Materials Characterization

Year	Title	Author(s)
2009	Considering PCC Slab Warping in the Context of Reliability Based Pavement Design	Byrum PhD, PE, Christopher Ronald
2009	Bitumen-Stabilized Materials: New Dimension in Flexible Pavements	Collings, David Coppin
2009	Application of Artificial Neural Networks for Estimating Dynamic Modulus of Asphalt Concrete	Sakhaei Far, Maryam Sadat; Underwood, Benjamin Shane; Kim, Youngsoo Richard
2009	LTPP Computed Parameter: Dynamic Modulus	Y. Richard Kim, Underwood B., Sakhaei Far M., Jackson N., Puccinelli, J
2008	Backcalculation Analysis of Rigid Pavement Properties Considering Presence of Subbase Layer	Fwa, T F; Setiadji, Bagus Hario
2008	Effects of Design and Material Modifications on Early Cracking of Continuously Reinforced Concrete Pavements in South Dakota	Johnston, Daniel P; Surdahl, Roger W.
2008	Backcalculation of Dynamic Modulus from Resilient Modulus of Asphalt Concrete with an Artificial Neural Network	LaCroix, Andrew T; Kim, Youngsoo Richard; Ranjithan, S Ranji
2008	Subgrade Resilient Modulus Prediction Models for Coarse and Fine-Grained Soils Based on Long-Term Pavement Performance Data	Malla, Ramesh B; Joshi, Shraddha
2008	An Experimental Plan for Validation of an Endurance Limit for HMA Pavements	Bonaquist, Ramon F.
2007	Effectiveness of Crumb Rubber Materials as Modifiers in Paving Asphalts	MacLeod, Daryl; Johnston, Art; Ho, Susanna
2007	Resilient Modulus Prediction Models Based on Analysis of LTPP Data for Subgrade Soils and Experimental Verification	Malla, Ramesh B; Joshi, Shraddha
2007	Effect of Coefficient of Thermal Expansion Test Variability on Concrete Pavement Performance as Predicted by Mechanistic-Empirical	Tanesi, Jussara ; Kutay, Muhammed Emin; Abbas, Ala Rebhi; Meininger, Richard C.
2007	Quantification of Effect of Polymer-Modified Asphalt on Flexible Pavement Performance	Von Quintus, Harold L; Mallela, Jagannath; Buncher, Mark S.
2007	Predicting the Resilient Modulus of Asphalt Concrete from the Dynamic Modulus	Lacroix, Andrew; Khandan, A. Ardalan Mosavi; Kim, Youngsoo Richard

2007	Study of Crumb Rubber Materials as Paving Asphalt Modifiers	MacLeod, D; Ho, S; Wirth, R; Zanzotto, L.
2007	Long Term Pavement Performance Project Laboratory Materials Testing and Handling Guide	Simpson, Amy L; Schmalzer, Peter Nils; Rada, Gonzalo R
2007	Subgrades and Subbases for Concrete Pavements	American Concrete Pavement Association
2006	Calibrating the Aging Difference between In-Service Fatigue Performance of Flexible Pavements and Accelerated Pavement Testing	Guo, Runhua; Prozzi, Jorge A.
2006	Determination of Typical Resilient Modulus Values for Selected Soils in Wisconsin	Titi, Hani H; et al
2006	Effect of Design and Site Factors on Long-Term Performance of Flexible Pavements in SPS-1 Experiment	Chatti, Karim
2006	Effects of Base Type on Modeling of Long-Term Pavement Performance Continuously Reinforced Concrete Sections	Johnston, Daniel P.; Surdahl, Roger W.
2006	Establish Subgrade Support Values for Typical Soils in New England	Malla, Ramesh B; Joshi, Shraddha
2006	Evaluation of Backcalculation Methods for Nondestructive Determination of Concrete Pavement Properties	Fwa, T F; Setiadji, Bagus Hario
2006	Evaluation of Resilient Modulus Model Parameters for Mechanistic–Empirical Pavement Design	Elias, Mohammed B; Titi, Hani H.
2006	Guidance on Minimum Roadway Placement Temperatures Technical Advisory	Texas Department of Transportation, Construction Division
2006	Guidelines for Review and Evaluation of Backcalculation Results	Stubstad, R. N; Jiang, Y J; Lukanen, E. O.
2006	Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide	Simpson, A.L; Schmalzer, P.N; Rada, G.R.
2006	LTPP Materials Reference Library (MRL)	
2006	Network-Level Evaluation of Specific Pavement Study-2 Experiment: Using a Long-Term Pavement Performance Database	Buch, Neeraj; et al
2006	Portland Cement Concrete Coefficient of Thermal Expansion Input for Mechanistic-Empirical Pavement Design Guide	Tanesi, Jussara et al
2006	Review of the Long-Term Pavement Performance Backcalculation Results Final Report	Stubstad, R. N et al
2006	Seasonal Variations in the Moduli of Unbound Pavement Layers	Richter, Cheryl A.
2006	Truck/Pavement/Economic Modeling and In-Situ	Sargand, Shad; Wu,

	Field Test Data Analysis Applications – Volume 1: Influence of Drainage on Selection of Base	Shin; Figueroa, J. Ludwig
2006	Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis App - Volume 1: Influence of Drainage on Selection of Base	Sargand, Shad M; Wu, Shin; Figueroa, J. Ludwig
2006	Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications – Volume 3: Stiffness and Modulus Estimation for Different Soil Types Using FWD Deflection Criteria	Sargand, Shad; Huntae, Kim
2006	Verification of the Rate of Asphalt Mix Aging Simulated by AASHTO PP2-99 Protocol	Zapata, Claudia E; Raghavendra, Suresh
2005	Development of an Automated Procedure for Implementing Resilient Modulus Test for Design of Pavement	Ping, W.V; Yang Z.
2005	Development of a New Method for Assessing Asphalt Binder Durability with Field Validation.	Glover, Charles J, et al
2005	Effect of Seasonal Moisture Variation on Subgrade Resilient Modulus	Salem, Hassan M.
2005	Evaluation of PCC Joint Stiffness Using LTPP Data	Khazanovich, Lev; Gotlif, Alex
2005	Long-Term Pavement Performance Materials Characterization Program: Verification of Dynamic Test Systems with an Emphasis on Resilient Modulus (Contract DTFH61-95-Z-00086 Final Report)	Groeger, Jonathan; Bro, Anders
2005	LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements	Chatti, K; Buch, et al
2005	Rapid Pavement Backcalculation Technique for Evaluating Flexible Pavement Systems	Bayrak, Mustafa Birkan; Guclu, Alper; Ceylan, Halil
2005	Sensitivity Analysis of Rigid Pavement Systems Using Mechanistic- Empirical Pavement Design Guide	Guclu, Alper; Ceylan, Halil
2005	Study of LTPP Pavement Temperatures	Lukanen, E. O; Stubstad, R. N; Clevenson, M. I.
2005	Survival Analysis of Fatigue Cracking for Flexible Pavements Based on Long-Term Pavement Performance Data	Wang, Yuhong, et al
2005	Synthesis of CalTrans Rubberized Asphalt Concrete Projects	
2005	Understanding the True Economics of Using	Buncher, Mark;

	Polymer Modified Asphalt Through Life Cycle Cost Analysis	Rosenberger, Carlos
2005	Verification for the Calibrated Permanent Deformation Models for the 2002 Design Guide	El-Basyouny, Mohamed M, et al
2004	Evaluation of Asphaltic Expansion Joints	Mogawer, Walaa S; Austerman, Alexander J.
2004	Evaluation and Analysis of LTPP Pavement Layer Thickness Data	Selezneva, O. I; Jiang, Y. J; Mladenovic, G.
2004	Laboratory Determination of Resilient Modulus for Flexible Pavement Design	
2004	Long Term Monitoring of Seasonal Weather Stations and Analysis of Data from SHRP Pavements	Figeroa, J. Ludwig
2004	LTPP SPS Materials Data Resolution: Update and Final Action Plan	FHWA & MACTEC Engineering and Consulting, Inc.
2004	Predicting Elastic Response Characteristics of Unbound Materials and Soils	Yau, A; Von Quintus, H. L.
2004	Prediction of Resilient Modulus from Soil Index Properties	George, K. P.
2004	Researcher's Guide to the Long-Term Pavement Performance Layer Thickness Data	Jiang, Y. J; Selezneva, O. I; Mladenovic, G.
2003	Assessment of Selected LTPP Material Data Tables and Development of Representative Test Tables	Titus-Glover, L, et al
2003	Automated Pavement Analysis in Missouri Using Ground Penetrating Radar	Cardimona, S, et al
2003	Effects of Excessive Pavement Joint Opening and Freezing on Sealants	Lee, S. W; Stoffels, S. M.
2003	Estimation of Pavement Layer Thickness Variability for Reliability-Based Design	Jiang, Y; Selezneva, O; Mladenovic, G; Aref, S; Darter, M.
2003	Evaluation of Seasonal Effects on Subgrade Soils	Heydinger, A. G.
2003	Long Term Pavement Performance: Guide for Determining Design Resilient Modulus Values for Unbound Materials	
2003	LTPP Data Analysis: Daily and Seasonal Variations in Insitu Material Properties	Drumm, E. C; Meier, R.
2003	Temperature Correction of Backcalculated AC Modulus	Fernando, Emmanuel G.
2003	Using LTPPBind VS.1 to Improve Crack Sealing in Asphalt Concrete Pavements	Nieves, A.
2003	Utilizing the Falling Weight Deflectometer in	Tawfiq, K.

	Evaluating Soil Support Values of Pavement Layers	
2002	Back-Calculation of Layer Parameters for LTPP Test Sections, Volume II: Layered Elastic analysis for Flexible and Rigid Pavements	Von Quintus, H. L; Simpson, A. L.
2002	Benefiting from LTPP - A State's Perspective	Hoffman, G.
2002	Determination of Pavement Layer Stiffness on the Ohio SHRP Test Road Using Non-Destructive Testing Techniques	Sargand, Shad
2002	LTPP Data Analysis: Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality	Stubstad, R. N.
2002	Study of LTPP Laboratory Resilient Modulus Test Data and Response Characteristics	Yau, A; Von Quintus, H. L.
2002	Variability of Concrete Materials Data in the Long-Term Pavement Performance Program	Tayabji, S. D; Wu, C-L.
2001	Backcalculation of Layer Parameters for Performance / LTPP Test Sections, Volume I: Slab on Elastic Solid and Slab on Dense-Liquid Foundation Analysis of Rigid Pavements	Khazanovich, Lev; Tayabji, Shiraz D; Darter, Michael I
2001	Characterization of Mechanical Properties and Variability of PCC Materials for Rigid Pavement Design	Mallela, J, et al
2001	Evaluation of Moisture Sensitivity Properties of ADOT Mixtures on US 93. Volume I - Final Report	Sebaaly, Peter E; Eid, Zein; Epps, Jon A.
2001	Evaluation of Superpave Fine Aggregate Angularity Specification	Chowdhury, A; Button, J; Kohale, V; Jahn, D.
2001	Laboratory Characterization of Materials & Data Management for Ohio - SHRP Projects (U.S. 23)	Masada, T.
2001	LTPP Data Analysis: Factors Affecting Pavement Smoothness	Perera, R.W; Kohn, S. D.
2001	Parameter Study of Load Transfer and Curling Effects on Rigid Pavement Deflections	Lee, Y-H; Sheu, R-S.
2001	Test Method for Determining the Creep Compliance, Resilient Modulus and Strength of Asphalt Materials using the Indirect Tensile Test Devise	LAW PCS
2001	Washington State Department of Transportation Superpave Implementation	Leahy, R. B; Briggs, R. N.
2000	Characterizing Seasonal Variations in Pavement Material Properties for Use in a Mechanistic-Empirical Design Procedure	Ovik, J. M; Birgisson, B; Newcomb, D. E.
2000	Computed Parameters: Moisture Content for Unbound Materials at Seasonal Monitoring	

	Program Sites	
2000	LTPP Rigid Pavement FWD Deflection Analysis and Backcalculation Procedure	Khazanocich, L; McPeak, T. J; Tayabji, S. D.
2000	Subgrade Characterization for Highway Pavement Design	George, K. P; Uddin, Waheed
2000	Temperature Predictions and Adjustment Factors for Asphalt Pavement	Lukanen, E. O; Stubstad, R; Briggs, R.
2000	Variations in Backcalculated Pavement Layer Moduli in LTPP Seasonal Monitoring Sites	Briggs, R. C; Lukanen, E. O.
1999	Computed Parameters: An Input for Moisture Calculations - Dielectric Constant from Apparent Length	
1999	Determination of Resilient Modulus for Maine Roadway Soils	Smart, A. L; Humphrey, D. N.
1999	Evaluation of In-Situ Moisture Content at Long-Term Pavement Performance Seasonal Monitoring Program Sites	Jiang, Y. J; Tayabji, S. D.
1999	Evaluation of Rigid Pavement Joint Seal Movement	Morian, D. A; Suthahar, N; Stoffels, S.
1999	LTPPBind: A New Tool for Selecting Cost-Effective SuperPave Asphalt Binder Performance Grades	
1999	Preliminary Evaluation of LTPP Continuously Reinforced Concrete (CRC) Pavement Test Sections	Tayabji, S. D; Selezneva, O; Jiang, Y. J.
1999	Selection and Evaluation of Performance-Graded Asphalt Binders for Virginia	Prowell, B. D.
1999	Videotapes Explain the How and Why of LTPP's Revised Resilient Modulus Laboratory Tests and Procedures	
1998	Analyses Relating to Pavement Material Characterizations and Their Effects on Pavement Performance	Von Quintus, H; Killingsworth, B.
1998	LTPP Seasonal Asphalt Concrete (AC) Pavement Temperature Models	Mohseni, A.
1998	Seasonal Instrumentation of SHRP Pavements - The University of Toledo	Heydinger, A. G; Randolph, B. W.
1997	Backcalculation of Layer Moduli of LTPP General Pavement Study (GPS) Sites	Killingsworth, B; Von Quintus, H.
1997	Investigation of Modified Asphalt Performance Using SHRP Binder Specifications	Bahia, Hussain U, et al
1997	LTPP Materials Characterization Program:	Alavi, S, et al

