The decade-long reconstruction project is considered by many industry experts to be one of the most complex ever undertaken by the Texas Department of Transportation (TxDOT). Much was learned concerning constructability of urban freeway reconstruction projects, presenting the opportunity to document lessons and store them in an electronic format. A relational database using Microsoft Access was created to classify and store the lessons for easy retrieval and distribution.

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01-3123 “Paris-Lexington Road Project: Interim Report”

The Paris-Lexington Road Project is the four-lane roadway reconstruction project of the two-lane Paris Pike, a twelve-plus-mile section of US27/58. This section of highway has been dedicated as a historic corridor, and has had its share of archeological and environmental sensitive sites along the corridor. In addition, Paris Pike is one of the major thoroughfares through picturesque horse farms that make up the prosperous Kentucky thoroughbred industry. Over the years safety and traffic operations problems have become noticeable the Kentucky Department of Highways. However, when the KDOH attempted to use their standard department procedures were to study, plan, design and construct a solution to rectify these problems, they found that the special circumstances of Paris Pike required something innovative. This paper attempts to give some background insight of the special circumstances that the KDOH had to consider, historic, environmental, and political. To ensure compliance to the agreement regarding the special historic and environmental preservation requirements of this project, the KDOH used innovative approaches in contracting the design segments. This paper then reports on the preliminary findings on the effectiveness of construction phase of the first three of five design segments that have been contracted. Although, further investigation is ongoing, some comparison can be made of the results being observed to those of the typical results achieved for highway construction projects performed under traditional design-bid-build contracting methods.

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01-3253 “Allocation of Risks Under Build-Operate-Transfer Delivery Approach for Transport Infrastructure Projects”

The need for the Build-Operate-Transfer (BOT) approach in the development of infrastructure projects has risen in recent years, due to budgetary and financial constraints faced by the public sector in both developing and developed countries, tightened by the necessity to repair, maintain, and modernize the existing infrastructure facilities. This paper aims at presenting the risk factors that influence the parties of a prospective BOT contract during the various phases of the contract. In particular, it addresses those factors pertaining to the pre-contract stage and to the political, construction, commercial, and financial categories of possible risks. Integrated schemes assimilating the risks involved and the corresponding alleviation measures are also offered.

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01-3291 “Critical Path Method/Line of Balance Model for Efficient Scheduling of Repetitive Construction Projects”

This paper presents a general model for efficient scheduling and resource management in construction projects that involve high degree of repetition, such as highways and pipelines. The proposed model has three main features: 1) it fully integrates the critical path method (CPM) for network analysis and the line of balance line (LOB) technique for linear scheduling; 2) it allows realistic schedule development considering project deadline and resource constraints; and 3) it incorporates improved schedule presentation that shows crews’ movements along the repetitive units and their detailed work assignments. The detailed formulation of the proposed model is described in this paper and an example application is presented. Through that example, the proposed model has been demonstrated to offer significant advantages as a resource-driven approach. Future extensions to the proposed model are then outlined.

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01-3439 “Evaluating Design-Build Procurement Documents for Highway Projects: How Good Are They?”

This paper presents recent innovations by the Arizona Department of Transportation (ADOT) in the use of design-build procurement for highway construction. Explosive population growth in Arizona has pushed ADOT to the limits of its capacity and challenged the Department to develop innovative ways to stretch its resources to meet the constituents’ needs. In 1996 the Department spearheaded the passage of a pilot design-build law aimed at completing public construction projects more rapidly than could be done using traditional methods. This paper describes an evaluation made of the procurement documents used for the second project in the design-build pilot program which involved widening an extremely congested eight-mile segment of Interstate 17, a primary artery carrying 180,000 vehicles per day through the city of Phoenix, from six lanes to ten. The Department utilized a two step method for selection of the winning design team utilizing both a Request for Qualification (RFQ) and the Request for Proposal (RFP). Both documents were evaluated for the clarity of thought and fairness of the point distribution methodology utilized by the selection teams as well as time allowed for response and proposal

costs incurred. The primary method of data gathering for this research was by written survey of all the proposing teams followed by unstructured interviews with responding principals. Analysis of the data gather from this research clearly showed where the procurement documents were unclear and where the Department needed to make corrections for future projects.

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3. Construction: Pavements

01-2904 “Feasibility of Using Precast Concrete Panels to Expedite Construction of Portland Cement Concrete Pavements”

As the number of vehicles on America’s roadways, continues to grow at an unprecedented rate, pavements continue to deteriorate faster and require replacement. In urban and densely populated areas, however, pavement construction causes traffic delays, which increase user costs. A method for expediting pavement construction, thereby reducing traffic delays and user costs is therefore needed. This paper will describe a feasible method for expediting construction of portland cement concrete pavements through the use of precast concrete panels. The main advantage of precast concrete panels is that they can be set in place and assembled quickly, allowing traffic back onto the pavement almost immediately. This will allow pavement construction to be carried out in overnight or weekend operations, when traffic volumes are low, resulting in tremendous savings in user costs. The concept for a precast concrete pavement, presented in this paper, should have the same, if not better, durability as conventional cast-in-place concrete pavements currently being constructed. Also, by incorporating prestressing, it will be demonstrated that equivalent load repetitions and design life can be achieved with a significant reduction in pavement thickness over conventional pavements. Although the initial construction costs may at first be higher for a precast pavement, the savings in user costs will far outweigh any additional construction costs.

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01-0143 “Establishing Production Rates for Hot-Mix Asphalt”

This paper presents four methods of computing production rates for use in contract time calculations. Production rates are defined as units of work (*i.e.*, cubic yards, tons, etc.) per unit of time (*i.e.*, day, hour, etc.). The four methods, which are used to generate four values of contract time, are generated for a given unit of work but with four different values of time. Data from thirty-six historical Louisiana Department of Transportation and Development (LaDOTD) rural hot mix asphalt (HMA) overlay projects were used to generate and validate the production rates. Due to their historical nature, each project had two additional values of contract time; (1) the original LaDOTD estimate and (2) the actual construction time. The actual construction time is assumed to act as the “control” group for the statistical analysis. This statistical analysis showed that mean production rates produce reasonable estimates of actual contract time. Therefore, the recommendation was that LaDOTD use mean production rates to calculate pre-bid estimates of contract time on rural HMA overlay projects.

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01-0268 “New Jersey’s Superpave Specification: The Next Generation”

The testing of New Jersey's first acceptance procedure for hot-mix asphalt (HMA) pavement designed by the Superpave method began in 1998 with the construction of a series of pilot projects. A distinct feature of the prototype specification was the use of a composite pay equation that expressed the pay factor as a function of the average of the quality levels for air voids, thickness, and riding quality. Although the quality received under this specification has ranged from good to excellent, a national survey recently conducted by the NJDOT suggests that pavement performance is more appropriately characterized by an additive function rather than by the average of the individual quality measures. A new pay schedule, developed from a combination of performance and analytical data and the opinion survey, produces larger bonuses for superior quality and larger pay reductions for poor quality. NJDOT engineers also realized that the original RQL provision based on individual quality measures did not properly account for the combined effect of deficient quality in two or more quality measures. It was also discovered that the use of a composite quality measure not only corrects these deficiencies, it also makes it possible to key the pay equation more directly to performance while substantially reducing the complexity of the acceptance procedure as a whole. Consequently, the new procedure is much closer to a true performance-related specification and, at the same time, is far simpler to understand and apply than its predecessors. The new version of the specification was developed cooperatively through a task force representing the NJDOT, FHWA, and several Industry associations, and is currently under test on a series of pilot projects.

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01-0344 “Development of Critical Field Permeability and Pavement Density Values for Coarse-Graded Superpave Pavements”

Within the hot mix asphalt (HMA) community, it is generally accepted that the proper compaction of HMA is vital for a stable and durable pavement. Low in-place air voids have been shown to lead to rutting and shoving while high in-place air voids have been shown to reduce a pavement's durability through moisture damage and excessive oxidation of the asphalt binder. Recent research has suggested that coarse graded Superpave designed mixes are more permeable than conventionally designed pavements at a given air void content. This higher permeability can lead to durability problems. This study was conducted to evaluate at what pavement density coarse-graded Superpave mixes become permeable using a field permeability device. Based upon the data collected, 9.5 and 12.5 mm nominal maximum size mixtures (NMAS) become excessively permeable at approximately 7.7 percent in-place air voids, which corresponded to a field permeability value of 100×10^{-5} cm/sec. Mixtures having a 19.0 mm NMAS became permeable at an in-place air void content of 5.5 percent air voids, which provided a field permeability value of 120×10^{-5} cm/sec. Coarse-graded mixes having an NMAS of 25.0 mm became permeable at 4.4 percent air voids, which corresponded to a field permeability value of 150×10^{-5} cm/sec.

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01-0346 “Effect of Superpave Gyrotory Compactor Type on Compacted Hot-Mix Asphalt Density”

The Superior Performing Asphalt Pavements (Superpave) gyrotory compactor was developed as a tool in the Superpave mix design system to better simulate the field compaction of hot mix asphalt (HMA) mixes. All Superpave gyrotory compactors are designed to meet the specification criteria found in AASHTO TP4. At the present time, AASHTO TP4 does not contain a precision statement. Furthermore, many agencies have reported differences in the bulk specific gravity of compacted samples from different Superpave gyrotory compactors, which have been properly calibrated. Data is presented and analyzed from three gyrotory compactor proficiency sample testing programs, from field project Superpave gyrotory compaction comparisons, and from mix design and quality control/assurance results from a state DOT. The data was then analyzed to determine the statistical (precision) and potential project implications which result from the observed differences. The results indicate that the precision of the Superpave gyrotory compactor is better than the mechanical Marshall hammer. However, there were significant differences between the bulk specific gravity of mixes compacted in different gyrotory compactors. These differences could potentially lead to discrepancies during the mix design/verification and quality control/assurance testing of a given mix.

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01-0390 “Evaluation of Field Density Measuring Devices”

The use of non-destructive devices for the measurement of in-place density of a compacted asphalt mat would be beneficial in that it would save time and money compared to cutting roadway cores for the determination of pay factors by Florida Department of Transportation (FDOT) Acceptance personnel. However, the use of non-destructive devices was discontinued by the FDOT in 1997 during the onset of Superpave construction because it was found that the gauges were not providing accurate readings when compared to the core densities. The recent development of non-nuclear density measuring devices has prompted the need for research studies that would again compare core density values to gauge density values for both coarse and fine graded Superpave mixes. This study compared core and gauge densities for two separate test sections (one coarse and one fine graded Superpave mix). Nuclear gauges from Troxler and CPN and non-nuclear gauges from Transtech were used in the study. The results indicate that when comparing standard deviations and means of the gauge densities to the core densities, the CPN MC3 gauge outperformed all of the other gauges used in this study. The Transtech gauges had comparably equivalent mean density values but had very high standard deviations. The Troxler gauges (three models were tested) had mixed results. In general, all of the gauges did not perform better on the fine graded mix as compared to the coarse graded mix. Although the CPN MC3 gauge used in this study provided results very close to the core density values, use of the gauge for Acceptance is not recommended at this time since these results are based on one gauge and there are issues related to requiring a specific manufacturer's gauge to be used. It is recommended that the Transtech gauges be allowed for use as a Quality Control tool since their variability is not necessarily worse than an allowable nuclear gauge.

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4. Construction: Structures

01-0196 “Nighttime Bridge Deck Replacement with Full-Depth Precast Concrete Panels at Route 7 over Route 50, Fairfax County, Virginia”

With increasing highway traffic, replacement of deteriorated and obsolete concrete bridge decks requires special attention from highway agencies. During bridge deck replacement, traffic congestion results in delays and inconvenience to motorists. Nighttime redecking with precast modular deck panels is a viable method of deck replacement that minimizes disruption to traffic, reduces total construction time and allows better quality control of concrete. More importantly, this construction method allows opening the portion of the bridge under construction to traffic during daytime. This paper presents the design and construction aspects of nighttime redecking of two bridges of Route 50 interchange at Route 7 in Fairfax County, Virginia. The single-span bridges carry Route 7 Eastbound and Westbound and are steel girders with composite concrete decks. After about 40 years of service in a corrosive environment, the decks had deteriorated and needed replacement. A preliminary study indicated that conventional cast-in-place redecking would result in significant traffic delays. Nighttime redecking with precast concrete modular panels, on the other hand, would cost slightly more but with minimal interruption to traffic. The nighttime precast deck replacement design was completed in 1998. The construction of the bridges began in September of 1999 and was successfully completed in less than two months. The redecking of each bridge was accomplished in 3 stages. In each stage, a portion of the existing deck was removed and replaced with precast panels. Construction time was limited to 8 hours per day, from 9:00 p.m. to 5:00 a.m. During the construction hours, the bridges were partially open to traffic. All of the traffic lanes were open during peak travel times from 5:00 a.m. to 9:00 p.m.

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5. Facilities, Equipment Design and Performance

01-3523 “States Flexing Main Street Design: Report on Efforts by Various States to “Flex” Their Highway Standards Toward Better Main Street Design”

Rutgers Transportation Policy Institute is investigating the importance of flexible design standards for highways that serve as main streets through communities. One component is to research similar policies and standards in other states, especially in the post-ISTEA landscape, states have the wherewithal to develop standards independent of the AASHTO Green Book. Our research found that few states have actually written new geometric standards — lane widths, stopping sight distance, corner radii — and of those that have, the deviations from Green Book values are relatively slight. More states have concentrated on policies and laws on performance standards — design speed, level of service, functional classification — perhaps because these have less to do with hard science and more with politics.

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6. Bituminous Materials

01-2277 “Improvement in Determination of Failure Stress of Asphalt Binder and Test Repeatability Through Sample Preparation in Direct Tension Testing”

We found that during Superpave direct tension testing (DTT) of asphalt binder materials, the failure stress and failure strain values were highly dependent on the DT mold temperature and the rate of cooling of these samples. A sample preparation method in DTT of asphalt binder materials was developed. In this method, aged asphalt binder was allowed to stay fluid in the DT molds for a short period of time to allow the molecules inside the asphalt to form a uniform network. Ceramic tiles holding the direct tension molds were heated in an oven with controlled temperatures specific to the Performance Grade (PG) of the binder. These heated ceramic tiles provided a means for the poured asphalt to stay fluid and to cool slowly and uniformly. The detailed method development and the sample preparation method are described. It was found that with this method, the failure stress of asphalt binder determined by the DT method increased as compared to those samples prepared without controlled cooling. With this sample preparation method, the variability of failure stress and failure strain values of the 6 specimens within the same run is usually less than 15% for the softer asphalt, e.g., 200/300 asphalt, and somewhat higher for the harder asphalt, e.g., 85/100 asphalt. The average results of the best 4 out of 6 specimens usually agreed with another run within 10-15%, regardless of asphalt type. The theory of this method is discussed. Important points to follow or to avoid during preparation of DT samples are discussed. The incorporation of the details of this sample preparation method in the DT procedure will lead to better agreement of direct tension results between different laboratories.

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01-2981 “Correlations Between Superpave Asphalt Stiffnesses and In-Service Pavement Performance”

One of the primary concerns in the State of Indiana is the early appearance of flexible pavement distresses. The early distresses may result in pavement failure and/or shorter pavement service life. The SHRP developed Superpave asphalt binder specifications are directed toward in-service pavement performance. Superpave binder tests and associated criteria were selected to control distresses that affect in-service HMA performance, specifically: permanent deformation, fatigue cracking, and low temperature thermal cracking. The Indiana Department of Transportation (INDOT) was interested in answering the question of whether or not the changes in in-service asphalt can be related to pavement distresses. Several factors were included in this study. The factors included the type and severity of distresses as documented by pavement condition surveys. Also, Superpave asphalt binder tests were conducted on the original and the recovered in-service binders. One important aspect of this study was how the changes of in-service asphalts can be related to distresses such as permanent deformation, fatigue cracking or low temperature thermal cracking. This study documents the relationship between in-service asphalt binder stiffnesses, as characterized by complex shear modulus or binder stiffness (G^*), and in-service permanent deformation and cracking, as characterized by PAVER deduct values. The study documents poor relationship between in-service binder stiffness and in-service permanent deformation or rutting. The study also documents a very good relationship between in-service stiffness and in-service cracking.

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01-3282 “Techniques for Determining Errors in Asphalt Binder Rheological Data”

A number of new methods for specifying asphalt binders, based on more complex theoretical approaches, have emerged in the past years and researchers are increasingly using these methods for studying asphalt binders. These methods require an increased degree of accuracy and precision in the laboratory data. This paper details a number of simple techniques that can be successfully used to identify errors in rheological data obtained for asphalt binders. Asphalt binders do not exhibit sudden changes in their behavior with respect to time or temperature. Therefore, any discontinuities revealed by the visual inspection of the test data in graphical format can be attributed to testing errors. A powerful yet simple tool in identifying potential problems with the DSR test data is the Black diagram. Black diagram is a plot of phase angle versus $\log |G^*|$ which, unlike master curves, does not require shifting of the data generated at different temperatures. However, pseudo Black diagrams should not be used with the BBR data due to the errors in calculating m-values associated with the use of the polynomial approximation. For the DT the secant modulus calculated from the stress-strain data provides a better tool in identifying errors in the test data.

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01-0392 “Effects of Sample Preconditioning on Asphalt Pavement Analyzer Wet Rut Depths”

Moisture damage of asphalt mixes, better known as stripping, is a major distress affecting pavement performance. AASHTO T 283 has historically been used to detect moisture susceptible pavements through the determination of a tensile strength ratio (TSR). Results from AASHTO T 283 have been inconsistent. As a result there has been increased interest in finding an alternative test. Preliminary indications reveal that loaded wheel rut testers, such as the Asphalt Pavement Analyzer (APA), have the potential to detect moisture susceptible mixtures. To date no standard test methodology has been developed. The objective of this study was to evaluate the effects of sample preconditioning on APA rut depths and to further evaluate the APA's suitability for predicting moisture susceptible mixtures. Eight different mixes from seven project sites were evaluated with the APA. Samples were tested using four different preconditioning procedures: dry, soaked, saturated, and saturated with a freeze cycle. The results were compared with TSR values as well as the methylene blue and sand equivalent tests. Samples were also tested using three additive states: no additive, with lime and with liquid anti-strip. The results were evaluated to determine the viability of using the APA to predict moisture damage. The results indicate that the APA can be utilized to evaluate the moisture susceptibility of asphalt mixes. Additionally, the results indicate that the harsher preconditioning of saturation and saturation with a freeze cycle did not result in increased wet rut depths. Using only dry and soaked conditioning appears to be adequate.

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01-2076 “Asphalt Permeability Testing: Specimen Preparation and Testing Variability”

The concern over asphalt mixtures allowing surface water to enter has led to an interest in developing a reliable permeability test. Over the last several years, several studies related to permeability testing have been conducted, and the American Society for Testing and Materials (ASTM) is currently developing a falling head test method to determine asphalt permeability. The Virginia Department of Transportation became interested in testing its pavements and using permeability as a design consideration. As a member of the ASTM task group, the author investigated the effect of sawing specimens, a technique that is often used to separate the asphalt layers. Sawing was found to cause a reduction in permeability. Since a falling head test might be used in acceptance and design specifications, it was important to determine its associated variability. Permeability variability was computed from test data derived from field cores and specimens prepared in the laboratory. Repeat tests by different operators indicated differences that warrant additional investigation.

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01-2763 “Evaluation of Factors Affecting Permeability of Superpave-Designed Pavements”

It can be expected that the life of a permeable pavement would be shorter than that of an impermeable pavement, due to deterioration of mix through water and air infiltration, and subsequent stripping and oxidation and hardening of binder. Recent work has indicated that coarse graded Superpave mixes can be excessively permeable to water at air void levels around 6 percent. The objectives of this study were to evaluate the permeability of Superpave designed mixes used by Maine Department of Transportation and determine the effect of gradation, lift-thickness, and in-place density on the permeability of these mixes. Five Superpave projects were selected for this study. These projects included coarse-graded 9.5 mm, 12.5 mm, 19.0 mm, and 25.0 mm nominal maximum aggregate size (NMAS) mixes and one fine-graded 9.5 mm NMAS mix. Based on the National Center for Asphalt Technology permeameter, a field permeameter was developed at the Worcester Polytechnic Institute (WPI) laboratory. This permeameter was used for testing at ten locations per project. One core was obtained at each of these test locations. The cores were used to determine in-place density at each of the test locations. Field testing was done at random locations, immediately behind the finish roller. Loose mixes were also obtained from each project. The loose mixes were compacted to 5 percent air voids, and to different thickness to evaluate the effect of thickness on permeability. On the basis of results obtained in this study, the following conclusions can be made: 1. Air void content (as measured by voids in total mix) of dense graded HMA has a significant effect on in-place permeability of pavements, 2. There is a significant effect of NMAS on the permeability of coarse-graded Superpave designed mixes. It was shown that at a given in-place air void content the permeability increased by one order of magnitude as the NMAS increased, 3. Samples with different thicknesses showed that there is a decrease in permeability with an increase in thickness. It is recommended that State DOTs consider designing mixes to be placed 100 mm below the pavement surface on the fine side of the maximum density line. By designing base mixes on the fine side of the maximum density line, these mixes could be made less permeable than coarse graded mixes at similar void levels and thus less susceptible to allowing moisture or moisture vapor to propagate upward through the pavement structure. This in turn should reduce the potential for moisture damage within pavement structures.