	Resilient Modulus of Unbound Materials (LTPP Protocol P46). Laboratory Startup and Quality Control Procedure	
1997	Seasonal Variation in Material Properties of a Flexible Pavement	Watson, D K; Rajapakse, R.K.N.D.
1994	Asphalt Concrete Synthetic Reference Sample Program and the LTPP Asphalt Concrete Core Proficiency Sample Program	Steele, G. W.
1994	Dynamic Linear Back Calculation of Pavement Material Parameters	Uzan, Jacob
1994	Influence of Stress Levels and Seasonal Variations on in Situ Pavement Layer Properties	Noureldin, A. S.
1994	Materials and Construction Variability Based on SHRP-LTPP Data	Hadley, W. O; Irick, P; Anderson, V.
1994	Round 1 Type I Unbound Granular Base Course Proficiency Sample Program	Steele, G. W; Anderson, D A; Antle, C. E.
1994	Round 1 Type II Unbound Cohesive Subgrade Soil Proficiency Sample Program	Steele, G. W; Antle, C. E; Anderson, D. A.
1994	Round 1 Hot Mix Asphalt Laboratory Molded Proficiency Sample Program	Steele, G. W; Antle, C E; Anderson, D. A.
1994	SHRP-LTPP Materials Characterization: Five-Year Report	Hadley, W. O; Groeger, J. L.
1994	Strategic Highway Research Programs Long-Term Pavement Performance (SHRP-LTPP) Asphalt Resilient Modulus Pilot Study	Hadley, W. O; Anderson, V.
1994	Type I Unbound Granular Base Synthetic Reference Sample Program	Steele, G. W; Antle, C. E; Anderson, D. A.
1994	Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program	Steele, G.W; Antle, C. E; Anderson, D. A.
1993	Portland Cement Concrete Core Proficiency Sample Program	Steel, G. W.
1993	SHRP's Layer Moduli Backcalculation Procedure	PCS/Law Engineering
1993	Soil Moisture Proficiency Sample Program	Steel, G. W.
1992	Introduction to Strategic Highway Research Program--Long-Term Pavement Performance Asphalt Concrete Resilient Modulus Testing Program	Hadley, W. O; Groeger, J. L.
1991	An Overview of LTPP Materials Sampling and Testing. Strategic Highway Research Program Products. Proceedings of a Specialty Conference Sponsored by the Highway Division of the American Society of Civil Engineers and the Federal Highway Administration	Pelzner, A.
1989	Operational Guidelines on Test Pits	

Title: Subgrades and Subbases for Concrete Pavements

Author(s): American Concrete Pavement Association

Date: 2007

Publisher: American Concrete Pavement Association

Abstract/Synopsis:
This paper describes how the analysis of the Federal Highway Administration's (FHWA"s) Long-Term Pavement Performance (LTPP) data reveals that a pavement's foundation (base or subbase and subgrade) is one of the most critical design factors in achieving excellent performance for any type of pavement. For concrete pavements, the design and construction requirements of a roadbed or foundation structure may vary considerably, depending upon subgrade soil type, environmental conditions, and the amount of anticipated heavy traffic. In any case, the primary objective for building a roadbed or foundation for concrete pavement is to obtain a condition of uniform support for the pavement that will prevail throughout its service life. Drainage considerations are also important in the proper design and construction of a roadbed or foundation for concrete pavements.

Application/Use: The results from this project are applicable for new and reconstructed pavement construction and are useful for pavement designers.

Contribution: Cost Savings; Improvement in Knowledge, Lessons Learned.

Present Benefit: A more detailed understanding of the effects of subgrades and subbases on pavements is a valuable tool for pavement designers. Proper consideration of the underlying materials supporting the pavement structure and providing adequate drainage will result in better performing pavements. The LTPP database was a primary resource for determining the effect of the supporting pavement layers on overall pavement performance.

Future Benefit: Quantifying the effect of pavement materials will continue to assist pavement engineers in developing adequate pavement designs to accommodate for site conditions. The LTPP program has been and will continue to be an integral part of further advancing the pavement industry.

<u>Title:</u> Long Term Pavement Performance Project Laboratory Materials Testing and Handling Guide

<u>Author(s):</u> Simpson, Amy L; Schmalzer, Peter Nils; Rada, Gonzalo R

<u>Date:</u> September 2007

<u>Publisher:</u> MACTEC Engineering and Consulting, Incorporated; Federal Highway Administration

Abstract/Synopsis:
The Long Term Pavement Performance (LTPP) Laboratory Materials Testing Guide was originally prepared for laboratory material handling and testing of material specimens and samples of asphalt materials, portland cement concrete, aggregates, and soils under the supervision of the Strategic Highway Research Program. This version of the Guide has been updated to provide a historical reference document for analysts of the LTPP data. It provides the basis for the quality control program used in performing the laboratory testing, the protocols used in testing the material samples, and the guidelines for handling these samples in the laboratory. Additionally, this document provides the guidelines used for identifying the pavement structure based on the material properties of the sampled layers.

<u>Application/Use:</u> The guide documents the LTPP processes and procedures in performing laboratory testing. It can be utilized to ensure uniform testing by labs providing LTPP data.

<u>Contribution:</u> Cost Savings; Advancement in Technology; Implementation/Usage.

<u>Present Benefit:</u> In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the Guide allows the test results from various laboratories to be compared without applying adjustment factors. The Guide also provides information on the codes utilized in the LTPP Information Management System (IMS) and the proper population of key testing tables in the IMS (i.e., TST_L05B). Furthermore, this Guide has been updated to provide a historical reference document for analysts of the LTPP data.

<u>Future Benefit:</u> The Guide will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available data with newly sampled materials, the Guide provides the information necessary to do so.

Title: Study of Crumb Rubber Materials as Paving Asphalt Modifiers

Author(s): MacLeod, D; Ho, S; Wirth, R; Zanzotto, L.

Date: September 2007

Publisher: Canadian Journal of Civil Engineering Vol. 34 No. 10; National Research Council of Canada

Abstract/Synopsis:
Waste tire crumb rubber materials (CRM) were used to modify paving asphalts. The mixing time, hot-storage stability, Superpave grades, pumping and handling properties, phase separation tests, and repeated creep properties of the modified asphalts were studied using base asphalts of different hardness. Applying the Long-Term Pavement Performance (LTPP) program and the Transportation Association of Canada (TAC) model, optimal levels of CRM and suitable base asphalts were selected for the climatic conditions of Lethbridge, Alberta, Canada. High-temperature grade bumping protocol, regarding traffic volume and speed, was also considered. With joint efforts from the Tire Recycling Management Association of Alberta (TRMA), Husky Energy, and the City of Lethbridge, three test sections in different Lethbridge locations with various traffic volumes were paved from the years 2003 to 2005. So far, the City of Lethbridge is pleased with the initial performance of the test sections.

Application/Use: This is directly applicable to materials selection/pavement design in Canada, and can also be useful to pavement managers and rehabilitation engineers in general.

Contribution: Cost Savings; Lessons Learned; Advancement in Technology.

Present Benefit: Using the LTPP protocol process, three test sites were constructed in Canada to determine the overall performance of using crumb rubber as an asphalt modifier. This experiment is useful to evaluate the practical implications of implementing crumb rubber as an optional asphalt modifier in pavements.

Future Benefit: As agencies continue to investigate the use of crumb rubber, this document will prove to be a valuable data source. Performance data along with vital information on materials, construction, in situ conditions, and traffic will be an essential component to the evaluation of crumb rubber modifier applications. The LTPP program protocol for test sections and data collection was a significant benchmark and assisted these researchers in developing adequate test sites for this experiment.

Title: Predicting the Resilient Modulus of Asphalt Concrete from the Dynamic Modulus

Author(s): Lacroix, Andrew; Khandan, A. Ardalan Mosavi; Kim, Youngsoo Richard

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2001

Abstract/Synopsis:
The NCHRP 1-37A Guide for Mechanistic–Empirical Design of New and Rehabilitated Design Structures introduces the dynamic modulus as the material property to characterize asphalt concrete. This is a significant change from the resilient modulus used in the previous AASHTO pavement design guide. This paper presents an analytical method of calculating the resilient modulus from the dynamic modulus. It involves the application of multiaxial linear viscoelastic theory to linear elastic solutions for the indirect tension test developed by Hondros. The prediction method is verified by using three 12.5-mm surface course mixtures with different aggregate shapes and binder types and one 25.0-mm base mixture. Results show that the predicted and measured resilient modulus values are in close agreement. The results provide a forward model for the potential back-calculation of the dynamic modulus from resilient modulus databases already available in highway agencies, such as the Long-Term Pavement Performance Materials Database.

Application/Use: The results from this study are applicable to pavement engineers using the resilient modulus in pavement design.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The LTPP database has provided researchers and pavement engineers with information that has been used to improve current pavement design, evaluation, and rehabilitation methods. As pavement design methods change, it is important that the LTPP database is able to accommodate for these changes. The ability to relate the dynamic modulus to the resilient modulus is extremely useful to pavement engineers in being able to use the LTPP database and convert it to the desired moduli needed for design. This will better ensure that pavement engineers will be able to fully capitalize on the benefits of the LTPP database to develop cost-effective strategies to achieve higher performing pavements.

Future Benefit: As pavement engineers continue to move toward mechanistic-empirical design methods, the dynamic modulus will become the dominant material property used to evaluate and design new and rehabilitated pavements. Therefore, the ability to relate the resilient modulus to the dynamic modulus is important in utilizing the LTPP database.

Title: Quantification of Effect of Polymer-Modified Asphalt on Flexible Pavement Performance

Author(s): Von Quintus, Harold L; Mallela, Jagannath; Buncher, Mark S.

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2001

Abstract/Synopsis:
Polymer-modified asphalt (PMA) mixtures are routinely used today in flexible pavement structures or overlays carrying high volumes of traffic. Although there have been numerous laboratory and field studies comparing the performance of PMA and conventional hot-mix asphalt (HMA) mixtures, for example, Superpave® and Marshall, there has not been a concerted effort to quantify the benefits of using PMA mixtures or to develop guidance on when the use of PMA mixtures is cost-effective. An investigation of nearly three dozen real-world pavement sections in North America was conducted to quantify the benefits of using PMA mixtures. The test sections used in performance comparisons included both roadway and accelerated pavement test sections. Performance data for the test sections were derived from published literature or other public sources such as the Long-Term Pavement Performance or the National Center for Asphalt Technology databases. On the basis of the performance comparisons made between PMA and conventional sections, it was found that PMA mixtures significantly enhance not only the rutting performance of flexible pavements but also their fatigue and fracture performance. The examples used in this study show an extended service life for deep-strength HMA pavements of 5 to 10 years through the use of PMA mixtures, on the basis of the performance observations from the companion test sections, which were constructed mostly with older Marshall or Hveem mixtures. A definite bias exists between the predicted and measured distress values for the sections with PMA mixtures when using current mechanistic–empirical distress prediction models. This finding suggests a need for different calibration factors in PMA mixtures for use in rutting and fatigue cracking prediction equations.

Application/Use: The results from this study have been used by those interested in evaluating the cost-to-benefit ratio of using polymer modified binders.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Data collected at LTPP test sections provides sufficient data to support studies of this nature. The life cycle cost analysis conducted in this study provides information that allows agencies to make cost-effective policy decisions on the use of polymer modified binder.

Future Benefit: The decision to use polymer modified binder can have lasting effects on the pavement network in terms of overall condition and service to the public. Therefore, it is important to use quality data and sound analysis methods when conducting evaluations of this type. LTPP data will continue to support these analyses.

Title: Effect of Coefficient of Thermal Expansion Test Variability on Concrete Pavement Performance as Predicted by Mechanistic-Empirical

Author(s): Tanesi, Jussara ; Kutay, Muhammed Emin; Abbas, Ala Rebhi; Meininger, Richard C.

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2020

Abstract/Synopsis:
The coefficient of thermal expansion (CTE) of concrete is a property that can affect the performance of the pavement and its service life and is one of the most important inputs in the Mechanistic–Empirical Pavement Design Guide (MEPDG). The CTE can be either estimated or measured in the laboratory. The test method used to determine this property is AASHTO TP 60, still a provisional test method and not yet evaluated for its precision. CTEs of more than 1,800 concrete specimens were measured at the Turner–Fairbank Highway Research Center. The specimens included cylinders that were cast in the laboratory as well as field cores obtained from the Long-Term Pavement Performance pavement sections. Approximately 150 of the specimens were tested individually several times for assessment of repeatability of the test method. An analysis is presented of test differences observed, as is a sensitivity analysis of the CTE test variability on predicted performance based on the MEPDG. The differences in predicted international roughness index (IRI), percent slabs cracked, and faulting due to test variability were determined for concretes with CTEs ranging from 4 to 7 × .000001 in./in./°F. It was observed that differences in test results may result in significant discrepancies in the predicted IRI, percent slabs cracked, and faulting. Thus, a single test result should not be used as representative of the CTE of a mixture due to the considerable impact of the test variability on the predicted pavement performance. Moreover, the specifications should state the minimum number of tests necessary for the CTE determination and the acceptable test variability.

Application/Use: The findings from this paper will be used by those interested in the effect of CTE on predicted performance in the MEPDG.

Contribution: Improvement in Knowledge

Present Benefit: Determining the variability in CTE provides valuable information to materials and pavement engineers. Additionally, evaluating the interaction between CTE and other design parameters can offer insight into the MEPDG. A benefit provided by LTPP is the availability of materials data that can be used in evaluation studies such as this.

Future Benefit: This study will be beneficial in the future as the MEPDG continues to be evaluated and implemented.

Title: Considering PCC Slab Warping in the Context of Reliability Based Pavement Design

Author(s): Byrum PhD, PE, Christopher Ronald

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
This paper provides a guide for estimating the likely average slab curvature magnitude that will be present at a concrete pavement design site, from combined warping and curling and in the context of reliability based pavement design procedures. Measurements of the average slab curvature present in the FHWA LTPP GPS3 test sites are used to show that local annual precipitation can be used as a primary basis for establishing an estimate of the likely mean value of average slab curvature that will be present during the daytime. The actual slab curvature variability observed in the GPS3 sites is used to establish confidence intervals for possible variation from the overall likely mean value. It is also shown that warping variability is generally higher for normal heat of hydration cements versus low heat cements, higher for clay subgrades compared to granular subgrades, and is lower for sites with dowel bars at contraction joints. Adjustment factors to the confidence intervals are provided for these different design conditions. It is demonstrated how the average slab curvature value for a site can be attached to slab theory and transformed to other index values such as approximate equivalent thermal gradient in a flat slab that would match a design sites likely average curvature. On average, warping is shown to have effects similar to thermal gradient magnitudes of about 2 to 3 degrees F per inch (0.044 to 0.066 deg C per mm) in arid regions, and about -1 to 0 degrees F per inch (-0.022 to 0 deg C per mm) in regions with high annual precipitation.

Application/Use: Predicting warping in Portland Cement Concrete (PCC) slabs can be used by those responsible for pavement management and pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The ability to effectively predict warping in PCC slabs is beneficial when determining the condition of PCC roadways and can assist pavement managers in being more strategic in for planning pavement rehabilitation on their road network. This research was significantly based on findings from the LTPP program.

Future Benefit: The LTPP program will continue to be a resource to the concrete industry and will help agencies better predict conditions of PCC pavements.