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01-2997 “Hydraulic Conductivity (Permeability) of Laboratory-Compacted Asphalt Mixtures”

A flexible-wall permeameter was used to study the hydraulic conductivity (also referred to as permeability) of asphalt mixtures commonly used in Wisconsin. Effects of saturation, hydraulic gradient, and side-wall leakage were studied to determine an appropriate testing procedure. The test procedure was then used to study how mixture design variables affect hydraulic conductivity. Four aggregate gradations were tested to develop relationships between hydraulic conductivity and volumetric properties. Two mixtures were also compacted to different heights (ranging from 37.5 mm to 110.0 mm) to evaluate how lift thickness affects hydraulic conductivity. Results of the tests indicate that the backpressure saturation procedure can be used to ensure that specimens are saturated and that the saturated hydraulic conductivity is measured. Sidewall leakage was eliminated by using bentonite clay as a sealing agent and the hydraulic gradient was selected based on a parametric experiment showing how gradient affects hydraulic conductivity. Tests on the various mixtures showed that a power law relationship exists between air voids content and hydraulic conductivity, but that the hydraulic conductivity also depends on the gradation. Lift thickness is also important, with lower hydraulic conductivity obtained with greater lift thickness at a given air voids content. The results show that hydraulic conductivity cannot be controlled only by limiting air voids and that a hydraulic conductivity test is necessary for a mixture design that includes hydraulic conductivity as a criterion.

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01-3443 “Aggregate Wear and Pavement Friction”

The laboratory program developed by the Michigan Department of Transportation for assessing the polishing potential of HMA coarse aggregates consists of an indoor wear track and a tire mounted friction tester. Aggregate test specimens are prepared by source and tested under the action of 4,000,000 wheel passes on the wear track. Surface friction is measured throughout the test and the measured value of friction at the end of the test is used to calculate an Aggregate Wear Index (AWI). The AWI is used as a measure of the polishing potential of the aggregate source tested. Field friction measurements from selected pavements were compared to the AWI values of the aggregates used to construct the pavement wear course. For pavements with lane average daily traffic (LADT) levels below 2,000, AWI values did not influence the resulting pavement friction value over time. For pavements with LADT values above 2,000, AWI values were found to correlate with pavement friction with higher AWI values corresponding to higher pavement friction.

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01-2790 “Some Characteristics of Foamed Bitumen Mixes”

An experimental work was recently carried out within the School of Engineering, Griffith University. The research involved characterisation of a range of foamed bitumen mixes in the

laboratory. Both Marshall compactor and servo-controlled gyratory compactor were used in specimen preparation. For the determination of resilient modulus, a closed-loop servo-controlled dynamic loading system was utilised. It was found that Marshall compaction method produced higher resilient modulus values compared to the gyratory compaction. Moreover, Marshall compaction showed an optimum bitumen content associated with the maximum density. The Australian made gyratory compactor produced specimens which were less dependent on bitumen content but had higher density values. In addition, the temperature used to cure the specimens was also examined. An accelerated curing temperature of 60°C was found to be too high, resulting in an overestimation of the resilient modulus compared with specimens cured at an ambient temperature. Furthermore, the resilience test results also showed that the resilient modulus was significantly affected by the induced strain; with higher strain, a lower modulus resulted. Due to the relatively low bitumen content as well as the use of lime additive, temperature variation affects the resilient modulus of foamed bitumen mixes to a lesser degree as compared to typical asphalt mixes.

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01-3097 “Field Aging Effects on Fatigue of Asphalt Concrete and Asphalt-Rubber Concrete”

This paper describes a study to investigate the influence of field aging on the fatigue performance of asphalt concrete and asphalt-rubber concrete. Two California mixes were investigated: 1) Conventional asphalt concrete dense-graded mix (CAC-DG) and 2) Asphalt-rubber hot mix gap-graded (ARHM-GG). Laboratory fatigue tests were conducted on beam specimens obtained from a 10-year old pavement section in southern California. Both stiffness and fatigue were determined using controlled-strain fatigue beam tests performed at 22°C and -20°C. Results were compared with previously published data for the original (unaged) materials. Stiffness and fatigue data were also used in pavement analysis in order to assess the influence of aging on predicted fatigue performance. Results indicate that field aging reduced the beam fatigue resistance of CAC-DG and to a lesser extent, ARHM-GG. Aging effects on beam fatigue life were more severe at -20°C than at 22°C. The influence of aging on predicted pavement fatigue life depends not only on the stiffness of the mix and its fatigue properties but also on the stiffness or layer moduli of the pavement components. For new pavement construction and overlaid pavement sections, longer fatigue life predictions were obtained for ARHM-GG than CAC-DG, for both aged and unaged conditions. Aging of the CAC-DG could be detrimental to pavement fatigue. In comparison, aging of ARHM-GG showed increased fatigue life performance.

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01-3122 “Effects of Short-Term Oven Aging on Volumetrics and Selection of N-Design”

This paper presents the field evaluation of the impact of flat and elongated particles on the breakdown in the mixture during construction. This is a supplement to the initial paper examining volumetric changes induced by precisely controlled Flat and elongated particles in gyratory compaction. Samples were taken from the quarry, plant stockpile, truck, pavement behind paver, and after the rollers on several projects in Illinois. The samples were examined for

gradation changes produced at any point in the construction cycle. Aggregate wear during mix production was evident. There appears to be limited breakdown during compaction for normal lift thickness, and no relation to the presence of flat and elongated particles was noted. Thin lift construction demonstrated excessive breakdown during compaction.

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01-3318 “Development of Performance-Based Mix Design for Cold In-Place Recycling of Asphalt Mixtures”

The high cost and environmental impact of pavement rehabilitation has led to an increase in the use of Cold In-Place Recycling (CIR) as an effective alternative to other rehabilitation strategies. However, currently there is not a universally accepted or standard mix-design for CIR.

Therefore, the project is being undertaken with the objective to develop a performance-based mix-design procedure for CIR through laboratory evaluation and limited field verification. The present project focuses on partial-depth CIR using asphalt emulsions as the recycling agent. After evaluating the modified Marshall mix-design recommended by the AASHTO Task Force No. 38, a new volumetric mix-design has been developed utilizing the Superpave gyratory compactor and technology. It requires that specimens are prepared at densities similar to those found in the field. It also suggests that specimens should be cured at 1400 F for 24 hours. This will allow for the most consistent specimens, while at the same time, most effectively utilizing the time of laboratory personnel. The performance of CIR mixtures prepared and constructed in accordance with the new mix-design is being evaluated in the laboratory as well as in the field. The resistance characteristics, in relation to rutting and fatigue cracking, were predicted using the computer program, VESYS. Creep compliance and strength were determined using the Indirect Tensile Tester (IDT) to evaluate the resistance against the low-temperature cracking.

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01-0140 “Gradation Effects on Hot-Mix Asphalt Performance”

The effect of gradation on hot mix asphalt (HMA) performance has long been a contentious issue. One objective of National Pooled Fund Study No. 176 was to evaluate the impact of gradation on the rutting performance of HMA mixture. To this end twenty-one Superpave mixtures were designed employing a range of materials, aggregate nominal maximum aggregate sizes, and gradations typical of those used throughout the United States. A suite of tests that included both laboratory and prototype scale loading were then used to evaluate the permanent deformation characteristics of the mixtures. Analysis of the data revealed that adequate performance could be obtained with mixture gradations plotting above (ARZ), through (TRZ), and below (BRZ) the restricted zone. Laboratory tests suggested that ARZ and/or TRZ gradations might provide better deformation resistance than BRZ gradations. However, prototype scale accelerated pavement testing did not show any clear trends in performance relative to gradation alone with respect to the restricted zone. This means that the restricted zone alone is not adequate to characterize gradation to ensure acceptable rutting performance and should therefore be omitted from Superpave specifications

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01-0141 “Impact of Gradation Relative to Superpave Restricted Zone on Hot-Mix Asphalt Performance”

Significant controversy has revolved around the Superpave gradation specifications, in particular the restricted zone, since the completion of the Strategic Highway Research Program (SHRP). The reason for this is simple, dense-graded mixtures which encroach on the restricted zone had historically provided good performance prior to SHRP. However, current Superpave guidelines recommend that gradations passing through the restricted zone not be used. The objective of this paper is to provide a synopsis of recent research related specifically to the impact of the Superpave restricted zone on performance of hot mix asphalt (HMA). The evolution and purpose of the Superpave restricted zone are presented along with findings of both recently completed and on-going research. Studies involving laboratory and full scale accelerated performance tests of mixtures with gradations plotting above (ARZ), through (TRZ) and below (BRZ) the restricted zone were considered. The research reviewed clearly suggests that good performance can be achieved with fine-graded (ARZ and TRZ) mixtures and that no relationship exists between the Superpave restricted zone and HMA rutting or fatigue performance. Based on this it is suggested that the restricted zone recommendation be eliminated from the Superpave volumetric mixture design specifications.

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01-2051 “Effect of Mix Gradation on Rutting Potential of Dense-Graded Asphalt Mixtures”

The objective of this study was to evaluate the effect of mix gradations, both complying with and violating the Superpave restricted zone, on rutting potential of hot mix asphalt (HMA) mixtures. Superpave gyratory samples of mixes with granite, limestone, and gravel aggregates were used. The following gradations were used: gradation above the restricted zone, gradation through the restricted zone in close proximity to the maximum density line, and gradation below the restricted zone. Rut tests were conducted at 64 C with the Asphalt Pavement Analyzer (APA) under 689 kPa contact pressure and 45.2 kg wheel load. Rut depths were measured at the end of 8,000 cycles. Repeated shear tests at constant height were also conducted with the Superpave shear tester (SST). Statistical analysis of rut data generally indicates a significant difference between rut depths obtained in mixes using different aggregate types and different gradations. The gradations violating the restricted zone did not necessarily give relatively higher rut depths compared to the gradations in compliance with the zone.

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01-2786 “Effect of Aggregate Gradation on Permanent Deformation of Superpave Hot-Mix Asphalt”

The restricted zone in aggregate gradings is one of the most controversial components of the Superpave mix design process. The restricted zone was adopted in order to reduce premature

rutting in hot mix asphalt (HMA) pavements. The validity of the restricted zone requirement has been questioned by both the owner agencies and the paving and aggregate industries. The purpose of this paper is to examine the effect of the restricted zone on pavement rutting. Four different types of aggregate were studied: crushed granite, crushed limestone, partially crushed river gravel, and mixture of partially crushed river gravel as coarse aggregate with natural sand as fines. For each aggregate, HMA mixtures were designed using three different gradations: above the restricted zone, through the restricted zone, and below the restricted zone. Mixtures were tested using Superpave Shear Tester (SST). Four different tests were performed: simple shear at constant height, frequency sweep at constant height, repeated shear at constant stress ratio, and repeated shear at constant height. All twelve mixtures were also tested with Asphalt Pavement Analyzer (APA) to evaluate the rutting potential of those mixtures. From the analysis of the test results of SST and APA, we conclude that there is no relationship between restricted zone and permanent deformation. Further, these gradings passing below the restricted zone most often exhibited the greatest permanent deformation. Furthermore, hardly ever did a gradation through the restricted zone yield the highest permanent deformation.

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7. Cement and Concrete

01-3188 “Michigan's Approach to a Statewide Investigation of Material-Related Distress in Concrete Pavements”

This paper describes an approach being used to identify to what degree Michigan roads are affected by materials related distress (MRD) and methods being used determine what distress mechanisms are at work. The approach includes detailed visual inspections, field sampling, and laboratory analyses on selected projects to determine the distress mechanisms. It was concluded that although the majority of Michigan's concrete surfaced pavements were unaffected by MRD, a significant percentage of the concrete pavement network, over a broad geographical region, had distress manifestations consistent with the occurrence of MRD. These manifestations included staining in the vicinity of joints and cracks, D-cracking, joint/crack deterioration, progressive map cracking with exudate, scaling, and corrosion of embedded steel. Fifteen pavement sections were visually assessed, tested using a falling weight deflectometer, air permeability was measured, and core samples were taken and analyzed. The results of this process revealed that the presence of MRD affected the mechanical properties of the pavement concrete. Petrographic analysis determined that a large number of different MRD types are at work in some of Michigan's concrete pavements, including aggregate freeze-thaw deterioration, corrosion of embedded steel, and alkali-silica reactivity. This work also found that dedolomization of certain carbonate aggregates and sulfate attack may also pose a problem. With this knowledge, the Michigan Department of Transportation is able to better address the cause of distress when selecting repair options and prevent MRD from affecting future concrete pavements.

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01-0255 “Influence of Rapid Chloride Permeability Test Parameters on Results of Silica Fume and Non-Silica-Fume Concrete”

During bridge construction, an early prediction of the permeability of the concrete overlay is always desirable. However, the field-extracted Rapid Chloride Permeability Test (RCPT) specimens often have a thickness that differs from the ASTM (AASHTO) standard one (50.8 mm). The need may arise to test specimens at earlier age for an early prediction of the overlays' performance. It has also been documented that thinner specimens may exhibit an increase in temperature during the RCPT progress. This study investigates the impact of the RCPT Test parameters on concrete made with and without silica fume. Silica fume and non-silica fume concrete specimens were prepared with two compaction techniques. Test specimens were also prepared at various thickness and subjected to the rapid chloride permeability test. The coulomb charge passing each specimen was recorded every thirty minutes during test progress. A supplementary group of specimens was prepared six months later using same constituents to strengthen some of the findings. Results reveal that the relation between the coulomb charge and specimen thickness is non-linear. Also, strong indications exist for a possible prediction of the 56-day coulomb value for the silica fume concrete based on 28-day results and of a more or less trend for the coulomb value with time. Results indicate that the relation between the coulomb charge and time while testing is in general a linear one; at least for good quality concrete. Specimen compaction technique seems to have little impact on the measured coulomb charge.

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01-0363 “Performance Characteristics of Synthetic Synergy Fiber-Reinforced Concretes: Strength and Toughness Properties”

This paper presents the results of an experimental investigation about the performance characteristics of concrete reinforced with a newly developed synthetic synergy fiber. A number of three-dimensionally reinforced concrete specimens (beams and cylinders) using four fiber dosages (0.5, 1.0, 1.5, 2.0 percent by volume) had been cast and tested to evaluate the strength and toughness characteristics. The strength tests included the compressive strength, flexural strength (modulus of rupture), first crack strength, and impact strength. The toughness properties evaluated were modulus of elasticity, the toughness indices I5, I10, I20, I30 and residual strengths calculated according to ASTM C1018 test procedure, and the flexural toughness factor (JCI) and the equivalent flexural strength calculated according to the Japanese Society of Civil Engineers standard specifications. A new test method (ASTM C1399-98) was also used to determine the average residual strength of the concretes reinforced with the four different synthetic synergy fiber dosages. The fiber reinforced concretes were mixed, placed, consolidated, finished and cured under identical conditions. There was a significant increase in the flexural strength and a slight increase in the first crack strength as the fiber content was increased from 0.5 to 2.0 percent by volume. The ASTM toughness indices and the Japanese toughness factors and equivalent flexural strengths were also significantly increased as the fiber content increased. There was also a tremendous increase in impact strength for an increase in fiber content. Very high average residual strengths (ARS) (ASTM C1399) were obtained and the ARS values increased as the fiber content increased.

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01-0109 “Wisconsin Department of Transportation Experience with High Fly Ash Content and Reduction of Fly Ash Replacement Ratio in Concrete Pavements”

In the mid 1990's, shortages and price increases of portland cement generated interest in determining the durability and constructability of PCC pavements with higher fly ash contents than the 15-20% typically allowed by most states. WisDOT constructed pilot projects with test sections with up to 40% Class C fly ash content, and performed extensive laboratory testing to evaluate the engineering properties of these mixes. WisDOT also subsequently evaluated the effect of reducing the fly ash/cement replacement ratio from the traditional 1.3:1 down to a 1:1 ratio. The test results indicated improvement in the concrete properties of long term compressive strength, rapid chloride permeability, drying shrinkage, freeze thaw durability and scaling resistance with increasing Class C fly ash content up to 30% in comparison with control WisDOT Grade A concrete with straight portland cement. Mixes with 40% fly ash content showed significantly increased scaling in comparison with control Grade A concrete. Reduction of the fly ash / cement replacement ratio from the traditional 1.3:1 ratio used by WisDOT to a 1:1 ratio did not cause any decrease in concrete quality in terms of the concrete properties cited above. Fly ash mixes with a 1:1 replacement ratio and 30 or 40% fly ash content had reduced compressive strength at ages of 3 and 7 days in comparison with control Grade A and Grade A-FA mixes, which would result in a typical delay of 1 day in reaching the compressive strength required for opening a concrete pavement to traffic. WisDOT now allows up to 30% Class C fly ash content at a 1:1 replacement ratio for PCC pavements.

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01-2939 “Concrete Maturity Progress: Survey of Departments of Transportation”

This paper provides the results of a concrete maturity survey that was distributed to 50 departments of transportation in the summer of 2000. The purpose of this paper is to display nation-wide advances and practices relating to concrete maturity and its applications for predicting in-situ portland cement concrete strength. All recipients were then asked to forward the survey to relevant persons within their department. Information such as research and DOT project details, method of maturity determination, state applications, and general attitudes toward the concept was requested. Representatives from 41 states replied to the 12-question survey. Results revealed that about 73% of those states that responded either have conducted, or are currently involved in at least minor research with the concept. Furthermore, approximately 29% of the represented states have protocol or specifications governing the use of this developing technology. Representatives throughout the United States have reported that maturity is being used to predict critical strengths for actions such as pavement opening to the public, pavement opening to construction traffic, structural acceptance, and formwork removal for bridges, pavements, and other highway structures.

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8. Mineral Aggregates

01-0152 “Permanent Deformation Behavior of Granular Materials and the Shakedown Theory”

The paper describes the accepted understanding of the shakedown concept. It then describes the results of several repeated load triaxial tests performed on crushed rock aggregates at different stress levels for a large number of repetitions of loading. The development of the resulting permanent deformation which accumulates with the repeated loading is described and compared with the types of responses usually described by the shakedown approach. It is shown that the existing shakedown approach can describe some, but not all, of the observed responses. Thus a modified set of possible responses is defined in shakedown terms and some explanation of the differences from the conventional approach are given. It is concluded that the method of description could give a powerful material assessment and pavement design tool for the engineering of unbound pavement bases. A design chart is derived from the data described, so as to illustrate a possible design approach.

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01-2481 “Stress Path Testing for Proper Characterization of Unbound Aggregate Behavior”

Realistic pavement stresses induced by moving wheel loads were examined in granular base layers and the important effects of rotation of principal stress axes were indicated for a proper characterization of unbound aggregate behavior. Granular material resilient moduli are commonly determined at the centerline of the static wheel loading without taking into account the effects of moving wheel loads and the constantly rotating field principal stress states. Differences between field and laboratory applied stress states were shown by comparing the field stresses simulated using a nonlinear axisymmetric finite element program GT-PAVE with the stress states commonly used in the standard test procedure, AASHTO T294-94 (1). Three sets of complete triaxial test data obtained from testing aggregates under various realistic in-situ stress paths due to moving wheel loading were analyzed (2,3,4). Seven different granular material modulus models were developed based on the experimental test data to include the applied mean stress, applied shear stress, and the slope of stress path loading. Due to the complex loading regimes followed in the laboratory tests, characterization models that analyzed simultaneously the static and dynamic components of the applied mean and deviator stresses produced the greatest accuracy. The model that considered the stress path slope variations predicted the best stress path dependency of aggregate behavior due to moving wheel loads as obtained from the test data of Tutumluer and Seyhan (4). Such advanced models that allow for the effects of principal stress rotation better describe the granular material behavior under the actual field loading conditions.

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01-2485 “Cross-Anisotropic Characterization of Unbound Granular Materials”

The mechanical properties of granular materials are nonlinear and stress dependent. Several researchers have identified cross-anisotropy as a better model by which to characterize granular materials. However, determination of cross-anisotropic material properties from conventional triaxial setup has been extremely difficult. A laboratory testing protocol has been developed based on theories of elasticity and the system identification method. The testing protocol is efficient and precise. Material properties determined with the testing protocol satisfy elasticity requirements. The cross-anisotropic material properties of four granular materials were determined. The material properties were used as input into a finite element program, modified to accept these properties, to determine pavement response. It was observed that nonlinear cross-anisotropic modeling eliminates tension zones predicted by isotropic models in granular layers. This is an important step since the presence of such tensile zones have required adjustments in layered pavement models which seek to predict pavement performance based on response parameters.

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01-2706 “Study of Failure in Cohesive Particulate Media using Distinct Element Method”

Permissible stresses or strains in pavement layers constitute the empirical part of the Mechanistic-Empirical method. Whereas it appears to be possible to predict the actual stresses or strains under a load (the mechanistic part) reasonably correct, there is much uncertainty with respect to the permissible values. This paper explores some of the possibilities that the Distinct Element Method (DEM) raises, for calculating permanent deformation and failure in pavement materials. The study is limited to two dimensions and makes a number of assumptions that may not be strictly correct. The results should, therefore, only be considered as indicative of some of the possibilities of DEM. After a brief description of DEM, the paper presents tests to failure of two different samples of elements, with different element shape and size distribution, and thus different resulting pore volume after compaction. For one of the samples, seven different stress paths are followed to failure (pure tension, uniaxial tension, pure shear etc.). From this a non-linear relationship between the permissible shear stress and the hydrostatic stress is deduced. It is demonstrated that using this relationship as the basis for the kinetic equation in Continuum Damage Mechanics, can lead to cracking from the top as well as from the bottom of a slab. Finally DEM is used to study the effect of repeated loading on permanent deformation and failure, for one of the samples. The effect on permanent deformation was found to be pronounced, whereas the effect on failure was much more uncertain, although there could be some indication of fatigue.