Title: Bitumen-Stabilized Materials: New Dimension in Flexible Pavements

Author(s): Collings, David Coppin

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
This paper explains the nature of a bitumen stabilized material and why these materials are being used to an ever increasing extent in the construction and rehabilitation of flexible pavements, worldwide. The characteristics of a bitumen stabilized material are explained together with their performance capabilities and comparisons made with other commonly used pavement materials. As with most new technologies, however, research has tended to lag behind usage and bitumen stabilization is no different. Initially regarded as a “poor man’s” asphalt, field performance proved different and only recently have the non-continuous binding properties of these materials been appreciated. Results emanating from applied research efforts (primarily in South Africa, Holland and the USA) are now providing an understanding of the behavior of these materials (particularly the non-continuously bonding) and their potential. The benefits of using bitumen stabilized materials in pavement structures are discussed. These include: ƒ{ their application to a wide range of materials, especially material recycled from existing pavements; ƒ{ immediate strength gain that allows the material to withstand early trafficking; ƒ{ energy savings; and ƒ{ durability aspects. These enhanced durability aspects have only recently been appreciated from long term pavement performance (LTPP) exercises. By selectively dispersing amongst the finer fraction only, the bitumen captures and immobilizes those particles that are susceptible to moisture. Additional benefits accrue from the hydrophobic nature of bitumen that prevents water from entering a layer of well-compacted material. The acceptance of this technology by various countries has been largely dictated by culture and economic health. It has now been used successfully on all continents (except Antarctica) and is gaining popularity, primarily due to the substantial savings in cost and energy emissions coupled with the promise of being a candidate for “Perpetual Pavement Material” classification when good quality materials are stabilized.

Application/Use: This study is directly related to pavement managers and designers.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology

Present Benefit: Knowing the advantages and applications of bitumen-stabilized materials in flexible pavements is beneficial for pavement designers and pavement managers in selecting cost-effective pavements with a higher overall performance. The LTPP program was essential in revealing the durability aspects of these materials in pavement designs.

Future Benefit: The LTPP program has been an invaluable resource in bringing advancements to the pavement industry. The LTPP database will continue to allow researchers to obtain a greater understanding of how various materials perform in pavement applications and how to achieve high performance pavements in a cost-effective manner.

Title: Application of Artificial Neural Networks for Estimating Dynamic Modulus of Asphalt Concrete

Author(s): Sakhaei Far, Maryam Sadat; Underwood, Benjamin Shane; Kim, Youngsoo Richard

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
This paper presents a research effort to develop estimates of the dynamic modulus (|E*|) of hot mix asphalt (HMA) layers on Long-Term Pavement Performance (LTPP) test sections. The goal of the work is the development of a new, rational and effective set of dynamic modulus |E*| predictive models for HMA mixtures. These predictive models use Artificial Neural Networks (ANNs) trained with the same set of parameters used in other popular predictive equations, the modified Witczak and Hirsch models. The main advantage of using ANNs for predicting the |E*| is that an ANN can be created for different sets of variables without knowing the form of the predictive relationship a priori. The primary disadvantage of ANNs is the difficulty in predicting responses when the inputs are outside of the training database, i.e., extrapolation. To overcome this shortcoming, a large data set that covers the complete range of potential input conditions is needed. For this study, modulus values from multiple mixtures and binders are required and have been assembled from existing national efforts and from data obtained at North Carolina State University (NCSU). The data consist of moduli measured using two test protocols, the Simple Performance Test (SPT) and AASHTO TP-62, and at different aging conditions. Prediction models are developed using a portion of the data from these databases and then verified using the remaining data in the database. The results show that the predicted and measured |E*| values are in close agreement using these new ANN models.

Application/Use: The ability to estimate the dynamic modulus of asphalt concrete is directly applicable for pavement designers and rehabilitation specialists.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology

Present Benefit: The dynamic modulus of asphalt concrete plays a significant role in determining the overall pavement strength. Thus, the ability to more accurately predict the dynamic modulus of asphalt pavements is a valuable asset to pavement designers and rehabilitation specialists, enabling them to more accurately predict the pavement strength and, therefore, more effectively identify the necessary strategies to maintain their network pavements. The LTPP database was the foundation for these prediction models. They could not have been generated without the data from the LTPP program.

Future Benefit: As these prediction models are used more widely by state and federal pavement engineers, the future benefits include higher performance pavements and more cost-effective designs. These benefits would not have been possible without the LTPP database. Furthermore, the LTPP database will continue to be an essential resource providing the foundation for further pavement-related discoveries.

Title: An Experimental Plan for Validation of an Endurance Limit for HMA Pavements

Author(s): Bonaquist, Ramon F.

Date: December 2008

Publisher: NCHRP Web Document No. 134, National Cooperative Highway Research Program

Abstract/Synopsis:
This report documents the work completed in National Cooperative Highway Research Program (NCHRP) Project 9-44. The objective of NCHRP Project 9-44 was to prepare a research plan and associated cost estimate for a future study to validate the endurance limit for hot mix asphalt (HMA) and to improve mechanistic-empirical pavement design. The primary product of NCHRP Project 9-44 is the HMA Endurance Limit Validation Study Research Plan. The planned research is based on the hypothesis that the endurance limit for HMA is the result of a balance of damage caused by loading and healing or damage recovery that occurs during rest periods. Under this hypothesis the primary objective in designing a flexible pavement to resist bottom initiated fatigue cracking will be to make sure that the damage induced by loading remains small enough so that healing occurs and there is no accumulation of damage over the life of the pavement. This is a significant departure from current cumulative or incremental damage models, which assume that no healing occurs and that each load cycle uses up a portion of the finite fatigue life of the HMA. This research plan includes the framework for a design procedure that is based on layered elastic analysis and compatible with the Mechanistic-Empirical Pavement Design Guide (MEPDG). It uses allowable strains to identify satisfactory conditions for full healing. The allowable strains are a function of the properties of the HMA, the pavement temperature, and the duration of rest periods between traffic loads. Five laboratory experiments that are needed to fully develop the procedure are described. Studies using data from completed accelerated pavement tests and test roads are proposed to verify critical aspects of the design procedure. Finally, an experiment to calibrate the design procedure using selected test sections from the Long Term Pavement Performance Program is presented.

Application/Use: The research associated with this project is directly applicable to researchers and research investors with an inquiry on the endurance limit of HMA pavements.

Contribution: Improvement in Knowledge

Present Benefit: As pavement designs continue to move toward a mechanistic-empirical approach, a better understanding of pavement behavior and its effect on pavement performance is critical. This research paper shows the need to further study the endurance limit for HMA pavements in order to improve mechanistic-empirical pavement design and also lists the associated costs for undergoing this study. In this proposed experiment, the LTPP database essential to calibrate the design procedure based on field data.

<u>Future Benefit:</u> The LTPP database will continue to be a source of information for researchers to further understand pavement behavior and its effect on pavement performance. As the LTPP program continues, it will further the advancement of the way pavements are designed, built, and maintained.

Title: Subgrade Resilient Modulus Prediction Models for Coarse and Fine-Grained Soils Based on Long-Term Pavement Performance Data

Author(s): Malla, Ramesh B; Joshi, Shraddha

Date: 2008

Publisher: International Journal of Pavement Engineering Vol. 9 No. 6

Abstract/Synopsis:
Resilient modulus (M and subscript R) of subgrade soils is the elastic modulus based on the recoverable strain under repeated loads and depends on several factors such as soil properties, soil type and stress states. This paper presents the prediction equations to estimate (M and subscript R) from a set of soil physical properties for the unified soil classification system soil types namely coarse-grained and fine-grained subgrade soils. Data extracted from long-term pavement performance information management system database for 259 test specimens of reconstituted soil samples from 19 states in New England and nearby regions in the USA and two provinces in Canada were used in this study. Generalised constitutive model consisting bulk stress and octahedral shear stress was used to predict the M and subscript R of subgrade soils by developing equations for the regression coefficients (k-coefficients) in the constitutive model that relates them to various soil properties. Prediction models were developed by conducting multiple linear regression analysis using computer software SAS and superscript®. To verify the prediction models, a set of fresh laboratory M and subscript R tests were conducted on representative New England subgrade soils using AASHTO standards. The laboratory test results show that the developed models predict M and subscript R values fairly well for the soils with their properties values within the range used in developing the prediction models.

Application/Use: The results from this study are directly applicable to state agency pavement managers and highway engineers regarding soil properties within the range used in developing prediction models.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The ability to more accurately predict the resilient modulus for coarse and fine-grained materials is of great benefit to state agency officials and pavement managers. Significant time and cost savings can be achieved by agencies knowing soil properties within the range used in developing the prediction models, as it will enable them to predict the resilient modulus with fewer field measurements. This study was heavily dependent upon the LTPP database to generate the prediction models.

Future Benefit: Field testing is one of the largest cost factors in pavement management for agencies. Therefore the ability to predict the subgrade moduli more accurately can result in significant cost savings. As agencies utilize these methods, they will be able to better strategize maintaining their pavement network. The LTPP database is an invaluable resource for researchers and engineers in developing cost-effective strategies to produce higher performance pavements. The LTPP database will continue to be the foundation for advancements in the pavement industry.

Title: Resilient Modulus Prediction Models Based on Analysis of LTPP Data for Subgrade Soils and Experimental Verification

Author(s): Malla, Ramesh B; Joshi, Shraddha

Date: September 2007

Publisher: Journal of Transportation Engineering Vol. 133 No. 9

Abstract/Synopsis:
Resilient modulus (MR) value of a subgrade soil is the primary property needed for pavement design and analysis. It is the elastic modulus based on the recoverable strain under repeated loads, and depends on several factors including soil properties, soil type, and state of stresses. This paper presents prediction equations developed using regression analysis for six AASHTO soil types (A-1-b, A-3, A-2-4, A-4, A-6, and A-7-6) for estimating MR. Data extracted from the Long-Term Pavement Performance Information Management System (LTPP IMS) database for 258 test specimens (approximately 3,870 MR values) collected in 19 states in New England and the nearby regions in the United States and two provinces in Canada were used in this study. A generalized constitutive model that captures the effect of both bulk stress and octahedral shear stress was used to predict the MR of subgrade soils by developing regression equations that relate the k coefficients to the soil physical properties. The prediction models developed were verified for four types of soils collected in the New England region by independent laboratory MR tests. It was observed that MR values from the prediction models compared well with the laboratory values for the majority of the soil types.

Application/Use: The results from this paper are directly applicable to state agency pavement engineers interested in estimating the resilient modulus values of subgrade soils.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The ability to accurately estimate the resilient modulus of subgrade soils has a valuable application in pavement design, and can assist pavement engineers in selecting cost-effective solutions by meeting the pavement needs without over-designing. The LTPP database was used to develop the prediction model in this study.

Future Benefit: The LTPP program has been an invaluable resource to pavement research and will continue to aid in the further advancement of the pavement industry. As prediction models are further developed and their effectiveness is investigated, the future benefit is significant in being able to cost-effectively design higher performing pavements.

Title: Backcalculation of Dynamic Modulus from Resilient Modulus of Asphalt Concrete with an Artificial Neural Network

Author(s): LaCroix, Andrew T; Kim, Youngsoo Richard; Ranjithan, S Ranji

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis:
The NCHRP Project 1-37A "Guide for Mechanistic–Empirical Design of New and Rehabilitated Pavement Structures" introduces the dynamic modulus (|E*|) as the material property for the characterization of hot-mix asphalt mixtures. This is a significant change from the resilient modulus used in the previous AASHTO "Guide for the Design of Pavement Structures." One of the challenges of changing the material characterization is that databases, such as the Long-Term Pavement Performance Materials Database, contain older material characterization information. Thus, such databases must convert their data to the currently accepted standard (i.e., |E*|). Other investigators have presented evidence that the resilient modulus can be predicted from the dynamic modulus by using the theory of viscoelasticity. By using their prediction method, this study proposes the population of a database of measured dynamic moduli with the corresponding predicted resilient moduli to train an artificial neural network (ANN). The ANN model was verified with four 12.5-mm surface course mixtures with different aggregate types and binder types and one 25.0-mm base mixture. The dynamic moduli predicted from the measured resilient moduli with the trained ANN were found to be reasonable compared with the measured dynamic moduli.

Application/Use: The results from this study are directly applicable to LTPP database engineers and secondarily applicable to pavement engineers using mechanistic-empirical pavement design methods.

Contribution: Cost Savings; Advancement in Technology; Lessons Learned

Present Benefit: The LTPP database has provided researchers and pavement engineers with information that has been used to improve current pavement design, evaluation, and rehabilitation methods. Therefore, as pavement design methods change, it is important that the LTPP database is updated to accommodate for these changes. This will better ensure that pavement engineers will be able to fully capitalize on the benefits of the LTPP database to develop cost-effective strategies to achieve higher performing pavements.

Future Benefit: As state agency pavement engineers continue to move toward mechanistic-empirical design methods, the dynamic modulus will become the dominant material property used to evaluate and design new and rehabilitated pavements. Therefore, updating the LTPP database to accommodate for these changes will better equip pavement managers and engineers in making cost-effective decisions to have the maximum impact on their pavement networks.

Title: Effects of Design and Material Modifications on Early Cracking of Continuously Reinforced Concrete Pavements in South Dakota

Author(s): Johnston, Daniel P; Surdahl, Roger W.

Date: 2008

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2081

Abstract/Synopsis:
Newer continuously reinforced concrete pavements (CRCPs) in South Dakota have exhibited undesirable levels and types of transverse cracking. This poor performance was not expected under the current recommended design practices. Research was undertaken to identify design, construction, and material issues that may be contributing to the undesirable cracking. After preliminary surveys of existing projects and analysis of the available Long-Term Pavement Performance CRCP data, a systematic construction program was initiated whereby changes in design and materials were incorporated and monitored for any beneficial effects. Beneficial changes were incorporated into projects scheduled for construction the following year and parameters were modified in order to distinguish with minimum ambiguity each parameter's effects on cracking behavior. The preliminary results are a series of recommended changes in design, construction, and materials, yielding normal and more desirable cracking patterns.

Application/Use: The results from this paper have applications in pavement design, rehabilitation, and construction practices.

Contribution: Cost Savings; Improvement in Knowledge; Lessons Learned

Present Benefit: A better understanding of the effects of construction practices, materials used, and designs implemented on pavement performance is significantly beneficial for pavement engineers. With this improved knowledge, designers will be able to better strategize to achieve a cost-effective design for continuously reinforced concrete pavements that will yield better overall performance. The LTPP database was an essential tool in achieving this project's success.

Future Benefit: The LTPP database has been an invaluable resource for further understanding pavement behavior so that more cost-effective design methods can be implemented to achieve pavements with better overall performance. As agencies utilize CRCPs in their network, it is imperative that they are able to determine the factors affecting overall performance. The future benefit is more cost-effective solutions for higher performing pavements.