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9. Pavement Management and Rehabilitation

01-2133 “Roughness Progression Model Based on Historical Data: Case Study from Brunswick”

Prediction models are vital to the decision-making process in pavement and infrastructure management. Roughness progression, in particular, is used for estimating service life of pavement sections, assessing technically feasible treatments, and more importantly, for

predicting implications to life-cycle user costs, and hence serviceability of the facility to users. Development of reliable prediction models has been impeded by lack of historical data. Limited modeling approaches has considered climatic factors in historical roughness progression models. The paper presents the development of roughness progression model based on the province-wide historical data in New Brunswick. The model formulation identifies the interrelated effects of traffic loading, and climatic factors - annual precipitation, and frost measured by degree-days below -200C. Cluster analysis was employed to assign climatic factors to the historical roughness data. Several incremental annual roughness models were formulated and tested. The findings demonstrate the formulation of IRI progression models relating traffic loading and climatic factors based on historical data.

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01-2970 “Illinois's Experience with Pavement Analysis and Management Systems”

The Illinois Department of Transportation (IDOT) has undergone several phases in developing and implementing pavement management and analysis systems. This paper discusses the lessons learned from the DOT's decades of experience, as well as the future directions of these systems in Illinois. In the late 1980s, IDOT developed the Illinois Pavement Feedback System (IPFS) to store detailed current and historical data on Interstate pavement sections. IPFS data have been used to conduct numerous engineering studies that helped in evaluating pavement design, construction, and rehabilitation practices. These data also provided the ILLINET pavement management system (PMS) with the database to answer ‘what if’ questions to help improve management strategies, budgeting and to produce optimized multi-year rehabilitation programs. The Illinois Roadway Information System (IRIS) was developed in the late 1980s to store current year data on both Interstate and non-Interstate pavements. IDOT is currently developing a geographic information system (GIS) based PMS that uses current and historical data for both Interstate and non-Interstate pavements, employs engineering and economic analysis procedures, and runs on a personal computer. The data, derived from both the IPFS and IRIS, include pavement construction, rehabilitation, and traffic data. In addition, the system is equipped with prediction models that can predict pavement and traffic conditions for the future. Historic, current, and future traffic and pavement data can be displayed at the touch of a button. It is easy to learn and use, and requires no experience in GIS. IDOT anticipates that it will save considerable resources, in terms of both staff time and improved decision making.

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01-3498 “Development of GIS Implementation Plan for Texas Department of Transportation PMIS”

Integrating a GIS with an existing pavement management system (PMS) such as the TxDOT PMIS is not as simple as merely installing a new piece of software into the existing PMS and then operating it. A successful GIS implementation involves not only the information technologies themselves but also other elements, such as personnel and their GIS skills, the organizational structure within which they work and the institutional relationships that govern the management of information flow. All of these elements need to be managed in an interactive

manner. GIS can serve as a platform for integrating various types of data, systems, and technologies. Due to the nature of rapid changes in GIS and related information technology, a well-developed GIS implementation plan is essential. This paper presents the development of a comprehensive and practical implementation plan of using GIS to enhance the pavement management practice in TxDOT. As the basis of the implementation plan, a “three-stage implementation” concept was used to assess the current practice, define the visionary system, and identify the intermediate solutions. The paper also presents various key issues and aspects that are important to the successful implementation of GIS for pavement management.

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01-3517 “Alaska Airports Pavement Management Program: Case Study of Implementing Micro-PAVER at 48 Airports in Alaska”

The State of Alaska is nearly one quarter the size of the lower 48 states. This state has 1,112 designated airports, seaplane bases, and aircraft landing areas. Alaska is unique in that road systems to many communities do not exist. The aviation system in Alaska links virtually all communities, providing the only dependable year-round transportation access. Alaska Department of Transportation & Public Facilities (ADOT&PF) owns and operates the majority of these public airports. Of the 286 public airports, local municipalities own and operate a scarce 8%. ADOT&PF develops, maintains, and operates most of the 49 paved airports in Alaska. This level of state involvement in airport operations creates a unique opportunity for a long-term study of the performance of airport pavement throughout Alaska. In this paper, we present the preliminary findings from our implementation of PAVER, our use of the Pavement Condition Index (PCI), and our assessment of maintenance needs for the airports in Alaska. We focus on specific issues we found critical to the success of the project. Our experience in implementing PAVER in 48 airports may prove an instructive case study for other airport managers and operators.

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01-0198 “AASHTO Drainage Coefficients for Flexible Pavements”

A method for determination of American Association of State Highway and Transportation Officials (AASHTO) drainage (m) coefficients for flexible pavements is presented. In essence, m-coefficients were developed as ratios of the layer coefficients of the AASHO Road Test granular base material under any given drainage and climate condition to the layer coefficient of the Road Test base material under Road Test site conditions. The layer coefficients were calculated from resilient moduli determined for varying conditions by use of elastic layered analysis. The moduli were varied by changing subgrade and base moisture conditions for any given time of year. The base material moisture sensitivity (effect on theta model constants k, and k₂) was determined, in part, by the resilient modulus laboratory testing of granular materials. The result of the above analysis was the creation of a set of tables which guides the designer to a choice of m-coefficients. The new m-values can be used to provide a rational measure of the influence of pavement drainage on pavement performance.

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01-0422 “Design, Construction, and Maintenance Guidelines for Porous Asphalt Pavements”

Oregon has been using open-graded hot-mix on its roadway system since the late 1970s. Because of the performance of these early jobs (and the continued good performance of these mixes), open-graded hot-mix has been the preferred choice for a surface course on Oregon highways. This paper describes the following with respect to the use of these mixes in Oregon:

- 1) Historical perspective
- 2) Design, including both mix and structural design
- 3) Construction, including QC/QA considerations
- 4) Maintenance and rehabilitation practices with porous pavements

The continued success of the use of these materials, both from a performance and public acceptance standpoint, suggests they will be the pavement of choice in Oregon for the foreseeable future.

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01-2817 “Flexible Pavement Design in Michigan: Transition from Empirical to Mechanistic Methods”

Michigan is rapidly moving toward the adoption and use of mechanistic-empirical design for flexible pavements. To facilitate the transition from empirical to mechanistic design methods, the Michigan Department of Transportation (MDOT) contracted the development of the software named the Michigan Flexible Pavement Design System (MFPDS). This software provides a holistic framework for the analysis and design of flexible pavements. MFPDS includes modules for AASHTO design, linear and nonlinear mechanistic analysis, backcalculation, and mechanistic design (including overlay design). The software incorporates enhanced elastic layer and finite element models within an easy-to-use Windows user-interface, and can be used on a routine basis. New response models to predict fatigue life and rut depth also were developed as part of this effort and are included in MFPDS. New pavements and overlays may be designed to limit predicted distresses to user-specified threshold values. The features of the mechanistic analysis and design approaches used are presented.

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01-0193 “Assessment of Hot-in-Place Recycling Process on US-175”

This paper documents the effectiveness of a recycle-in-place (Remixer) process on US175, using results from GPR, FWD, PSPA, condition surveys (crack mapping) and laboratory testing. FWD and PSPA results indicate that the remixed sections are stiff, and the deflection values are in the range typically observed in the Interstate Highway system. This recycling process removes 38mm of AC and adds 25% new material, for a finished thickness of 48mm. The stiffness of the overall pavement structure was not significantly increased by the Remixer process, as the studied pavement sections were already very stiff. Laboratory testing indicated that the Remixer process yields a low penetration number, meaning the material is relatively hard and brittle. Based on the results from FWD, PSPA, and laboratory testing, the pavement structure of the Remixer section possesses sufficient strength to resist rutting. PSPA and Hamburg Wheel-Tracking test results

show that the Remixer yields a stiffer material than a conventional overlay. The pavement structure is stiff and should resist rutting. Many reflected cracks have been observed in the Remixer sections. Crack-seal may need to be applied after 1-2 years (or as soon as those cracks open enough to apply crack-seal) to prevent water from entering the pavement layers. The cause for the next major rehabilitation to US175 will mainly be related to reflected cracking. It is concluded that the Remixer treatment with 75% RAP is not a viable treatment in cases where there is a problem with cracking. It is suggested that for US175, the RAP reclaim content should be lowered to approximately 30%, using lower-viscosity asphalt to reduce cracking.

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01-2147 “Thin Bonded Concrete Overlays in Illinois: Preliminary Report on Performance”

In recent years, two bonded concrete overlays (BCO) have been constructed in Illinois. The first was constructed in 1994 - 1995 on a section of Interstate-80 (I-80), east of Moline, Illinois. The second bonded concrete overlay was placed in 1996 on a section of Interstate-88 (I-88), further east of Moline. Both the I-80 and the I-88 BCO sections were placed on 203-mm (8-inch) thick continuously reinforced concrete pavements. The I-80 BCO is 102 mm (4 inches) thick and includes six experimental sections with various percentages of microsilica added to the standard mix design and different bonding agents used between the original pavement and the BCO. The I-88 BCO is 76 mm (3 inches) thick and includes two experimental sections involving different surface preparation methods prior to BCO placement. This paper summarizes the performance of the bonded concrete overlays to date. Visual distress surveys were conducted annually on selected test sections of the I-80 and I-88 overlays. The I-80 and I-88 overlays were also tested annually for International Roughness Index values. Condition Rating Surveys were conducted every two years on I-80 and I-88 to define the overall condition of the pavement. The results of the tests and surveys are included. Significant differences have been observed in the performance of the I-80 and I-88 bonded concrete overlays. While the I-88 BCO has been performing very well, the I-80 BCO, particularly the overlay in the eastbound direction, was in need of rehabilitation only a few years after construction.

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01-2200 “Overlay Performance in Canadian Strategic Highway Research Program's LTPP Study”

The Canadian Long Term Pavement Performance (C-LTPP) study, initiated in 1989, involves 65 sections in the 24 provincial sites that received rehabilitation comprising various thicknesses of asphalt overlays. This paper describes the impacts of the various alternative rehabilitation treatments on pavement performance in terms of roughness progression under comparative traffic loading, climate, and subgrade soil conditions. Roughness trends are the main subject of the C-LTPP study. Progression of roughness for thin overlays (30-60 mm) is significantly higher on a national basis than for medium (60-100 mm) and thick (100-185 mm) overlays. Factor effects, including climatic zone, subgrade type and traffic level were also evaluated. Some findings are that: (a) in wet, high freeze zones, thinner overlays show a higher rate of roughness progression than thicker overlays, regardless of subgrade type; (b) in dry, high freeze zones, roughness progression for medium and thick overlays is relatively small; (c) in wet, low-freeze zones, thinner overlays combined with a fine subgrade show the highest rate of roughness

progression, (d) traffic, in terms of Equivalent Single Axle Loads (ESALs) seemed to have a limited effect for all the above; this was attributed largely to all the traffic essentially falling into one level and the 200,000 ESALs per year designated as the boundary between low and high traffic levels. In conclusion, the C-LTPP experiment has provided valuable information on roughness trends after only eight years of observations. The methodology developed in this study for pavement roughness evaluation can be applied to performance trends analysis of other measured LTPP data.