Title: Backcalculation Analysis of Rigid Pavement Properties Considering Presence of Subbase Layer

Author(s): Fwa, T F; Setiadji, Bagus Hario

Date: 2008

Publisher: Transportation Research Board 87th Annual Meeting

Abstract/Synopsis:
The common backcalculation methods for evaluating rigid-pavement properties provide estimates of two parameters, namely the elastic modulus of pavement slab, Ec and the modulus of subgrade reaction, k. The backcalculated Ec and k allow the structural capacity of the rigid-pavement system to be computed readily. However, the backcalculated k is a composite value representing the combined effect of the subbase and the subgrade, it does not enable one to assess the existing structural condition of the subbase and subgrade separately. To overcome this shortcoming, this paper proposes the use of a 2-layer foundation backcalculation procedure to backcalculate the elastic modulus values Ec, Eb, and Es of the pavement slab, the subbase layer, and the subgrade respectively. Using LTPP measured data, it is shown that (i) the Ec computed by the Ec-k and the Ec-Eb-Es backcalculation schemes represent the upper- and lower-bound values respectively; (ii) although the parameters computed by the two backcalculation schemes, i.e. k versus Eb and Es, cannot be related directly by theory because they represent different theoretical foundation models, the two sets of values are found to provide consistent representation of the structural capacity of pavement foundation. This additional information permits the pavement engineer to better assess the structural condition of pavement slab, subbase and subgrade respectively. It is proposed that both the Ec-k backcalculation program and the Ec-Eb-Es backcalculation program be used in parallel to provide a more complete evaluation for rigid-pavement structures.

Application/Use: This study can be used for rigid pavement forensic investigation and by those interested in evaluating rigid pavement sublayer properties.

Contribution: Improvement in Knowledge

Present Benefit: This report investigates existing backcalculation results for LTPP test sections and also provides an alternative method for backcalculating the sublayer structural parameters in more detail, by backcalculating structural parameters of the subbase and subgrade separately. This information will be beneficial in identifying the conditions of the pavement structural layers, individually, which can be a significant tool. The LTPP database was used to compare the two different backcalculation methods and validate this alternative backcalculation method.

Future Benefit: The results from this study will provide future use in the areas of pavement evaluation, in situ material properties, and pavement design. The LTPP database is a very useful tool for pavement researchers and engineers and will continue to assist them in obtaining a better understanding of identifying more effective pavement evaluation methods of analysis.

Title: Effectiveness of Crumb Rubber Materials as Modifiers in Paving Asphalts

Author(s): MacLeod, Daryl; Johnston, Art; Ho, Susanna

Date: 2007

Publisher: Fifty-Second Annual Conference of the Canadian Technical Asphalt Association (CTAA); Polyscience Publications

Abstract/Synopsis:
This paper, from the proceedings of the 52nd Annual Conference of the Canadian Technical Asphalt Association (CTAA), reports on a study that used waste tire crumb rubber materials (CRM) as modifiers in paving asphalts. The effectiveness of CRM as a modifier was studied in terms of the Superpave specification, phase separation tests, elastic recovery, Dynamic Shear Rheometer (DSR) phase angle reduction, and multiple stress, creep and recovery tests. The authors found that the use of CRM in the asphalt was limited by the 135 deg. C viscosity or by the pumping and handling capabilities when the CRM levels were higher than 10.5 percent. The optimal CRM level was determined to be at 10.5 percent for PG 58-31 base asphalt. This asphalt mixture met all of the Superpave requirements, as well as the common Superpave Plus requirements, in the areas of phase angle, elastic recovery, and multiple stress creep and recovery. The authors then applied the Long-Term Pavement Performance (LTPP) program and the Transportation Association of Canada (TAC) model to select optimal levels of CRM and suitable base asphalts for the specific climatic conditions, high-temperature grade bumping protocol, traffic volume, and speed for the City of Lethbridge, Alberta, Canada. They report on the findings from three test sections in different Lethbridge locations with various traffic volumes; these locations were paved from 2003 to 2005.

Application/Use: This is directly applicable to materials selection/pavement design in Canada, but can also be useful to pavement managers and rehabilitation engineers in general.

Contribution: Cost Savings; Lessons Learned; Advancement in Technology; Implementation/Usage

Present Benefit: Using LTPP protocols as a model for data testing and collection, three test sites were constructed in Canada to determine the overall performance of using crumb rubber as a asphalt modifier. This experiment is useful to evaluate the practical implications of implementing crumb rubber as an optional asphalt modifier in pavements.

Future Benefit: As agencies continue to investigate the use of crumb rubber, this document will prove to be a valuable data source. Performance data along with key information on materials, construction, in situ conditions, and traffic will be an essential component to the evaluation of crumb rubber modifier applications.

Title: LTPP Computed Parameter: Dynamic Modulus

Author(s): Y. Richard Kim, Underwood B., Sakhaei Far M., Jackson N., Puccinelli, J.

Date: November 2009

Publisher: Federal Highway Administration

Abstract/Synopsis: The dynamic modulus, |*E**|, is a fundamental property that defines the stiffness characteristics of hot mix asphalt (HMA) mixtures as a function of loading rate and temperature. In spite of the demonstrated significance of the |*E**|, it is not included in the current long-term pavement performance (LTPP) materials tables because the database structure was established long before the |*E**| was identified as the main HMA property in the MEPDG. As such, the objective of the Dynamic Modulus project was to use readily available binder, volumetric, and resilient material properties in the LTPP database to develop |*E**| estimates. This report provides a thorough review of existing prediction models. In addition, several models have been developed using Artificial Neural Networks (ANNs) for use in this project. Included in the report are assessments of each model, quality control checks applied to the data, and the final structure and format of the dynamic modulus data added to the LTPP database. A program was also developed to assist in populating the LTPP database, and the details on the program are provided in the report.

Application/Use: This study is directly applicable to pavement designers and pavement researchers interested in the relationship between E* and pavement performance.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: With the addition of the E* modulus in the LTPP database, a better understanding of the relationship between the dynamic modulus and pavement performance can be obtained. Pavement researchers can now use the extensive data in the LTPP database to relate pavement performance with the dynamic modulus. With a better understanding of how the dynamic modulus relates to pavement performance, designers may be able to improve their designs and cost-effectively develop higher performing pavements.

Future Benefit: The LTPP database may be used to develop mathematical models to predict pavement performance based on the dynamic modulus of the asphalt concrete. The LTPP program has been instrumental in bringing advancements to the pavement industry, and will continue to be an invaluable resource in gaining a better understanding of pavement behavior and for developing cost-effective strategies to improve pavement performance.

Title: Calibrating the Aging Difference between In-Service Fatigue Performance of Flexible Pavements and Accelerated Pavement Testing

Author(s): Guo, Runhua; Prozzi, Jorge A.

Date: 2006

Publisher: American Society of Civil Engineers

Conference Title: Airfield and Highway Pavements. Proceedings of the 2006 Airfield and Highway Pavement Specialty Conference

Abstract/Synopsis: Accelerated Pavement Testing (APT) programs have led to advances in practice and economic savings. Because of the limited

Title: Determination of Typical Resilient Modulus Values for Selected Soils in Wisconsin

Author(s): Titi, Hani H; Elias, Mohammed B; Helwany, Sam

Date: 2006

Publisher: University of Wisconsin, Milwaukee; Wisconsin Department of Transportation; Federal Highway Administration

Abstract/Synopsis: The objective of this research is to develop correlations for estimating the resilient modulus of various Wisconsin subgrade soils from basic soil properties. A laboratory testing program was conducted on common subgrade soils to evaluate their physical and compaction properties. The resilient modulus of the investigated soils was determined from the repeated load triaxial test following the American Association of State Highway and Transportation Officials (AASHTO) T 307 procedure. The laboratory testing program produced a high quality and consistent test results database. The high quality test results were assured through a repeatability study and also by performing two tests on each soil specimen at the specified physical conditions. The resilient modulus constitutive equation adopted by National Cooperative Highway Research Program (NCHRP) Project 1-37A was selected for this study. Comprehensive statistical analysis was performed to develop correlations between basic soil properties and the resilient modulus model parameters k sub i. The analysis did not yield good results when the whole test database was used. However, good results were obtained when fine-grained and coarse-grained soils were analyzed separately. The correlations developed in this study were able to estimate the resilient modulus of the compacted subgrade soils with reasonable accuracy. In order to inspect the performance of the models developed in this study, comparison with the models developed based on the Long-Term Pavement Performance (LTPP) database was made. The LTPP models did not yield good results compared to the models proposed by this study. This is due to differences in the test procedures, test equipment, sample preparation, and other conditions involved with development of both LTPP and the models of this study.

Application/Use: This study is applicable to materials and pavement engineers interested in the resilient modulus of subgrade.

Contribution: Improvement in Knowledge

Present Benefit: This study provides information that will be beneficial to using the M-E PDG. The ability to relate soil properties to resilient modulus model parameters will result in better estimates of resilient modulus and better pavement performance predictions. The LTPP database has provided a reference set of data that was used to evaluate the dataset developed in the study.

Future Benefit: The future benefit provided by this study will be realized as the M-E PDG is implemented and subgrade estimations are needed.

Title: Effect of Design and Site Factors on Long-Term Performance of Flexible Pavements in SPS-1 Experiment

Author(s): Chatti, Karim

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: Results are presented from a study to evaluate the relative influence of design and site factors on the performance of in-service flexible pavements. The data are from the SPS-1 experiment of the Long-Term Performance Pavement (LTPP) program. This experiment was designed to investigate the effects of HMA surface layer thickness, base type, base thickness, and drainage on the performance of new flexible pavements constructed in different site conditions (subgrade type and climate). Base type was found to be the most critical design factor affecting fatigue cracking, roughness (IRI), and longitudinal cracking (wheel path). The best performance was shown by pavement sections with asphalt treated bases (ATB). This effect should be interpreted in light of the fact that an ATB effectively means a thicker HMA layer. Drainage and base type, when combined, also play an important role in improving performance, especially in terms of fatigue and longitudinal cracking. Base thickness has only secondary effects on performance, mainly in the case of roughness and rutting. In addition, climatic conditions were found to have a significant effect on flexible pavement performance. Longitudinal cracking (wheel path) and transverse cracking seem to be associated with a wet-freeze environment, while longitudinal cracking (non-wheel path) seems to be dominant in a freeze climate. In general, pavements built on fine-grained soils have shown the worst performance, especially in terms of roughness. Although most of the findings from this study support the existing understanding of pavement performance, they also provide an overview of the interactions between design and site factors and new insights for achieving better long-term pavement performance.

Application/Use: This study is used by those interested in the contribution of design factors on flexible pavement performance.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The present benefit for this study is an understanding in the interaction between design parameters and climate and the resultant changes in pavement performance. The LTPP database provides a means of conducting this type of study on a national scale.

Future Benefit: The findings from this study will be useful in transferring mechanistic evaluations to field performance for various design parameters.

Title: Effects of Base Type on Modeling of Long-Term Pavement Performance Continuously Reinforced Concrete Sections

Author(s): Johnston, Daniel P.; Surdahl, Roger W.

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: Newer continuously reinforced concrete (CRC) pavements in South Dakota have exhibited undesirable levels of transverse cracking. This poor performance was not expected under the current recommended design practices. Long Term Pavement Performance (LTPP) CRC pavement data, previously analyzed by others, also could not account for the cracking. To seek an explanation the original LTPP CRC data was reanalyzed using a more thorough approach. Using multiple regression techniques on selected LTPP CRC data sets of comparable accuracy, consequential conclusions can be drawn once the base types are separated into subsets in the database. A similar model was developed for newer CRC pavements in South Dakota and showed the same response variables as the LTPP subset for granular bases. Significant correlation was found between cracks and steel depth, cracks and steel size, and cracks and pavement thickness, such that recommendations are made for South Dakota to decrease the steel depth and decrease the steel size and percentage. The nominal top size of the coarse aggregate was also found to be a significant contributor to crack width with a shift from 3/4" to 1-1/2" resulting in a reduction in crack width and a much slower development of cracking over time.

Application/Use: The study has been used by South Dakota Department of Transportation to evaluate current and future CRCP specifications.

Contribution: Cost savings; Improvement in Knowledge.

Present Benefit: The materials and inventory data in the LTPP database along with performance monitoring provided the information required to evaluate CRCP in South Dakota. Determining factors that can improve performance is beneficial to the state highway agency as well as the traveling public.

Future Benefit: The findings from this study will be used to guide future work and specification changes in South Dakota. The LTPP database will continue to afford studies such as this to be conducted as long as the data remains accessible.

Title: Establish Subgrade Support Values for Typical Soils in New England

Author(s): Malla, Ramesh B; Joshi, Shraddha

Date: 2006

Publisher: University of Connecticut, Storrs; New England Transportation Consortium

Abstract/Synopsis: The main objective of this research project was to establish prediction models for subgrade support (resilient modulus, M sub R) values for typical soils in New England. This soil strength property can be measured in the laboratory by means of repeated load triaxial tests. Nondestructive tests like Falling Weight Deflectometer (FWD) can be used to estimate the modulus value using the backcalculation process. The current study used data extracted from the Long Term Pavement Performance Information Management System (LTPP IMS) Database for 300 test specimens from 19 states in New England and nearby regions in the U.S. and 2 provinces in Canada. Prediction equations were developed using SAS® for six AASHTO soil types, viz. A-1-b, A-3, A-2-4, A-4, A-6, and A-7-6, and Unified Soil Classification Systems (USCS) soil types Coarse Grained Soils and Fine Grained Soils found in the New England region to estimate M sub R. To verify the prediction models, M sub R values for 5 types of soils in New England were determined from laboratory testing using AASHTO standards. The predicted and laboratory measured M sub R values matched reasonably well for the soils considered. Also an attempt was made to obtain the relationship between laboratory M sub R values and the FWD backcalculated modulus from the LTPP test data. No definitive conclusion could be drawn from the analysis. However, in general, FWD backcalculated modulus values were observed to be greater than the laboratory determined modulus values for the same soil type.

Application/Use: This study will be used by materials and pavement engineers looking for resilient modulus estimates for subgrade material in the New England area.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: Accurate estimates for subgrade resilient modulus are necessary for proper pavement design. The models developed will be a useful pavement design tool, particularly in scenarios where resilient modulus data was not obtained. Information on the relationship between FWD backcalculated results and measured resilient modulus can be useful in design as well.

Future Benefit: Pavement designs in New England may be based on correlations derived from this study. Additional benefit will be realized in further investigations of backcalculation and FWD data.

Title: Evaluation of Backcalculation Methods for Nondestructive Determination of Concrete Pavement Properties

Author(s): Fwa, T F; Setiadji, Bagus Hario

Date: 2006

Publisher: Transportation Research Board

Journal: Transportation Research Record: Journal of the Transportation Research Board No. 1949

Abstract/Synopsis: Different backcalculation algorithms often give different answers in backcalculated pavement properties. This is because of the differences in the type of pavement models, solution search procedure, and deflection matching criteria used in the backcalculation analysis. Regardless of the theory applied and the backcalculation algorithm adopted, a logical basis of selection of the backcalculation procedure for practical applications would be to assess whether the backcalculated pavement properties could provide good estimates of the actual pavement properties. Today, the ease and the convenience of access to the Long-Term Pavement Performance (LTPP) database of actual measured data enable a highway agency to adopt this approach to select a backcalculation algorithm that meets its needs. With the LTPP-measured data, this approach was applied to evaluate the relative merits of four backcalculation algorithms (two versions of ILLIBACK, NUSBACK, and LTPP best-fit method) by a comparison of the computed elastic modulus of concrete pavement slab and the modulus of subgrade reaction of concrete pavements against the LTPP measured values. The performance of the four algorithms was greatly affected by the constraints imposed by the deflection theory adopted and was significantly dependent on their respective criteria used to match the computed and measured deflections. The number of sensors used in the backcalculation, as well as the choice of sensor configuration, can significantly affect the performance of the backcalculation algorithms.