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01-2271 “Long-Term Field Performance of Crack-and-Seat Rehabilitation Strategy”

In 1993 and 1994, Florida initiated the construction of seven crack-and-seat projects on different parts of I-10. The primary intent was to obtain long-term field performance data to allow for a more rational assessment of the effectiveness of the crack-end-seat technique in minimizing reflection cracking in asphalt overlays. As a supplementary strategy to further reduce reflective cracks, the experiment also included an asphalt-rubber membrane interlayer (ARMI). The performance of a total of 14 four-lane sections was monitored, at the time of construction and periodically thereafter. After approximately seven years of service, all the projects still have very good to good ride characteristics while the majority of the sections exhibited less than 6-mm (0.25 in.) of rutting. In addition, the overall performance of the Florida crack-and-seat projects is still highly rated in terms of cracking and patching. Visual surveys indicated that the amount of cracking was still relatively insignificant in most of the tests sections. All the present performance indications are that the crack-and-seat technique, when used in conjunction with an ARMI as in this experiment, could be an effective rehabilitation strategy of PCC pavements.

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01-2459 “Structural and Performance Characteristics of Granular Overlays in Washington State”

The granular overlay system is an alternative type of overlay for rehabilitating mostly low-volume, rural pavements. The overlay consists of a layer of densely compacted, crushed stone overlain by a generally thin surface layer (either a bituminous surface treatment or asphalt concrete). The Washington State Department of Transportation (WSDOT) continues to be interested in these roadways as performance has been better than expected with rehabilitation survival lives doubling from 7 to 14 years with the addition of granular overlays. Previous attempts to backcalculate layer moduli and understand the structural characteristics of granular overlays were limited due to uncertainties associated with layer thicknesses. With known layer thicknesses obtained from four sites, backcalculation of granular overlay pavements were possible. These moduli along with straightforward performance information are used to characterize granular overlays.

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01-0319 “Study of Rut-Depth Measurements”

From time to time, Districts have reported that they see ruts on their highways, but not all ruts are reflected in the PMIS data. This study provides an opportunity to compare results from the rut-bar to those obtained by other devices and to determine why the rut-bar measurements are different from field observations. Also, it would be beneficial to upper management if the source or cause of the rutting could be identified based on an evaluation of the shape of the profiles collected by next-generation rut-bar vehicles. Trenching data was collected on 10 different pavements located in Texas. Rut depths were measured with several devices before a trench was cut across the traffic lane. Careful measurement of each pavement layer was performed to help determine the amount of rutting in each layer. It was found that although there may be 50mm of rut as measured by a straightedge, the rut-bar sometimes measured no rutting. The rut-bar yields zero rut depth in 10% of cases where there are ruts deeper than 16mm. This is mainly due to limitations of the current rut-bar setup, specifically the sensor spacing and rut-bar length. When a profile is collected accurately, its shape alone is still not adequate to determine the layer in which rutting occurred. Material-related problems such as bleeding yielded wide-basin rutting that appears to be base or subgrade rutting if it is observed from the profile alone. The profile has been found inadequate to determine the major source of rutting, except when there is a clear dual-wheel rut. This is a good indication of rutting isolated to the AC surface layer. The sensor spacing recommended for routine data collection is 100mm. Analysis of the data shows this spacing to be 95% accurate and capable of capturing dual-tire ruts.

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01-0349 “Application of Dynamic Cone Penetrometer in Evaluation of Base and Subgrade Layers”

DCP is one of the lowest-cost alternatives for characterization of pavement layer qualities. It is also fairly easy to collect and analyze DCP data. The DCP is not popular in the pavement engineering community, partly due to the lack of a solid correlation between DCP results and modulus values. In this study, over 60 DCP tests have been conducted on two APT test pavements to assess the validity of empirical equations proposed in previous literature to compute layer moduli from DCP data. The effect of testing procedure on the DCP values was studied, and the DCP moduli were compared with those from FWD-MDD and laboratory tests. It is found that the DCP values are dependent on the test procedure, which affects results by at least 10%. If there is an AC layer, it is preferable to conduct DCP tests through a drilled hole. A sample size of 6 is recommended for routine characterization of base and subgrade layers, because this number would achieve a 95% of confidence level and an error of estimate of less than 20%. DCP moduli using adopted equations yielded results compatible with those from FWD-MDD tests. Those equations have been recommended to TxDOT for further evaluation and use in routine analysis. The laboratory-determined subgrade moduli were only slightly higher than those from DCP and FWD-MDD tests. No correction factor is required for the FWD-backcalculated moduli to match the laboratory moduli.

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01-2259 “Procedure for Using Falling Weight Deflectometer to Determine Structural Layer Coefficients for Flexible Pavement Materials”

The American Association of State Highway and Transportation Officials (AASHTO) pavement design model is one of the most widely used empirical design models for flexible pavement design. A factor complicating its utility is the use of an abstract quality, in this case the structural number (SN), to quantify the strength of the total structure. A consequence of the SN is the need for structural layer coefficients (a_i) to characterize the component materials of the pavement structure. These layer coefficients are difficult to assess directly. However, this paper presents a method for determining layer coefficients using a falling weight deflectometer (FWD) that are representative of the in situ behavior of the pavement materials. This method is based on a model provided in the 1993 edition of the AASHTO Guide for Design of Pavement Structures for assessing the effective SN. When the FWD tests a pavement structure in an incremental fashion, for instance at the interface of each distinct material, the difference in the effective SNs successively determined may be used to determine the structural layer coefficient for the material bounded by any two interfaces. The Vermont Agency of Transportation (VTrans) has established a procedure using FWD data, and the AASHTO effective SN model, to characterize structural layer coefficients for Vermont pavement materials: 0.070 for sand subbase, 0.139 for crushed stone subbase, 0.384 for ACC base, 0.580 for ACC binder, and 0.606 for ACC surface. However, the structural layer coefficients determined by this method are only useful if they represent performance conditions in the final structure. A statistical comparison of these findings with an elastic layer simulation of the final structure was performed. The statistical findings of this study indicate $p > 0.05$ when comparing FWD derived layer coefficients to layer coefficients estimated for the final structure using an elastic layer simulation.

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01-0203 “Verification of Network Level Pavement Roughness Measurements”

In 1997, the Ministry of Transportation of Ontario (MTO) switched to IRI measurements as an indicator of network-level pavement roughness within their pavement management system. Measurement of pavement roughness or ride quality in terms of International Roughness Index (IRI) can be performed using different measuring devices. However, the results of individual measurements on the same pavement section may vary significantly due to the use of different measuring devices, varying longitudinal profiles and measuring speeds. Recent evidence obtained by MTO indicates that the longitudinal profile measurements provided by different measuring devices contain systematic differences ranging from 0.1 to 1.0 m/km. Such IRI differences cause significant concerns for agencies that contract out network level roughness measurements on yearly basis. Through the process of verifying and comparing longitudinal profile measurements using different profilers, the MTO has gained insight into the functional relationships and factors affecting profile measurements in terms of precision and bias. This paper describes verification techniques used to obtain normalised, reproducible and time-stable IRI measurements supplied by different IRI providers. It addresses preliminary findings and statistical analyses of IRI values measured on a verification circuit, which is composed of 12 sections with four different pavement types. In addition, analysis of the various IRI measurements and their impacts on network level pavement serviceability are discussed.

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01-0322 “Smoothness Models for HMA-Surfaced Pavements Developed from LTPP Performance Data”

Washington DOT (WSDOT) has aggressively investigated selected components and concepts of the SHRP/Superpave technology to include the following: Performance Grade (PG) binder usage and specification validation, gyratory mix design; the Superpave Shear Tester (SST); and field performance of Superpave mixes. The focus of this paper, however, is on field performance of Superpave mixes. Validation of the binder specification with respect to low temperature cracking was accomplished using binder and field performance data from 28 projects. The results were very encouraging: the original SHRP algorithm for binder selection correctly "predicted" field performance in 22 of 28 cases, whereas the LTPP algorithm SHRP algorithm for binder selection correctly "predicted" field performance in 26 of 28 cases. Since 1993, WSDOT has placed 44 projects that include some component of the Superpave technology. For 17 of these projects parallel Hveem and Superpave mix designs were conducted. In 13 of the 17 cases, the Superpave design asphalt content was equal to or greater than the Hveem design asphalt content, although the difference was usually no more than 0.2 percent. A conventional Hveem mix design was conducted for 18 of the original 44 projects placed using a PG binder (Hveem-PG). The remaining 26 projects were truly Superpave, i.e., the materials selection and mix design were established in accordance with the Asphalt Institute's SP-2, Superpave Level 1 Mix Design. According to WSDOT practice the following numerical indices trigger maintenance: Pavement Structural Condition (PSC) ≤ 50 , rutting ≥ 13 mm, or International Roughness Index (IRI) ≥ 500 cm/km. Although relatively "young," all 44 projects are performing quite well. The average values of rutting, PSC and IRI (4, 91 and 121, respectively) are all well below the "trigger" values. With respect to rutting and PSC, the performance of Hveem-PG and Superpave projects is virtually identical. However, the ride quality of the Superpave projects is a bit rougher than that the Hveem-PG binder projects: IRI of 134 for the former and 103 for the latter. The higher values of IRI measured on the Superpave projects may be the result of the typically coarser aggregate gradation or differences in construction techniques

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01-0327 “As-Constructed Smoothness Measurement of Portland Cement Concrete Pavements Using Lightweight Profilometers”

Several lightweight, non-contact profilometers (LWP) are now available to measure profiles of the newly constructed Portland Cement Concrete Pavements (PCCP). As-constructed smoothness measurements by four LWP's and the California-type profilograph were done on four newly constructed PCCP sections on I-70 in Kansas. The LWP's are: Ames Engineering LISA, K. J. Law T6400, ICC ATV LWP and SSI LWP. Smoothness measurements by two high speed profilers, KDOT South Dakota profilometer and K. J. Law T6600, were also made. Data was statistically analyzed in the Analysis of Variance (ANOVA) and the Least Squares Means (LSMeans) approach. The lightweight profilometers showed statistically similar Profile Index (PI) values as the California-type profilograph. However, on average, the California-type profilograph reported lower PI values on most of the sections, especially on the driving lane. The International Roughness Index (IRI) values reported by LISA, T6400 and ICC ATV were statistically similar. The South Dakota type profiler reported statistically similar IRI values to

those reported by the LWP's and the K. J. Law T 6600 in most of the cases. However, significant differences were observed in some cases when compared with the K. J. Law T6600 profiler and SSI LWP. Variable coefficients of determination, R^2 values were obtained by doing a linear regression analysis between the PI's from the LWP's and those from the California-Type Profilograph. A correlation analysis was also done between with the PI and IRI data for the same section for a given profiler. The relationship between these smoothness statistics appeared to be more site-specific than being universal.

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01-0435 “Evaluation of Road Surface Profiler and Transverse Profiler for Determination of Rut Depth Measurements”

In recent years, the road surface profiler (RSP) also known as the high-speed profiler has been used as the standard equipment to measure rut depths. Typically, in highway pavements, a RSP with a three-sensor configuration is used to measure rut depth. The spacing between the sensors may vary from 0.74 m to 0.90 m depending on the manufacturer. In this study, rut depth measurements were taken using an RSP with three sensors at a spacing of 0.87 m and with a transverse profilograph (TP) on six projects, each approximately eight kilometers (five-miles) long. The rut depth at any given location from the RSP was, on average, three times less than the TP. Different values of rut depth were determined by simulating the lateral movement of the vehicle, effectively, vehicle wander. The comparison of the rut depth measurements between the actual RSP and the simulated RSP showed that the RSP vehicle had wandered from the center in almost all cases and the wander in some cases was up to 0.57 m. The distance between the maximum rut depths within each wheel path varied from 1.55 to 2.19 m with an average of 1.86 m. The measured rut depth increased by as much as 300 percent when the sensor spacing was varied from 0.75 to 1.20m. Measuring the transverse profile was determined to be the most accurate method of measuring rut depth. It will be possible to accomplish this either with additional sensors required to capture the transverse profile in the road surface profiler or with a transverse profilograph.

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01-2678 “Increasing Life Cycle of Pavement Structures by Lane Shifting”

Increasing the life cycle of a system by adopting a proper operational policy is the most efficient way of improving the productivity of the system. While a better design requires a higher initial cost, and a good maintenance program needs an ongoing expense, the cost of an optimum operation is often relatively low. Pavement systems are not an exception to this rule. A key factor in optimising the operation of a pavement system is to let the pavement cross-section deteriorate uniformly. In this note, lane shifting is proposed as an effective operational policy to increase the efficiency of pavement systems. The approach is based on the lateral transfer of wheel loads in order to reduce the damage due to load repetitions under the wheel paths. Based on a parametric study, factors involved in the effectiveness of this strategy are determined and a methodology for cost/benefit analysis is presented.

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01-2893 “Quality Analysis Methods for Pavement Distress Data”

The issue of validating and verifying the quality of pavement inventory data, including distress and roughness information, has been an elusive subject. This paper describes the development of a useful methodology for accomplishing this important objective. A process is described which can be used to identify an acceptable range, for purposes of comparing results from two independent sources. ASTM D2S concepts have been successfully applied to distress and other pavement performance information. Using these concepts, quality control and acceptance methods are identified for controlling and accepting the quality of pavement distress data for the Virginia DOT. The distress data considered has been collected using digital imaging interpreted by human raters. Data quality is enhanced by using multiple production raters and separate quality control raters.

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10. Safety

01-0204 “NCHRP Report 350 Compliance Testing of a Bullnose Median Barrier System”

A new bullnose guardrail system for the treatment of median hazards was developed and successfully crash tested according to the safety criteria set forth in NCHRP Report No. 350. The new system consists of a 4,500-mm wide by 4,824-mm long nose section comprised of three sections of curved three beam guardrail attached to parallel sides of three beam guardrail 4,500-mm apart. The nose section was designed to safely capture and contain vehicles impacting the nose. Two 7x19 steel cables were attached behind the top two humps of the nose section to ensure vehicle capture in the event that the three beam ruptured. Additionally, the first five sections of guardrail had horizontal slots cut in the valleys of the rail to improve vehicle capture and reduce the formation of large kinks that could pose a threat to a vehicle as the system deformed to absorb an impact. The research study included computer simulation modeling using LS-DYNA and full-scale vehicle testing using 2000-kg pickup trucks and 820-kg small cars in accordance with the TL-3 safety performance requirements specified in NCHRP Report No. 350. Nine full-scale crash tests were performed on the new system. Several changes were made to the bullnose system to improve its safety performance during the course of the testing and development.

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01-0276 “Washington State Cable Median Barrier”

In the mid 1960's, the New York State Department of Transportation developed a 3-strand cable barrier that has several desirable characteristics as compared to other roadside barriers. This system was crash tested in accordance with the National Cooperative Highway Research Program (NCHRP) Report 350 crash test criteria as a roadside barrier. With the roadside barrier, all 3 cables are placed on the traffic side of the posts. Since 1988, the American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide has contained information on a cable median barrier design that has the middle cable mounted on the opposite side of the posts so that it can contain and redirect vehicles that strike the system from either side. In the early 1990's, the Washington State Department of Transportation (WSDOT) became

interested in using this design for medians that are over 10 m in width. As a result of this interest, WSDOT sponsored crash tests to evaluate the performance of this barrier, in accordance with NCHRP Report 350 criteria, with a small car and a pickup truck. In both tests, the vehicle was contained and brought to a stop. The occupant risk values were within the preferred limits set by NCHRP 350 and the damage to both vehicles was relatively minor.

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01-0343 “W-Beam Guardrail Adjacent to a Slope”

A W-beam guardrail system was developed and successfully crash tested for use on a 2:1 foreslope. The guardrail design was constructed with 2.66-mm (12-gauge) thick W-beam rails totaling 53.34 m in length and incorporated a half-post spacing section of 17.15 m. The W-beam rail was supported by fifteen W150x13.5 by 1,829-mm long steel posts, spaced 1,905-mm on center, and nineteen W150x13.5 by 2,134-mm long steel posts, spaced 952.5-mm on center. Routed, 150x200x360 wood spacer blockouts were used to block the rail away from each post. The research study included bogie testing on steel posts placed in sloped fill, computer simulation modeling with BARRIER VII, and one full-scale vehicle crash test, using a ¾-ton pickup truck. The test, impacting at a speed of 100.7 km/hr and an angle of 28.5 degrees, was conducted and reported in accordance with the Test Level 3 (TL-3) requirements specified in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The safety performance of the W-beam barrier system was determined to be acceptable according to TL-3 criteria found in the NCHRP Report No. 350.

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01-2282 “Improvements to the Weak-Post W-Beam Guardrail”

The weak-post w-beam guardrail has been widely used in a number of northeastern states for many decades. Weak-post guardrails are characterized by larger dynamic deflections in a collision and are considered more forgiving than other, stiffer barriers. When located with adequate clear space behind the barrier most states have experienced good performance with these barriers over the past several decades. Unfortunately, recent crash tests of the standard weak-post w-beam guardrail involving the 2000-kg pickup truck resulted in a series of unacceptable test results including over-riding and penetrating the guardrail. Design modifications to the weak-post w-beam guardrail were explored using finite element simulations and full-scale crash tests. An improved version of the weak-post w-beam guardrail system was developed and tested and found to satisfy the requirements of NCHRP Report 350 for Test Level.

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11. Soils, Geology and Foundations

01-2444 “Performance Evaluation of Recycled and Stabilized Bases in Texas”

A structural evaluation was performed on 25 base recycling projects in the Bryan District of Texas Department of Transportation. The recycled layers were stabilized with cement or lime, and each was 250 mm thick. On the higher volume roadways, an unstabilized flexible base was placed over the stabilized layer followed by a two course surface treatment (2 CST). On the other pavements the 2 CST was placed directly on the stabilized layer. Testing involved the use of the Dynaflect, falling weight deflectometer, dynamic cone penetrometer, and ground- penetrating radar. A correlation was generated between the backcalculated layer moduli and the percentage of stabilizer used. Tentative moduli values, to be used in future thickness designs, are also proposed. Two visual surveys were completed. In the first year, of the 25 sections evaluated, 23 were judged to be performing well, with little or no surface distress. However in the next year, after a severe summer, only 17 were judged to be performing well. The major distress found was severe localized longitudinal cracking, which originated in the subgrade. The shrink/swell potential of the subgrade soil appears to be the major factor controlling pavement performance. Sections constructed on soils with a Plasticity Index of more than 35 did not perform well. The severity of the surface cracking was also related to the following secondary factors: a) the summer droughts of 1996 and 1998, b) the presence of trees near the edge of the pavement, c) the side slope conditions, and d) the strength of the stabilized layer. In conclusion, the base recycling technique applied by the Bryan District appears to be working well if the subgrade soils have low to moderate plasticity indices (PI's). This technique is not recommended for sections constructed on high PI subgrades.

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01-3379 “Evaluation of Structural Contribution of Lime Stabilization of Subgrade Soils in Mississippi”

The Mississippi Department of Transportation (MDOT) has used hydrated lime for over 30 years to stabilize subgrades. In 1998 a project was initiated to assess material properties and performance derived from lime treated subgrades (LTS). This paper describes some pertinent findings of the study. In situ properties of lime stabilized subgrades are identified based on Falling Weight Deflectometer (FWD) deflection measurements, Ground Penetration Radar (GPR) profiles, and Dynamic Cone Penetrometer (DCP) logs. The in situ properties are compared to laboratory strength and resilient modulus test results for the same materials to establish reliable design resilient and strength properties for these stabilized layers. A laboratory mixture design and testing protocol is presented for lime stabilized subgrades to assure that design resilient and strength properties are achieved. These properties are used in a mechanistic analysis to assess the effectiveness of the lime-stabilized subgrades in Mississippi.

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01-0172 “Design and Installation of Horizontal Wick Drains for Landslide Stabilization”

One of the most effective options to stabilize landslides is to reduce the amount of water they contain by installation of horizontal drains. A new type of horizontal drain material, geosynthetic

wick drains, and a new installation method, that of driving drains rather than drilling them, has been evaluated. Horizontal wick drains offer several advantages over conventional horizontal drains: they resist clogging, they are inexpensive, they may be deformed without rupture, and they may be installed by unskilled laborers with a minimal investment in equipment. We have installed more than 100 drains at eight sites in Missouri, Colorado, and Indiana using bulldozers, backhoes, and standard wick drain driving cranes. Drains have been driven 30m through materials with SPT values as high as 28. Both experience and research indicate that drains should be installed in clusters which fan outward, aiming for average spacing of 8m for typical clayey soils. As with drilled drains, some drains will be expected to be dry initially, although these drains will often become active during wet periods and serve as an important part of the overall slope stabilization scheme. Drain effectiveness is expected to build over the first few years as the effects of soil smear during drain installation are removed, peaking at 3-6 years after installation. The effectiveness is then expected to decrease as fine particles slowly clog the drain pores. Based on extrapolation of published tests, clogging occurs slowly enough in typical clay soils that the drain life will be comparable to project lifetime.

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01-0104 “Monitoring Effects of Deep Excavation on Two Adjacent Office Buildings”

This paper describes the instrumentation systems that were developed to monitor the effects of excavations for the Boston Central Artery/Third Harbor Tunnel (CA/T) project on two adjacent modern, high-rise office buildings. These are the Federal Reserve Bank of Boston (FRB) and the One Financial Center (OFC) buildings. The CA/T work adjacent to the FRB and OFC buildings consists of a multi-lane cut-and-cover highway tunnel extending to a maximum excavation depth of more than 33.55m (110 ft) below the ground surface and more than 21.35 m (70 ft) below the foundation levels of both buildings. Because even small excavation induced ground movements may have large effects on modern buildings, the FRB and OFC were extensively instrumented to monitor and help control the effects of the CA/T excavations on these buildings. A comprehensive array of instrumentation has been installed to measure excavation induced movements and stresses in the FRB and OFC buildings. The CA/T instrumentation specification describes threshold and limiting values for all of the FRB and OFC instruments which may trigger responses ranging from more frequent readings to modifications of construction procedures, and in the extreme to implementation of a specified contingency plan. The paper presents typical data and how it was used to control the adjacent construction process.