Application/Use: This study can be used by those interested in backcalculation of concrete pavements.

Contribution: Improvement in Knowledge

Present Benefit: Understanding the accuracy of backcalculation results and the influences on various factors on backcalculation processes is very important in pavement design and evaluation. The LTPP database offers FWD data as well as information on pavement structure and material along with monitored performance which provides a means of conducting backcalculation studies.

Future Benefit: The results from this paper will add value in future FWD analyses. Additionally, the LTPP data will continue to provide a source of data not available outside of LTPP.

Title: Evaluation of Resilient Modulus Model Parameters for Mechanistic–Empirical Pavement Design

Author(s): Elias, Mohammed B; Titi, Hani H.

Date: 2006

Publisher: American Society of Civil Engineers

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1967

Abstract/Synopsis: Correlations were developed to estimate the resilient modulus of various Wisconsin subgrade soils from basic soil properties. A laboratory testing program was conducted on common subgrade soils to evaluate their physical and compaction properties. The resilient modulus of the investigated soils was determined from repeated load triaxial testing according to the AASHTO T 307 procedure. The laboratory testing program produced consistent results and a high-quality database. The resilient modulus constitutive equation adopted by NCHRP Project 1-37A was selected for this study. Comprehensive statistical analysis was performed to develop correlations between basic soil properties and the resilient modulus model parameters k sub i. The analysis did not yield good results when the whole test database was used. However, good results were obtained when fine-grained and coarse-grained soils were analyzed separately. The correlations developed were able to estimate the resilient modulus of the compacted subgrade soils with reasonable accuracy. To inspect the performance of the models developed in this study, comparison with the models developed on the basis of the Long-Term Pavement Performance (LTPP) database was made. The LTPP models did not yield good results compared with the models proposed by this study because of differences in the test procedures, test equipment, sample preparation, and other conditions involved with development of both LTPP and the models of this study.

Application/Use: This study is applicable to materials and pavement engineers interested in the resilient modulus of subgrade.

Contribution: Improvement in Knowledge

Present Benefit: This study provides information that will be beneficial to using the M-E PDG. The ability to relate soil properties to resilient modulus model parameters will result in better estimates of resilient modulus and better pavement performance predictions. The LTPP database provided a reference data set that was used to evaluate the dataset developed in the study.

Future Benefit: The future benefit provided by this study will be realized as the M-E PDG is implemented and subgrade parameter estimations are needed.

Title: Guidance on Minimum Roadway Placement Temperatures Technical Advisory

Author(s): Texas Department of Transportation, Construction Division

Date: March, 2006

Publisher: Texas Department of Transportation

Abstract/Synopsis: The 2004 Standard Specifications contain wording that addresses minimum roadway surface temperatures for placing hot mix asphalt. Stone matrix asphalt (SMA) and permeable friction course (PFC) mixes represent the extreme case since they require that the roadway surface temperature be 70°F or higher, unless otherwise approved prior to paving. On more common mixes such as dense graded hot mix asphalt and performance design hot mix asphalt, the specifications state the following: “Place mixture when the roadway surface temperature is 60°F or higher unless otherwise approved.” A number of individuals have asked the question: “When is it appropriate to approve paving pavement temperatures lower than 60°F?” While there are times when waiving or lowering the pavement surface temperature requirements will not have a significant adverse impact on the performance of the mix, there are cases where low pavement surface temperatures can have a serious, detrimental effect on mix performance. This document provides some background and guidance regarding minimum pavement temperatures.

Application/Use: The technical advisory is directly applicable to pavement construction specifications in Texas.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The guidance provided in this document is intended to assist materials engineers and construction managers on determining minimum paving temperatures. The LTPP database is recommended for use in determining the number of days that would be lost with modified specifications. This technical advisory is an excellent example of how the LTPP database can be applied to various practical applications.

Future Benefit: It is well recognized that the LTPP database will continue to support research in the pavement community. While the future benefit provided by the program to endeavors outside of pavement engineering is not as obvious, it is likely that the LTPP program will enable evaluations that otherwise could not have been performed. In other cases, the LTPP program will supplement existing information to produce more robust findings.

Title: Guidelines for Review and Evaluation of Backcalculation Results

Author(s): Stubstad, R. N; Jiang, Y J; Lukanen, E. O.

Date: 2006

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: This document presents a new approach to determining layered elastic moduli from in situ load-deflection data, which was developed under the Federal Highway Administration's project for reviewing Long-Term Pavement Performance (LTPP) backcalculation data. This approach is called forwardcalculation, and it differs from backcalculation in that modulus estimates are calculated directly from the load and deflection data using closed-form formulae rather than through iteration. The closed-form forwardcalculation equations are used for the subgrade and the bound surface course, respectively, for both flexible and rigid pavement falling weight deflectometer (FWD) data. Intermediate layer moduli are estimated through commonly used modular ratios between adjacent layers. The audience for this document includes highway agency engineers, researchers, and consultants who are involved in pavement analysis, design, construction, and deflection data analysis.

Application/Use: The approach proposed in this paper can be utilized by pavement analysts and designers using FWD data in their evaluations.

Contribution: Improvement in Knowledge

Present Benefit: The methodology developed in this study is an additional tool for those in the pavement community. FWD data is useful in determining the structural adequacy of existing pavements, estimating subgrade properties, void detection, and load transfer efficiency.

Future Benefit: The data available from LTPP will benefit future studies looking at new procedures to analyze FWD data. This information will also support validation of existing procedures.

Title: Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide

Author(s): Simpson, A.L; Schmalzer, P.N; Rada, G.R.

Date: 2006

Publisher: FHWA, Office of Infrastructure Research and Development, McLean, VA

Abstract/Synopsis: The LTPP Laboratory Material Testing Guide was originally prepared for laboratory material handling and testing of material specimens and samples of asphalt materials, Portland cement concrete, aggregates and soils under the supervision of the Strategic Highway Research Program. This version of the Guide has been updated to provide a historical reference document for analysts of the LTPP data. It provides the basis for the quality control program used in performing the laboratory testing, the protocols used in testing the material samples, and the guidelines for handling these samples in the laboratory. Additionally, this document provides the guidelines used for identifying the pavement structure based on the material properties of the sampled layers.

This guide is supplemented by various other documents including:

- LTPP Materials Directives

Application/Use: The guide documents the LTPP processes and procedures in performing laboratory testing. Including previous versions, it has been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Advancement in Technology; Implementation/Usage.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the Guide allows the test results from various laboratories to be compared without applying adjustment factors. The Guide also provides information on the codes utilized in the LTPP Information Management System (IMS) and the proper population of key testing tables in the IMS (i.e., TST_L05B).

Recognizing the need for an improved test procedure, LTPP made a considerable investment into the development of the unbound resilient modulus testing protocol (P46). This protocol is included in the Guide—and is discussed in more detail elsewhere in this report.

Future Benefit: The Guide will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available data with newly sampled materials, the Guide provides the information necessary to do so.

Title: LTPP Materials Reference Library (MRL)

Date: 2006

Publisher: FHWA

Abstract/Synopsis: The MRL is a storage facility used to collect highway materials consisting of asphalt cement, portland cement, natural aggregates, or a combination of materials. The MRL also includes a film storage facility and houses LTPP seasonal and weather equipment. The LTPP program currently maintains the MRL to store materials collected at LTPP General Pavement Study and Specific Pavement Study sites throughout the United States and Canada. In addition, the facility contains asphalt and aggregate specimens from the Strategic Highway Research Program (SHRP) and material samples from the WesTrack project. Upon approval from FHWA, all of these materials are available to researchers.

Application/Use: To date, the MRL has filled 46 requests to researchers from seven countries around the world. This equates to over 8.5 tons of material from sites that have field performance monitoring data available.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: Understanding the relationship between laboratory-derived and actual field performance is essential to proper M-E pavement design. Materials collected, tested, and stored as part of the LTPP program are extremely valuable because the material can be linked to years of in-service performance monitoring data.

Future Benefit: A future benefit that will come from the LTPP program is the availability of materials for evaluating new testing protocols, which can be linked to in-service performance.

Title: Network-Level Evaluation of Specific Pavement Study-2 Experiment: Using a Long-Term Pavement Performance Database

Author(s): Buch, Neeraj; Chatti, Karim; Haider, Syed Waqar; Pulipaka, Aswani S; Lyles, Richard W; Gilliland, Dennis

Date: 2006

Publisher: Transportation Research Board

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1947

Abstract/Synopsis: The research described here was conducted as a part of NCHRP Project 20-50 (10&16), LTPP (Long-Term Pavement Performance) Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements. The relative effects of various design and site factors on the performance of jointed plain concrete (JPC) pavements are presented. The data used in this study were primarily drawn from Release 17 of DataPave. The Specific Pavement Study (SPS) 2 experiment was designed to investigate the effects of portland cement concrete (PCC) slab thickness, base type, drainage, PCC flexural strength, and slab width on the performance of JPC pavements. On the basis of the statistical analysis of 167 test sections, ranging in age from 5 to 12 years, it was concluded that base type was the most critical design factor affecting performance in terms of cracking and roughness as measured by the international roughness index. Pavement sections with a permeable asphalt-treated base and in-pavement drainage performed better than those with a dense-graded aggregate base or a lean concrete base.

Application/Use: The results from this study can be used by pavement engineers in evaluating the contribution of design features on pavement performance.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: The SPS-2 projects constructed and monitored as part of the LTPP program are extremely beneficial. At each site, at least 12 test sections, consisting of various base types, drainage, slab thicknesses, flexural strengths, and slab widths are located consecutively. This provides an opportunity to make direct comparisons between design features because other factors such as traffic, subgrade conditions, and climate are constant. These in-service pavements offer a wealth of knowledge that is not readily available elsewhere. Findings from this evaluation can be used to determine the cost-effectiveness of design features for specific applications. Efficient and proper pavement design can lead to significant cost savings.

Future Benefit: As the pavement community moves towards M-E PDG, the SPS-2 projects will play a vital role in the local calibration of the guide.

Title: Portland Cement Concrete Coefficient of Thermal Expansion Input for Mechanistic-Empirical Pavement Design Guide

Author(s): Tanesi, Jussara; Hossain, Mustaque; Khanum, Taslima; Schieber, Greg; Montney, Rodney A.

Date: 2006

Publisher: Transportation Research Board

Abstract/Synopsis: Portland cement concrete (PCC) has a positive coefficient of thermal expansion (CTE). The CTE is an important input parameter for the Jointed Plain Concrete Pavement (JPCP) design following the Mechanistic-Empirical Pavement Design Guide (MEPDG) because of its effect on critical PCC slab stresses and also on joint and crack openings. MEPDG suggests the use of PCC CTE input at three hierarchical levels depending upon the efficacy of design – level 1 from actual tests for highest accuracy; level 2 from less than optimal testing or by calculations considering the PCC as a matrix of aggregates and hardened cement paste and knowing their individual CTE's; and level 3 from agency database or knowledge. The effect of these hierarchical input levels of CTE on the predicted JPCP performance for six in-service pavement sections in Kansas were studied in this paper. The CTE results from the Long Term Pavement Performance (LTPP) projects in Iowa, Kansas, and Missouri were also reviewed. The results show that the range of measured PCC CTE values in Kansas according to the AASHTO TP-60 protocol is quite wide. The calculated PCC CTE value is always higher than the measured value. The effect of PCC CTE input on predicted roughness International Roughness Index (IRI) is more pronounced for JPCP with thinner slab or lower PCC strength. A combination of high cement factor and higher PCC CTE would result in higher JPCP faulting. In general, faulting is very sensitive to this input. PCC CTE also has a very significant effect on slab cracking. However, it does not affect the predicted IRI for a JPCP with widened lane and tied PCC shoulder. Level 2 CTE input may result in more conservative JPCP design than that using Level 1 input. The detrimental effects of high CTE value can be mitigated using higher PCC slab thickness, larger diameter dowel bars or widened lane with tied PCC shoulder. Among these alternatives, the widened lane appears to be the most effective solution since no additional cost is necessary for this strategy.

Application/Use: The findings from this paper will be used by those interested in the effect of CTE on predicted performance in the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Determining the variability in CTE provides valuable information to materials and pavement engineers. Additionally, evaluating the interaction between CTE and other design parameters can offer insight into the M-E PDG. A benefit provided by LTPP is the availability of materials data that can be used in evaluation studies such as this.

Future Benefit: This study will be beneficial in the future as the M-E PDG continues to be evaluated and implemented.

Title: Review of the Long-Term Pavement Performance Backcalculation Results Final Report

Author(s): Stubstad, R. N; Jiang, Y J; Clevenson, M L; Lukanen, E. O.

Date: 2006

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: A new approach to determine layered elastic moduli from in situ load-deflection data was developed. This "forwardcalculation" approach differs from backcalculation in that modulus estimates come directly from the load and deflection data using closed-form formulae rather than iteration. The forwardcalculation equations are used for the subgrade and the bound surface course for both flexible and rigid pavement falling weight deflectometer (FWD) data. Intermediate layer moduli are estimated through commonly used modular ratios between adjacent layers. The entire Long-Term Pavement Performance (LTPP) set of backcalculated parameters was screened using forwardcalculated moduli. Any assumed or fixed modulus value was left as is and not further screened (e.g., hard bottom). Further, any back- or forwardcalculated values outside a broad range of reasonable values were not further screened, but flagged as unreasonable. Finally, a set of broad range convergence flags (0=acceptable, 1=marginal, 2=questionable, and 3=unacceptable) were applied to the backcalculated dataset, depending on how closely the pairs of back- and forwardcalculated moduli matched. Since both techniques used identical FWD load-deflection data as input, the moduli derived from each approach should be reasonably close to each other (within a factor of 1.5 to qualify as acceptable, for example). Although backcalculated values cannot be rejected merely because they are outside a reasonable or acceptable range, the complementary forwardcalculated values were usually more stable on a section-by-section basis. The exception was the portion of the database based on slab-on-dense-liquid or slab-on-elastic-solid theory, where the correspondence between the two approaches was excellent and very stable. Therefore, it is recommended that the backcalculated database be retained as is, with the addition of checks and flags so the database user can choose the best method, depending on the application.

Application/Use: This evaluation can be used by those looking at FWD data in the LTPP database.

Contribution: Improvement in Knowledge

Present Benefit: Independent reviews conducted on the LTPP database are essential to ensure quality. Quality data benefits users of the data. The development and investigation of a fowardcalculation process also adds benefit by providing an additional tool for those evaluating FWD data.

Future Benefit: The data available from LTPP will benefit future studies looking at new procedures to analysis FWD data. This information will also support validation of existing procedures.

Title: Seasonal Variations in the Moduli of Unbound Pavement Layers

Author(s): Richter, Cheryl A.

Date: 2006

Publisher: Federal Highway Administration

Abstract/Synopsis: The in situ moduli of unbound pavement materials vary on a seasonal basis as a function of temperature and moisture conditions. Knowledge of these variations is required for accurate prediction of pavement life for pavement design and other pavement management activities. The primary objective of this study is to advance the rational estimation of seasonal variations in backcalculated pavement layer moduli using data collected via the Seasonal Monitoring Program of the Long-Term Pavement Performance Program. Principal components of this endeavor included: evaluation of the moisture predictive capabilities of the Enhanced Integrated Climatic Model (EICM); development of empirical models to predict backcalculated pavement layer moduli as a function of moisture content, stress state, and other explanatory variables; and trial application of the models developed to predict backcalculated moduli for unbound pavement layers. This investigation yielded two key findings. First, it provided the impetus for developing EICM Version 2.6 by demonstrating the practical inadequacies of EICM Versions 2.0 and 2.1 when applied to the prediction of in situ moisture content, and then demonstrated that substantial improvement in the moisture predictive capability of the EICM had been achieved in Version 2.6. Second, the research identified fundamental discrepancies between layer moduli backcalculated using linear-layered elastic theory and the laboratory resilient modulus test conditions. Other important findings included (1) variation in moisture content is not always the most important factor associated with seasonal variations in pavement layer moduli, and (2) a model form that fits linear elastic backcalculated moduli reasonably well. The overall accuracy of the modulus predictions achieved in the trial application of the predictive models was not fully acceptable. Several avenues for further research to improve upon these results are identified.

Application/Use: The findings from this study were used to update the EICM, which is used directly in the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Improvement to the EICM provides benefit by improving the prediction capability of the M-E PDG. Additional understanding of the relationship between backcaluclated layer moduli and linear-layered elastic theory is also a direct benefit from this study.

Future Benefit: The use of the updated EICM will increase in value as the M-E PDG is implemented and used. Along those lines, understanding changes in moduli with season and the correlation between backcaclulated and laboratory values will prove to be beneficial to designers in the future.

Title: Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications – Volume 1: Influence of Drainage on Selection of Base

Author(s):

Title: Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications - Volume 1: Influence of Drainage on Selection of Base

Author(s): Sargand, Shad M; Wu, Shin; Figueroa, J. Ludwig

Date: 2006

Publisher: Ohio University, Athens; Ohio Department of Transportation; Federal Highway Administration

Abstract/Synopsis: The primary objective of this study was to investigate how base materials should be properly selected for specific types of pavement, not only considering the performance of individual layers but also how they interact in the total pavement structure. Base types considered in this study included granular (GB), lean concrete (LCB), asphalt treated (ATB), cement treated (CTB), and permeable asphalt treated (PATB) bases as constructed under both asphalt concrete (AC) and Portland cement concrete (PCC) pavements. The Long Term Pavement Performance (LTPP) Seasonal Monitor Program (SMP) sites investigated for this report included four SMP sections in the North Carolina SPS-2 experiment on US52 and thirteen SMP sections in the SPS-1 and SPS-2 experiments on the Ohio SHRP Test Road on US23. The NC site contained two GB and two LCB sections, and the OH site contained eight GB, one ATB, two PATB, and two LCB sections. The NC sites are located in a wet-no-freeze zone and OH sites are located in a wet-freeze zone. Environmental data were collected via seasonal monitors and time domain reflectometry. The effects of service were measured by conducting surface profiles and falling weight deflectometer (FWD) measurements. It was found that the type of base had little impact on subgrade moisture. The choice of base depends chiefly on three requirements: appropriate stiffness, sufficient permeability, and good constructability. Guidelines for the selection of base under flexible and rigid pavements are given.

Application/Use: This study will be used by those interested in the effect of base type on subgrade moisture and pavement performance.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The proper material selection and pavement design are critical to a well performing and efficient pavement section. This study provides information that is beneficial to designers.

Future Benefit: As pavement design moves towards the M-E PDG, understanding the effect of base type on moisture content will be necessary to estimate the strength of subgrade materials.

Title: Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications – Volume 3: Stiffness and Modulus Estimation for Different Soil Types Using FWD Deflection Criteria

Author(s): Sargand, Shad; Huntae, Kim

Date: December 2006

Publisher: Ohio Department of Transportation

Abstract/Synopsis: In current U.S. practice, quality of subgrade in a pavement system is commonly evaluated using the degree of compaction in the field and comparing with the laboratory determined maximum dry density from Standard/Modified Proctor tests (AASHTO T-99/T-180) to confirm the degree of compaction. However density is inherently an indirect measurement of the subgrade quality. This report studies the use of nondestructive testing (NDT) devices, such as the Falling Weight Deflectometer (FWD), to directly and quickly measure subgrade and base stiffness and/or modulus. This study's main objective was assessment of material-specific stiffness and soil modulus of unbound granular soil materials using deflection data from 146 sections in ten states in the nationwide pavement database. In some cases, insufficient or unavailable in-situ soil data were supplemented with laboratory measurements. Calculation of stiffness and soil modulus was based on the linear elastic theory of granular soil material. To achieve high reliability of output results, establishment of the data screening procedures was another major concern in this study. Also, correlations between major engineering properties and stiffness or modulus of unbound granular materials were performed for validation of output results. Statistics for modulus and stiffness of 11 types of subgrade soils are presented, including mean with 95 percent confidence interval, median, standard deviation, and interquartile range. Similar statistics are given for bases made from aggregate or aggregate mixed with soil. The subgrade modulus is then correlated with various engineering properties, including moisture content, maximum dry density, plasticity index, and grain size distribution. Calculated mean stiffness and modulus values for base materials and coarse-grained soils agreed with typical previously published values, while those for fine-grained soils did not. For coarse-grained soils, modulus increased as moisture decreased, except below a threshold below which soil was too dry and modulus decreased. Well-graded soil had a higher modulus. The correlation analysis showed that for fine-grained soils, modulus was sensitive to the plasticity index, the weighted plasticity index, and number of fines. Stiffness and modulus for coarse-grained soils showed a good agreement and reliable relationship with other soil properties. Measured stiffness and modulus values in the pavement database exceeded the European standards, and all soils had been approved for construction. For practical purposes, subgrade stiffness and soil modulus values at the 25th percentile could be considered as the minimum limiting criteria for AASHTO soil types A-1, A-1-a, A-1-b, A-2-4, and A-2-6. Similarly, base stiffness and base modulus values at the 25% percentile appear to be reasonable as a minimum criterion. A table of values is given.

Application/Use: This is directly applicable to subgrade quality and construction specifications.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: This study illustrates how the LTPP database can be used to develop new construction quality evaluation techniques. In this case, the database was used to correlate FWD data to construction quality of subgrade materials.

Future Benefit: It is well recognized that the LTPP database will continue to support research in the pavement community. While the future benefit provided by the program to endeavors outside of pavement engineering is not as obvious, it is likely that the LTPP program will enable evaluations that otherwise could not have been performed. In other cases, the LTPP program will supplement existing information to produce more robust findings.

Title: Verification of the Rate of Asphalt Mix Aging Simulated by AASHTO PP2-99 Protocol

Author(s): Zapata, Claudia E; Raghavendra, Suresh

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: This paper describes how it is well documented that environmental effects play a significant role in modifying the material properties, which in turn affect the pavement performance. Studies under the Strategic Highway Research Program (SHRP) were carried out to study the oxidative age hardening characteristics of asphalt binders and mixes. As a result, laboratory procedures to simulate the field-hardening of asphalt binders and mixes were developed. These procedures were adopted by American Association of State Highway and Transportation Officials (AASHTO) as Provisional Protocols PP1-98 and PP2-99. A research study, National Cooperative Highway Research Program (NCHRP) 9-23, was initiated to verify these protocols, identify their limitations, and make recommendations to enhance their predictive capabilities. This paper is a part of the NCHRP 9-23, which deals with the PP2-99 Protocol. Binders and field cores were obtained from Long Term Pavement Performance (LTPP) and other sites across the United States. Plant-mix, laboratory-aged cores, and field-aged cores were characterized using complex modulus (E*) testing. Verification of the existing protocol was carried out using the data collected from testing. Warmer climates resulted in higher aging compared to cooler climates. Laboratory cores were found to have more uniform aging profiles than field cores. Hence, it was concluded that the existing protocol is insufficient to accurately predict the field aging of asphalt mixes. Based on the findings, recommendations were made for future research work and subsequent improvement of the protocol. The recommendations apply only for asphalt mixes containing conventional, non-modified binders.

Application/Use: Findings from this study can be used to better understand the relationship between laboratory and field performance of asphalt binders with respect to age hardening/oxidation.

Contribution: Improvement in Knowledge.

Present Benefit: Improving asphalt concrete mixture characterization and performance testing protocols will be extremely beneficial to the pavement community. Understanding the relationship between laboratory-derived and actual field performance is essential to proper M-E pavement design. Materials collected, tested, and stored as part of the LTPP program are extremely valuable because the material can be linked to years of in-service performance monitoring data.

Future Benefit: The findings in this study may be used to assess and revise existing testing protocols. A future benefit that will come from the LTPP program is the availability of materials for evaluating new testing protocols, which can be linked to in-service performance.

Title: Development of an Automated Procedure for Implementing Resilient Modulus Test for Design of Pavement

Author(s): Ping, W.V; Yang Z.

Date: November 2005

Publisher: Florida Department of Transportation

Abstract/Synopsis: The resilient modulus (MR) of pavement materials is an essential parameter for mechanistically based pavement design procedure. Conducting the MR test in a triaxial chamber is a time consuming task and calls for skill and carefulness. Besides running the test, the engineer needs to spend a lot of time in designing spreadsheets, entering data, consulting complementary protocols and eventually performing the statistical analysis and printing final reports. It is also inconvenient to maintain these Excel files and difficult to search the data from these files. The amount of time and effort in conducting the MR test and manipulating the test results could be significantly saved by using a computerized software program. The reliability of the test results could be significantly saved by using a computerized software program. The reliability of the test results could also be improved accordingly.

A resilient modulus database, Soil Lab Assistant (SLA) was developed to store the available MR test results and to facilitate soil resilient modulus evaluation and pavement design. The Soil Lab Assistant is a software application, written in Visual Basic 6, that was conceived as a way to assist soil lab technicians in running the soil triaxial test, analyzing the test data, storing the final test results to the data base, retrieving data from data base, and producing final test reports. The development and application of the SLA were described and summarized in this report.

Application/Use: This is directly applicable to materials testing.

Contribution: Cost Savings; Advancement in Technology.

Present Benefit: This report describes the development of a software program to assist in resilient modulus testing, data storage, and data analysis, and references the resilient modulus testing procedures developed by LTPP. The procedures developed by LTPP have significantly contributed to materials characterization and pavement design and are being utilized by many agencies and other testing labs.

Future Benefit: The use of resilient modulus testing will continue to grow, especially as the M-E PDG is implemented. Resilient modulus is one of the key inputs for unbound materials in the M-E PDG.

Title: Development of a New Method for Assessing Asphalt Binder Durability with Field Validation.

Author(s): Glover, Charles J; Davison, Richard R; Domke, Chris H; Ruan, Yonghong; Juristyarini, Pramitha; Knorr, Daniel B; Jung, Sung H.

Date: 2005

Publisher: Texas Transportation Institute; Texas Department of Transportation; Federal Highway Administration

Abstract/Synopsis: This project was a comprehensive study directed at developing an improved method of screening asphalt binders for long-term pavement performance. A new dynamic shear rheometer (DSR) function, G'/(eta'/G'), and a new aging procedure should warn of premature asphalt hardening and resulting fatigue cracking. For unmodified asphalts the new DSR function correlated well with ductility (at 15 deg C, 1 cm/min) below 10 cm. The correlation was originally developed for DSR measurements at 15 deg C and 0.005 rad/s. These conditions were time-temperature superposition shifted to 44.7 deg C and 10 rad/s to produce a method that is easily accessible to standard laboratory rheological equipment and methods. The recommended aging procedure uses the pressure aging vessel (PAV) apparatus but takes advantage of the higher average aging rate when the asphalt is aged in thinner films. This change, combined with somewhat longer aging, results in a more rigorous test of durability than the standard PAV method. At the same time, the resulting rankings of aged materials are more representative of rankings that are obtained from aging at atmospheric air pressure and 60 deg C. For modified asphalts, the results were complex. Generally for a given value of the DSR function, the ductility was better than indicated by the unmodified asphalt DSR-ductility correlation. Larger amounts of modifier produced increasing values of ductility for a given function value. This result was very asphalt dependent, however, so no general correlation could be found. As modified binders oxidize, the asphalt hardens and the improvement to ductility imparted by modifiers decreases. After enough aging, the improvement is gone and modified binders perform no better than their aged unmodified counterpart. A critical issue is whether the life extension produced by modifiers is life-cycle cost effective. Long-Term Pavement Performance (LTPP) and SH 21 binders indicate: seal coats may provide an opportunity for significant and very cost-effective in-place binder rejuvenation; G'/(eta'/G') is an excellent function for tracking pavement aging; pavements can oxidize rather uniformly with depth; brittle binders can be tolerated in stiff pavements; aggregates appear to have little effect on asphalt oxidation reactions; rolling thin-film oven tests plus PAV aging is not severe aging, in the context of pavement life.

Application/Use: This study is useful for materials engineers interested in binder oxidation and its effect on durability.

Contribution: Improvement in Knowledge

Present Benefit: The study provides benefit in proposing modifications to binder testing in an attempt to better determine oxidation performance. It also offers insight into the interaction of oxidation and other conditions.

Future Benefit: This paper furthers the development of binder testing and evaluation, which may lead to improved performance.

Title: Effect of Seasonal Moisture Variation on Subgrade Resilient Modulus

Author(s): Salem, Hassan M.

Date: 2005

Publisher: Federal Highway Administration; American Society of Civil Engineers

Abstract/Synopsis: It is well known that environmental changes have severe effects on pavement performance. While an asphalt layer may be more sensitive to temperature, a soil or untreated pavement layer might be more affected by the change in moisture. This research aims at quantifying the effect of subgrade moisture variation, caused by environmental changes, on a subgrade's resilient modulus and including its effects in the design process for new and rehabilitated pavements. To achieve this objective, data representing different soil types in non-freeze zones at various Long-Term Pavement Performance Seasonal Monitoring Program (LTPP-SMP) sites were downloaded from the DataPave 3.0 software. The downloaded data were analyzed to establish the effect of subgrade moisture variation on a subgrade's resilient strength represented by the backcalculated elastic modulus. The analysis indicated that moisture in the subgrade layer is related to the precipitation intensity. The study also revealed that a Seasonal Adjustment Factor (SAF) could be used to shift the subgrade modulus from a normal season to another. The SAF is considered a key input in the mechanistic-based pavement design system. It allows the inclusion of the seasonal effects on the layer moduli for different seasons. In this paper, a method is presented for calculating the SAF for the subgrade soils. Using the collected data, regression analysis was performed and correlation equations were developed. These equations relate the backcalculated subgrade modulus to the subgrade moisture content and to other soil properties. The SAF relates the change in the moisture content to the change in the modulus value.