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01-2998 “Laterally Loaded Drilled Shafts Embedded in Soft Weathered Rock”

The current design criterion for laterally loaded drilled shafts embedded in weathered Piedmont rock profiles is a challenging effort on the part of the engineer. A substantial cost savings could be realized, while maintaining an acceptable and safe performance, if a rational method is developed for the analysis and design of drilled shafts in such a profile. The objective of this paper is to present the results of a lateral load test embedded in Piedmont weathered rock. Two full-scale lateral load tests were performed on 0.762 meter (30 inch) diameter drilled shafts. A

site characterization was performed and fully instrumented drilled shafts were constructed and tested to obtain data and develop field P-y curves. In-situ rock dilatometer testing was performed as a part of the site characterization. Rock dilatometer testing indicated elastic modulus values that range from 170 MPa (25000 psi) to 400 MPa (58000 psi) for the soft weathered to competent rock, respectively. Results of this load test demonstrate that P-y curves can be successfully measured using the inclinometer and strain gage combination. Comparisons are made to a P-y curve obtained from the Reese's method, strain gages, and the rock dilatometer. The strain gage and rock dilatometer results indicated fair agreement. However, Reese's method overpredicted the P-y curve values mainly as a manifestation of the input rock properties.

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01-3350 “Real-Time Monitoring of Subsidence Along I-70 in Washington, Pennsylvania”

Two longwall panels were mined at a depth of approximately 168 m beneath I-70 east of Washington, Pennsylvania. Chain pillars between the two panels are located beneath a portion of the Interstate right-of-way but the highway curves such that it crosses the width of one panel at two locations. The Pennsylvania Department of Transportation assumed responsibility for real time monitoring of both ground deformation and changes in highway conditions. Innovative monitoring of ground deformation was accomplished with time domain reflectometry to interrogate coaxial cables installed in deep holes and an array of thirty-two tiltmeters along the highway shoulder. Surface monitoring was also conducted with global positioning system measurements at more than one hundred locations. The tiltmeters were connected to a central remote data acquisition system that automatically recorded and stored measurements. When specified tilt values were detected, the system initiated a phone call to key PennDOT personnel who then monitored tiltmeter measurements in real time via a phone line connection. Based on this information they could alert other agencies if necessary, and intensify visual reconnaissance to determine if lane closures were necessary.

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01-3394 “Instrumentation and Construction Performance Monitoring for I-15 Reconstruction Project, Salt Lake City, Utah”

The I-15 Reconstruction Project in Salt Lake City, Utah involves the widening and rebuilding of 27 kilometers of urban interstate on alluvial and lacustrine deposits. In some locales, these soils have low shear strength and require up to 2 to 3 years to complete primary consolidation settlement. The aggressive 4-year total construction schedule required much of the embankment and foundation work to be completed in the first 12 to 18 months of the project, including the time required to complete primary settlement. To meet rigorous schedule constraints, the geotechnical construction made extensive use of prefabricated vertical drains (PVD), ground modification, staged-embankment construction, light-weight fill, mechanically stabilized earth (MSE) walls and pile foundations. Also, due to rigid time constraints, initial foundation preparation and embankment construction proceeded as parallel activities with the geotechnical design. Thus, much of the initial geotechnical design was completed without the benefit of

exhaustive field testing. However, as construction progressed a substantial field instrumentation and performance monitoring program was implemented to verify the preliminary design and to ensure that construction proceeded with minimal risk of embankment failure and/or excessive deformation and settlement. Thus, instrumentation and performance monitoring played a vital role in affirming the initial design and developing additional understanding about the strength, deformation, and consolidation characteristics of the soft soils. This paper discusses the development of the instrumentation monitoring plan and how performance monitoring was implemented to impact construction processes and to improve subsequent geotechnical design.

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01-3323 “QA Procedure to Assess Maintenance Adequacy of Drainage Assets”

The engineering community has long known the need and importance of adequate maintenance of drainage structures. However, despite several regional and national studies that highlighted the ill-effects of poor maintenance not many agencies have looked to improve their inspection and maintenance schedules. Although inadequate funding is the most plausible reason for this scenario, the lack of formal procedures to survey drainage assets, determine their conditions vis-a-vis their functional objectives, and objectively quantify their condition also add to the problem. This paper describes a prototype maintenance quality assurance (QA) procedure developed to evaluate the adequacy of drainage asset maintenance in a consistent manner. Key components of the QA procedure are discussed in detail. A software program developed to implement the various components of the QA procedure is also described. The program is intended to serve as a simple tool to check the condition and functionality of drainage assets at any time. The program is designed to handle both surface and subsurface drainage assets and has the flexibility to be implemented at any level of maintenance jurisdiction. A complete description of the program's functionality, from the selection of inspection units to the generation of maintenance ratings, is provided.

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01-0231 “Real-Time Evaluation of Site Characterization to Direct and Conclude Exploration”

This paper demonstrates a computationally efficient method to direct and evaluate the sufficiency of site characterization activities associated with roadway construction. The method, entitled reliability-based exploration (RBE), combines 3D subsurface analysis with the uncertainty associated with subsurface data to produce a quantifiable measure of exploration sufficiency, which is directly related to the probability of project success. RBE employs a first-order Taylor series expansion to combine the performance model sensitivity and input data uncertainty to calculate the variance in project performance in real time, which, given enough time and computer resources, could be calculated by conventional Monte Carlo (MC) simulations. The study shows that the Taylor series, together with direct derivative coding (DDC), can generate the performance variance much faster than MC simulations. For the example presented, the Taylor series with DDC calculates results 160 times faster than MC. The RBE method begins with a prior model of the subsurface that can include engineering judgment. As new information is collected at a site, the prior subsurface model is updated with new site

data. The robustness and efficiency of RBE is illustrated with a practical example of exploration associated with two designs of a highway interchange. The example illustrates the RBE approach by identifying the next location for exploration and evaluating characterization sufficiency. Moreover, this paper describes the effects of different designs on exploration. The example shows that design affects 1) surface settlement, 2) location of the next boring, and 3) termination of exploration (number of required borings).

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01-0106 “Use of Falling Weight Deflectometer and Light Drop-Weight for Quality Assessment During Road Formation and Foundation Construction”

Mechanistic-empirical-based specifications, which focus on the mechanical properties of materials, facilitate quantitative evaluations of alternative construction practices and materials, such as reclaimed materials. Thus, quality-control and assurance testing would be expected to include stiffness along with density measurements. This paper presents two case studies in which Falling-Weight Deflectometer (FWD) was used during the construction of two major interchanges in Israel. FWD testing was found to be very useful in identifying local spots with poor performance, thus enabling execution of the required remedy actions. The two studies also indicated that for a given feature, both a representative central deflection at the 95% reliability level and a coefficient of variability of measured deflections may serve as potential quality-control indicators. The finding of these studies supported, however, (a) the use of target values derived from calibration tests on trial sections and (b) the introduction of restraining deflection values that characterize the contribution of each layer to decreasing the deflection value. This paper also concentrated on the possible use of the German Light Drop-Weight (LDW) device for measuring the mechanical properties of the formation of flexible pavements. Based on the cost per test, rate of testing, and quality of the data, the German LDW can serve as a cost-effectiveness testing device for quality control and assurance during subgrade and capping-layer compaction.

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01-0303 “Automated Measurement of Total Suction Characteristics in High Suction Range: Application to Assessment of Swelling Potential”

This paper describes an automated experimental system to characterize moisture content-total suction relationships, i.e., total suction characteristic curves, for unsaturated clayey soils. Unlike traditional techniques requiring independent measurement of total suction and moisture content (e.g., thermocouple psychrometry, filter paper, etc.), suction is directly controlled and corresponding moisture contents are continuously monitored. The system is applicable for total suction values ranging between approximately 620,000 kPa and 14,000 kPa. Total suction is controlled during testing by computer-automated rationing of "dry" and "wet" nitrogen gas in a closed environmental chamber. To develop characteristic curves, the equilibrium moisture content of soils placed in the chamber is measured with an integrated electronic balance as water vapor is adsorbed or desorbed. The system requires no user intervention and is capable of generating characteristic curves including wetting and drying loops in a time span on the order of one to two weeks. Concurrent measurements using the non-contact filter paper method (ASTM

D5298) are shown to agree very closely with those obtained from the automated system. Total suction characteristic curves are compared for a highly expansive smectite clay and non-expansive kaolinite clay. Hysteresis between the wetting and drying cycles and "step-wise" dehydration phenomena, which have been noted by previous researchers, are reproduced in the results. Comparison of the smectite and kaolinite characteristic curves demonstrates the system's potential to become a simple, non-labor intensive, quick, and reliable platform to qualitatively assess the relative swelling potential of clayey soils.

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01-3001 “Integrating Seismic and Deflection Methods to Estimate Pavement Moduli”

Nondestructive testing (NDT) of pavements has made substantial progress during the last two decades. Most algorithms currently used to determine the remaining life of pavements rely on stiffness parameters determined from NDT devices. One major area of continual improvement is the reliable and rapid extraction of stiffness parameters from nondestructive field data. Two of the most common NDT methods used are the deflection and seismic-based methods. The SASW tests are the most common seismic method. In this method, time records obtained with vibration sensors are used to obtain an experimental dispersion curve, which through an inversion procedure, provides an estimate of the elastic modulus profile of the pavement. Deflection bowls are also used to backcalculate modulus profiles of pavements through the inverse theory. The inversion processes used in both methods are complex and either requires a significant computational effort and/or frequent operator's intervention. Each method, of course, has its own limitations and strengths. To improve the accuracy of the predicted moduli, an algorithm for joint reduction of the deflection and seismic based data have been developed. Thickness and modulus of each pavement layer are estimated in real time using artificial neural network models. This paper provides an overview of a proposed joint inversion and its practical use in pavement analysis and design. The joint reduction algorithm shows promise since it seems to be more robust and to yield more consistent results when compared with the process and results from each method independently.

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01-3324 “User Query Interface for Deep Foundations Load Test Database”

The database is a result of research quality data collection over the last fifteen years. The database consists of soils data along with the deep foundations load test data gathered from prototype tests conducted all over the world. The soils data include general site information, stratigraphy, laboratory and in situ test details. The foundations data consist of general foundations information including foundation construction, and load-settlement information to failure. Over 1000 foundations are currently in the database and more are being added to the database. The database is checked for its validity and correctness both before and after the data is added to the database to make sure that the data integrity is preserved. Also, the data is periodically backed up and the data input is strictly administered by providing controlled access to the designated individuals. The database is structured to follow the rules of Relations Database Management Systems (RDBMS). The database resides in a Unix based Sun Solaris server and the database engine is Sybase RDBMS. The database front-end query application is under development for the Internet using Java as the programming language and will run under any

Internet capable browser (Netscape, Internet Explorer, etc.) environment. The application will use Java applets to communicate with the database server. The user community includes state highway engineers, geotechnical researchers, students, and practicing engineers. Interested users can access the database using the interface to view, download, and chart the data at run-time.

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