Application/Use: The findings from this study are directly applicable to M-E pavement design.

Contribution: Improvement in Knowledge

Present Benefit: Understanding changes in subgrade modulus as a function of changes in moisture content is beneficial in pavement design. It allows designers to select pavement sections that efficiently account for these seasonal variations.

Future Benefit: As pavement design moves towards M-E PDG practices, understanding modulus changes will be an essential part of the process. The results from this study will be useful in estimating subgrade modulus values in different seasons.

Title: Evaluation of PCC Joint Stiffness Using LTPP Data

Author(s): Khazanovich, Lev; Gotlif, Alex

Date: 2005

Publisher: Transportation Research Board

Conference Title: Eighth International Conference on Concrete Pavements

Abstract/Synopsis: Shear stiffness of joints and cracks profoundly affects the performance of concrete pavements. This paper presents a systematic analysis of stiffness of joints in jointed concrete pavement (JC) and cracks of continuously reinforced pavements (CRCP) using deflection data collected under the Long Term Pavement Performance (LTPP) program. To estimate joint behavior, representative load transfer efficiency (LTE) indexes were calculated for all LTPP sections and a trend analysis was performed to evaluate the effect of Falling Weight Deflectometer (FWD) load level on LTE. It was found that the majority of the joints did not show significant load-level dependency. This justifies use of a simple Tabatabae-Barenberg (TB) model for routine pavement analysis. The paper also discusses a backcalculation procedure for determination of TB model parameters. Joint stiffness was backcalculated from LTEs, coefficients of subgrade reactions, and radii of relative stiffness. As expected, it was found that cracks in CRCP usually have higher stiffness than joints of JCP, while non-doweled joints usually have much lower stiffness than doweled joints. It was also found that joint stiffness could vary significantly during the day.

Application/Use: Findings from this paper can be used by those interested in load transfer efficiency.

Contribution: Improvement in Knowledge

Present Benefit: Understanding variations and sensitivity of computed joint stiffness indices is critical to pavement evaluation. This type of information can aide pavement engineers in determining when improvements are needed as well as selecting the most appropriate treatment type.

Future Benefit: Pavement engineers can use findings from this study to make informed decisions on joint stiffness estimations and improvement strategies. This will lead to proper and effective treatment selection resulting in lower life cycle costs.

Title: Long-Term Pavement Performance Materials Characterization Program: Verification of Dynamic Test Systems with an Emphasis on Resilient Modulus (Contract DTFH61-95-Z-00086 Final Report)

Author(s): Groeger, Jonathan; Bro, Anders

Date: September 2005.

Publisher: FHWA Report FHWA-RD-02-034

Abstract/Synopsis: This document describes a procedure for verifying a dynamic testing system (closed-loop servo-hydraulic). The procedure is divided into three general phases: (1) electronic system performance verification, (2) calibration check and overall system performance verification, and (3) proficiency testing. This procedure may be used to evaluate a wide range of equipment and has applications to many test procedures. Implementation of this procedure in the Federal Highway Administration contractor laboratories has greatly reduced the within- and between-lab variability associated with the Long-Term Pavement Performance resilient modulus test procedures.

Application/Use: The results from this project are used to determine resilient modulus values for use in flexible pavement design.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage.

Present Benefit: Resilient modulus is a critical component in the design of flexible pavements. The study's evaluation of new and existing resilient modulus test methods was conducted to develop one procedure that would provide the most representative results. This improves the accuracy of resilient modulus estimates leading to more efficient pavement designs.

Future Benefit: The M-E PDG requires both bound and unbound materials resilient modulus inputs for use in the performance prediction of flexible pavements. Improved methods of estimating resilient modulus will lead to better performance predictions and optimized pavement design selections.

Title: LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements

Author(s): Chatti, K; Buch, N; Haider, S. W; Pulipaka, A. S; Lyles, R. W; Gilliland, D; Desaraju, P.

Date: 2005

Publisher: National Cooperative Highway Research Program

Journal Title NCHRP Web Document No. 74

Abstract/Synopsis: This report documents and presents the results of a study on the relative influence of design and construction features on the response and performance of new flexible and rigid pavements, included in SPS-1 and SPS-2 experiments. The SPS-1 experiment is designed to investigate the effects of hot mix asphalt (HMA) layer thickness, base type, base thickness, and drainage on flexible pavement performance, while the SPS-2 experiment is aimed at studying the effect of portland cement concrete (PCC) slab thickness, base type, PCC flexural strength, drainage, and lane width on rigid pavement performance. The effects of environmental factors, in absence of heavy traffic, were also studied based on data from the SPS-8 experiment. Various statistical methods were employed for analyses of the LTPP NIMS data (Release 17 of DataPave) for the experiments. In summary, base type seems to be the most critical design factor in achieving various levels of pavement performance for both flexible and rigid pavements, especially when provided with in-pavement drainage. The other design factors are also important, though not at the same level as base type. Subgrade soil type and climate also have considerable effects on the influence of

Title: Rapid Pavement Backcalculation Technique for Evaluating Flexible Pavement Systems

Author(s): Bayrak, Mustafa Birkan; Guclu, Alper; Ceylan, Halil

Date: 2005

Publisher: Iowa State University, Ames

Conference Title Proceedings of the 2005 Mid-Continent Transportation Research Symposium

Abstract/Synopsis: This study focuses on the use of artificial neural network (ANN)-based pavement backcalculation tools for analyzing falling weight deflectometer (FWD) data collected from flexible pavement sections. Some of the pavement sites have been part of the Long-Term Pavement Performance (LTPP) Program, and a history of pavement materials testing and FWD deflection data already exist in the LTPP database. Pavement backcalculation tools developed in this study have been utilized to predict the pavement layer moduli and critical pavement responses of flexible pavement layers under typical highway pavement loading conditions. Unlike the linear elastic layered theory commonly used in pavement layer backcalculation, nonlinear subgrade soil response models were used in the ILLI-PAVE finite element program to account for the softening nature of fine-grained subgrade soils and hardening behavior of the unbound base materials under increasing stress states. Preliminary investigations have shown that the ANN-based backcalculation models were capable of rapidly predicting the layer moduli and critical pavement responses with low average errors when compared to the models obtained directly from the finite element analyses. In addition to the analyses of large amounts of FWD data using the backcalculation tools developed in this study, predicted pavement layer moduli values were compared with the traditional backcalculation software solutions; the comparison results are presented in this paper. The advantages of using an ANN-based rapid pavement layer backcalculation tool are also discussed.

Application/Use: The findings from this study are applicable to those interested in using FWD data to analyze pavements.

Contribution: Improvement in Knowledge

Present Benefit: The paper has provided a backcalcualtion alternative and another tool in pavement design and evaluation. LTPP has added value by providing the FWD data and materials property data used to conduct the analysis.

Future Benefit: The results from this study could be used directly in pavement evaluations or could be used as a stepping stone for additional work on ANN-based backcalculation.

Title: Sensitivity Analysis of Rigid Pavement Systems Using Mechanistic- Empirical Pavement Design Guide

Author(s): Guclu, Alper; Ceylan, Halil

Date: 2005

Publisher: Iowa State University, Ames

Conference Title: Proceedings of the 2005 Mid-Continent Transportation Research Symposium

Abstract/Synopsis: Pavement design procedures available in the literature do not fully take advantage of mechanistic design concepts, and as a result, heavily rely on empirical approaches. Because of their heavy dependence on empirical procedures, the existing rigid pavement design methodologies do not capture the actual behavior of Portland Cement Concrete (PCC) pavements. However, reliance on empirical solutions can be reduced by introducing mechanistic-empirical methods, now adopted in the newly released Mechanistic-Empirical Pavement Design Guide (MEPDG). This new design procedure incorporates a wide range of input parameters associated with the mechanics of rigid pavements. A study was undertaken to compare the sensitivity of these various input parameters on the performance of concrete pavements. Two Jointed Plain Concrete Pavement (JPCP) sites were selected in Iowa. These two sections are also part of the Long Term Pavement Performance (LTPP) program, where a long history of pavement performance data exists. Data obtained from the Iowa Department of Transportation (Iowa DOT) Pavement Management Information System (PMIS) and LTPP database were used to form two standard pavement sections for the comprehensive sensitivity analyses. The sensitivity analyses were conducted using the MEPDG software to study the effects of design input parameters on pavement performance, specifically faulting, transverse cracking, and smoothness. Based on the sensitivity results, the rigid pavement input parameters were ranked and categorized from most sensitive to insensitive to help pavement design engineers to identify the level of importance for each input parameter. The curl/warp effective temperature difference (built-in curling and warping of the slabs) and PCC thermal properties are found to be the most sensitive input parameters. Based on the comprehensive sensitivity analyses, the idea of developing an expert system is introduced to help the designer identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria.

Application/Use: This paper is useful in implementing the M-E PDG for PCC pavements and of particular interest for pavement designers in Iowa.

Contribution: Improvement in Knowledge

Present Benefit: The M-E PDG implementation process consists of evaluating the sensitivity of the predictions. This paper provides insight into sensitivity for PCC pavements and will aide in establishing the level of effort necessary to quantify material properties used in the M-E PDG.

Future Benefit: As additional agencies begin implementing the M-E PDG, findings from this study will continue to be used as a reference. The LTPP database will also be utilized by many agencies in the implementation process.

Title: Study of LTPP Pavement Temperatures

Author(s): Lukanen, E. O; Stubstad, R. N; Clevenson, M. I.

Date: 2005

Publisher: Consulpav International; Federal Highway Administration

Abstract/Synopsis: This study focuses on the quality of the pavement temperature data in the Long-Term Pavement Performance (LTPP) program. Reliable pavement temperature data are necessary in the research planned for the LTPP program. Pavement surface temperature measurements and in-depth pavement temperature measurements have been recorded since the beginning of the LTPP program. Until this study, these data have been subject to only broad checks established for individual fields; no additional quality checks were made. The LTPP database is now undergoing various quality investigations focusing on comparisons of the data from two independent sources--infrared surface temperature measurements that were recorded automatically and in-depth temperature measurements that were made manually. The comparative processes identified various data errors and errors in associated data elements such as the time measurement. Examples of such errors include data entry errors such as transposition of numbers and errors in the tens-place entries. Missing data, malfunctioning infrared sensors, and time-recording errors such as errors with time zone changes or daylight savings time changes were identified. All identified pavement temperature errors were submitted for further evaluation, which could lead to either corrections or removal of erroneous data from the LTPP database.

Application/Use: The results from this study were used to investigate and resolve suspect temperature readings, thereby improving the quality of the data.

Contribution: Improvement in Knowledge

Present Benefit: Because FWD backcalculation results are sensitive to pavement temperature, it is important to have high quality temperature data stored with FWD data. The availability of data in the LTPP database allows various backcalculation methods to be evaluated and compared over a large data set.

Future Benefit: Improving the quality of data will benefit findings and results from future research, including enhanced prediction capabilities and reduced variability.

Title: Survival Analysis of Fatigue Cracking for Flexible Pavements Based on Long-Term Pavement Performance Data

Author(s): Wang, Yuhong; Mahboub, Kamyar C; Hancher, Donn E.

Date: 2005

Publisher: American Society of Civil Engineers

Journal Title Journal of Transportation Engineering Vol. 131 No. 8

Abstract/Synopsis: The study presented in this paper analyzed the development patterns of fatigue cracking shown in flexible pavement test sections of the Long-Term Pavement Performance (LTPP) Program. A large number of LTPP test sections exhibited a sudden burst of fatigue cracking after a few years of service. In order to characterize this type of LTPP cracking data, a survival analysis was conducted to investigate the relationship between fatigue failure time and various influencing factors. After dropping insignificant influencing factors, accelerated failure time models were developed to show the quantitative relationship between fatigue failure time and asphalt concrete layer thickness, Portland cement concrete base layer thickness, average traffic level, intensity of precipitation, and freeze-thaw cycles. The error distribution of the accelerated failure time model was found to be best represented by the generalized gamma distribution. The model can also be used to predict the average behavior of fatigue failures of flexible pavements.

Application/Use: The evaluation of fatigue cracking can be used to predict average fatigue performance, which is applicable in pavement management.

Contribution: Improvement in Knowledge

Present Benefit: This analysis investigates the contribution of key factors on fatigue accumulation and provides a pavement performance prediction tool. This is beneficial to those interested in predicting average fatigue performance for a given set of conditions.

Future Benefit: LTPP will continue to benefit the pavement community by providing quality data for research.

Title: Synthesis of CalTrans Rubberized Asphalt Concrete Projects

Date: October 2005

Publisher: California Department of Transportation

Abstract/Synopsis: This report summarizes the use of rubberized asphalt concrete (RAC) and modified binders (MB) by Caltrans. It briefly reviews some of the historical work, including descriptions of and findings from significant projects. Also, it describes the effects that these studies have had on the use of RAC in California. The report also outlines how these studies may affect Caltrans future direction with respect to the use of asphalt rubber and modified binders.

Application/Use: This is directly applicable to materials selection/pavement design in California.

Contribution: Cost Savings; Lessons Learned; Advancement in Technology.

Present Benefit: The SPS-5 project constructed in California for LTPP provided information on lab and field performance of RAC in comparison to AC. This experiment has been used by California to evaluate the practical implications of implementing RAC as a rehabilitation alternative.

Future Benefit: As agencies continue to investigate the use of RAC, the SPS-5 projects will prove to be a valuable data source. Performance data along with vital information on materials, construction, in situ conditions, and traffic will be an essential component to the evaluation of RAC material.

Title: Understanding the True Economics of Using Polymer Modified Asphalt Through Life Cycle Cost Analysis

Author(s): Buncher, Mark; Rosenberger, Carlos

Date: 2005

Publisher: Asphalt Institute

Abstract/Synopsis: This article reports on a study that analyzed an extensive collection of field performance data, making direct comparisons between polymer modified asphalt (PMA) mixes and unmodified conventional mixes. The data included 84 pairs of PMA and unmodified companion test sections from the Federal Highway Administration (FHWA) Long Term Pavement Performance (LTPP) program and other test sections across the U.S. and Canada. This article uses life cycle cost analysis (LCAA) to evaluate the overall long-term economic efficiency between competing alternative PMA strategies provided in the original study. The three example scenarios are: using conventional unmodified mixes for all layers, using PMS for the top 2-inch wearing surface only, and using PMA for both the wearing surface and bottom 4-inch base layer. The results showed that while PMA increased initial construction cost by 1 percent per inch of PMA used, the overall life cycle cost savings over 40 years was substantial (15.5%). Even in more conservative scenarios where more PMA was used, the life cycle cost savings were 4.5% to 14%.

Application/Use: The results from this study have been used by those interested in evaluating the cost-to-benefit ratio of using polymer modified binders.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Data collected at LTPP test sections provides sufficient data to support studies of this nature. The life cycle cost analysis conducted in this study provides information that allows agencies to make cost-effective policy designs on the use of polymer modified binder.

Future Benefit: The decision to use polymer modified binder can have lasting effects on the pavement network in terms of overall condition and service to the public. Therefore, it is important to use quality data and sound analysis methods when conducting evaluations of this type. LTPP data will continue to support these analyses.

Title: Verification for the Calibrated Permanent Deformation Models for the 2002 Design Guide (With Discussion)

Author(s): El-Basyouny, Mohamed M; Witczak, Matthew W; El-Badawy, Sherif

Date: 2005

Publisher: Association of Asphalt Paving Technologists

Conference Title: 2005 Journal of the Association of Asphalt Paving Technologists: From the Proceedings of the Technical Sessions

Journal Title: Journal of the Association of Asphalt Paving Technologists Vol. 74

Abstract/Synopsis: The new design approach adopted in the 2002 Design Guide utilized a mechanistic-empirical pavement design procedure. The 2002 Design Guide provides time series predictions of several major distress types. One such distress mechanism is the permanent deformation (rutting). The Design guide solution predicts the total pavement rut depth, as a function of time, by predicting and summing the individual rutting contributed by all rut susceptible layers (asphalt, granular base, subbase and subgrade). This necessitated that a set of rutting models be implemented in the new design method to reflect the new design procedure. The pavement rutting prediction models included in the Design Guide nationally were calibrated by using actual sections from the Long-Term Pavement Performance (LTPP) database, to reflect the field performance of the flexible pavements. To ensure that the calibrated model is as accurate as possible and that the predicted model trends are as close as possible to what experience, practical knowledge and reasonable engineering judgment of the performance of the asphalt concrete pavements allows; an extensive sensitivity analysis was conducted using a wide variety of salient variables that were felt to have an impact on pavement rutting considered in the Design Guide. This paper contains an in-depth detailed analysis for the entire sensitivity study. In this study, a typical section was run using the 2002 Design Guide software. Different levels for each variable considered were used while keeping the other variables constant. The results of the sensitivity runs and the performance of the section with respect to the variables were found to be very logical and rational. In fact, the Mechanistic-Empirical design approach appears to provide the user with a much more powerful tool to assess the complex interaction of design parameters to performance than is currently available in any other design methodology in the world.

Application/Use: The findings from this study can be used to understand the rutting prediction model of the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Quantifying the sensitivity of the M-E PDG models to inputs in the model will assist agencies during the implementation process of the M-E PDG. This provides information that can be used to prioritize material characterization efforts. The results can also be used to familiarize designers with the predictions and how changes in design effect those predictions.

Future Benefit: Understanding the sensitivity of the M-E PDG will be critical to developing cost effective pavement designs. The LTPP database is beneficial to the M-E PDG efforts because it provides data that are needed in the local calibration/validation process as well as sensitivity analysis.

Title: Evaluation of Asphaltic Expansion Joints

Author(s): Mogawer, Walaa S; Austerman, Alexander J.

Date: November 2004

Publisher: New England Transportation Consortium

Abstract/Synopsis: Asphaltic expansion joints, commonly referred to as Asphaltic Plug Joints (APJs), provide a relatively low cost joint option for bridges with approximately one-inch of movement. However, failure of these joints can expose the underlying structural bridge components to water and salts that can lead to corrosion. In New England, many of these joints have reached or nearing the end of there anticipated service life. The objectives of the research presented herein is to identify reasons of joint failure, identify the useful life span, evaluate the overall costs, identify flaws in installation and maintenance methods, and establish recommendations regarding initial design considerations (skew, expansion, etc.). Field inspections were conducted on 64 in-service APJs in five New England states to determine predominate materials distresses leading to failure. These distresses were determined to be debonding, cracking and rutting. Lab testing was conducted on virgin binder and aggregate as well as cores of in-service APJ material. Each binder was tested to determine its Superpave Performance Grade (PG) and evaluate its resiliency. The aggregates were tested to determine their gradation and amount of fines. The core material was extracted to determine gradation and approximate binder content. This testing information, along with a comprehensive review of existing specifications, was used to develop design guidelines, a design specification, an installation specification, and a repair specification for use in New England.

Application/Use: The report along with design guidelines and specifications will be of great use to bridge engineers.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The use of climatic information from the LTPP database in this report demonstrates how LTPP data can support research for a variety of industries. The comprehensive nature of the database lends itself to extensive analyses.

Future Benefit: It is well recognized that the LTPP database will continue to support research in the pavement community. While the future benefit provided by the program to endeavors outside of pavement engineering is not as obvious, it is likely that the LTPP program will enable evaluations that otherwise could not have been performed. In other cases, the LTPP program will supplement existing information to produce more robust findings.

Title: Evaluation and Analysis of LTPP Pavement Layer Thickness Data

Author(s): Selezneva, O. I; Jiang, Y. J; Mladenovic, G.

Date: 2004

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: In 2001, the Federal Highway Administration sponsored a study to review pavement layer thickness data for Long Term Pavement Performance (LTPP) sites. The main objective of the study was to assess the quality and completeness of pavement layering information and layer thickness data and to provide recommendations for improvement. In the course of the study, layer thickness data available in the LTPP database were examined for quality and completeness using Levels A to E data. Following the data completeness evaluation, pavement layering data were evaluated to determine the consistency of material type and thickness data between different data sources. In addition, layer thickness variability indicators, within-section material type consistency, and material type and thickness reasonableness were evaluated. In the cases where there were inconsistencies in the data, the data were reviewed and reported to the LTPP data managers along with recommendations for data anomaly resolution. In addition, the layer thickness data from Specific Pavement Studies (SPS) experiments were analyzed to determine characteristics of within-section layer thickness variation. The analysis included layers with different material and functional types. Descriptive statistics such as mean, standard deviation, skewness, and kurtosis were computed for each section. The statistical analysis results for 1,034 SPS layers indicated that 84% of all layer thickness variations within LTPP sections follow a normal distribution. The extent of differences between as-designed (inventory) and as-constructed (measured) layer thickness data was also investigated for the SPS sections. The results of analysis indicate that about 60% of all section/layers have mean thicknesses within 6.35 mm (0.25 in.) of the target thickness. For a tolerance level of 25.4 mm (1 in.), this percentage is above 90 for most layer types and target thickness values. For the same layer and material type, the mean constructed layer thicknesses tend to be above the designed value for the thinner layers and below the designed value for the thicker layers. One important product from this study is the Researcher's Guide to LTPP Layer Thickness Data. The main purpose of this guide is to provide guidance for the selection of layer material type and thickness data from the LTPP database. The guide also contains a discussion about within-section layer thickness variability and comparison between as-designed and as-constructed layer thickness. The guide is available as a separate publication.

Application/Use: The information provided in this report can be used by those accessing LTPP layer information.

Contribution: Lessons Learned

Present Benefit: Layer thickness information is essential to the majority of pavement analyses. By providing information on the sources and types of layer data in the LTPP database as well as their variability, this report aides researchers in obtaining appropriate information.

Future Benefit: The document will continue to be beneficial as LTPP data is utilized in future research efforts. The M-E PDG implementation process will likely involve LTPP test sections to locally validate/calibrate the prediction models. A key component in this analysis will be accurately accounting for layer thicknesses and material types. This report will be extremely beneficial in this regard.

Title: Laboratory Determination of Resilient Modulus for Flexible Pavement Design

Date: 2004

Publisher: Transportation Research Board

Journal Title: NCHRP Research Results Digest No. 285

Abstract/Synopsis: This digest presents the two key products from research conducted under National Cooperative Highway Research Program (NCHRP) Project 1-28A, "Harmonized Test Methods for Laboratory Determination of Resilient Modulus for Flexible Pavement Design." The objective of Project 1-28A was to develop (1) a test method for measurement of the resilient modulus of hot mix asphalt (HMA) that harmonizes the procedure proposed by NCHRP Project 1-28 with the existing American Association of State Highway and Transportation Officials (AASHTO) TP31 method and the Federal Highway Administration (FHWA) Long Term Pavement Performance (LTPP) "Laboratory Start-Up and Quality Control Procedure" and (2) a test method for measurement of the resilient modulus of unbound granular base and subbase materials and subgrade soils that harmonizes the procedure proposed by Project 1-28 with the existing AASHTO TP46, T 292, and T 294 methods and the FHWA LTPP "Laboratory Start-Up and Quality Control Procedure."

Application/Use: The results from this project are used to determine resilient modulus values for use in flexible pavement design.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage.

Present Benefit: Resilient modulus is a critical component in the design of flexible pavements. The study's evaluation of new and existing resilient modulus test methods was conducted to develop one procedure that would provide the most representative results. This improves the accuracy of resilient modulus estimates leading to more efficient pavement designs.

Future Benefit: The M-E PDG requires resilient modulus inputs for both bound and unbound material for use in the performance prediction of flexible pavements. Having improved methods of estimating resilient modulus will lead to better performance predictions and optimized pavement design selections.

Title: Long Term Monitoring of Seasonal Weather Stations and Analysis of Data from SHRP Pavements

Author(s): Figeroa, J. Ludwig

Date: March 2004

Publisher: Ohio Department of Transportation

Abstract/Synopsis: External agents such as traffic and climate directly affect the life of flexible and rigid pavements. To understand the influence of these factors, a test road located on U.S. 23, just North of Delaware in Ohio, was constructed as part of the Federal Highway Administration's SHRP Program. Material properties and the effect of environmental factors on pavements were studied. Knowing the dynamic response of pavement materials and environmental factors to which they are exposed, back calculation procedures to estimate the resilient modulus and the modulus of subgrade reaction of the subgrade soil from nondestructive testing deflections were developed using ILLIPAVE and ILLISLAB for flexible and rigid pavements, respectively. Relationships between the resilient modulus at the break point and the degree of saturation were developed for the subgrade soil, while relationships between resilient modulus and temperature were developed for asphaltic materials. All test data, including moisture content, pavement and soil temperature and resistivity, as well as weather-related parameters collected at all instrumented sections at the test road were processed. Seasonal findings include solar radiation versus temperature relations, asphalt concrete temperature versus air temperature equations, temperature differentials on PCC slabs, moisture content estimations for the subgrade soil and depth of frost penetration determination. A comparison of the degrees of saturation vs. depth among sections with and without drains did not show any significant difference in reducing the degree of saturation in sections with drains. A comparison between precipitation and degree of saturation showed a lag of 80 to 85 days in higher degree of saturation after substantial precipitation occurs. Displacement time histories obtained by the FWD were evaluated, along with two dynamic pavement analysis programs: Plaxis and FWD-DYN Comparisons of time history of displacement plots of both actual and simulated data showed that Plaxis and FWD-DYN over estimated deflections at and near the point of loading. This could be the result of the difference in loading rates for laboratory testing of pavement materials compared to the FWD test loading rate.

Application/Use: This is directly applicable to pavement design, particularly in Ohio.

Contribution: Cost Savings; Improvement in Knowledge, Advancement in Technology.

Present Benefit: The LTPP test sections at the Ohio Test Road provide a variety of subsurface, climatic, response, and performance data. This information can be used to quantify changes in subsurface condition with season and the effect these changes have on pavement response. Additional analysis can be conducted to link this response to long term performance. All of these investigations provide pavement design enhancements that will lead to more cost effective pavements with improved overall performance.

Future Benefit: The data collected at the Ohio Test Road will be vital in evaluating new analysis techniques. This includes backcalculation techniques, calibration/validation of the M-E PDG, seasonal evaluations, as well as many others theories yet to be developed.

Title: LTPP SPS Materials Data Resolution: Update and Final Action Plan

Author(s): FHWA & MACTEC Engineering and Consulting, Inc.

Date: 2004

Publisher: FHWA, Office of Infrastructure Research and Development, McLean, VA

Abstract/Synopsis: Upon completion of a thorough self-assessment, it was determined that there was a glaring need for improved materials information on the high profile (and high return) SPS projects. This plan provides both documentation of the materials needs at the time of its publication and the processes to increase the quantity and quality of SPS-1, 2, 5, 6 and 8 materials data stored in the Information Management System (IMS).

While there was no official document that superseded this plan, it is important to note that funding limitations associated with SAFETEA-LU precluded the complete implementation of the plan (particularly as related to new tests and the performance of forensic investigations). The Regional Support Contractors (RSCs) worked together with the Highway Agencies to collect and ship the materials, while all testing was done centrally—most by the LTPP Laboratory Contractor and the coefficient of thermal expansion testing by FHWA.

Application/Use: The plan highlights the need for additional materials sampling and testing and the processes to address this need. It is the key document utilized by the RSCs in developing site-specific materials sampling and testing plans.

Contribution: Cost Savings; Implementation/Usage.

Present Benefit: This document serves as a resource to the RSCs and Highway Agencies in planning and executing site-specific sampling activities and as a benchmark in assessing the ultimate success of the SPS Materials Action Plan (MAP). Currently, almost all of the MAP sampling has been completed, the central LTPP Laboratory contract has been awarded and testing results are being input into the IMS.

Future Benefit: Completion of the SPS MAP activities will provide complete suites of materials data necessary for analysis of the SPS-1, 2, 5, 6 and 8 projects. Virtually any research relating test section performance to materials characteristics will benefit from this improved data set.

This document will serve as a resource for anyone interested in how the materials sampling activities were established. It also provides an excellent resource for anyone looking to perform forensic investigations on LTPP test sections.

Title: Predicting Elastic Response Characteristics of Unbound Materials and Soils

Author(s): Yau, A; Von Quintus, H. L.

Date: 2004

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1874

Abstract/Synopsis: Most state transportation agencies in the United States use the 1986 or 1993 version of the AASHTO design guide. The AASHTO guide for the design of flexible pavements uses the resilient (elastic) modulus as the property for characterizing all pavement materials and soils. However, state agencies do not routinely measure the resilient modulus in the laboratory but instead estimate the value from strength tests or physical properties. Physical property and repeated load resilient modulus tests are being performed on all unbound materials and soils within the Long-Term Pavement Performance (LTPP) program. Other correlation studies have been performed relating physical properties to the k coefficients of the resilient modulus constitutive equation but have been confined to specific soils. The LTPP program includes a diverse range of soils and unbound pavement materials for which the physical properties and resilient modulus are being measured. Thus, statistical analyses were initiated to confirm these relationships and define the accuracy of predicting the elastic response parameters for use in design. Results from these analyses suggest that the correspondence between the physical properties and the elastic parameters of the resilient modulus constitutive equation was fair to poor. It was also found that sampling technique had an effect on the elastic parameters of some unbound materials and soils. On the basis of the findings, it was recommended that resilient modulus tests be performed to characterize unbound materials and soils accurately for use in design.

Application/Use: The results from this study are directly applicable to materials and pavement engineering.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Resilient modulus data is an essential component of pavement design practices. An evaluation of correlations between material properties and resilient modulus can improve pavement selection and design. The findings from this project found that correlations may lead to inaccurate estimates of resilient modulus and pavement thickness selection. Implementing the project recommendations will result in more cost-effective pavement designs.

Future Benefit: Accurate estimates of resilient modulus values will continue to provide benefit in the future. This benefit will be in the form of improved pavement design and better overall pavement performance.

Title: Prediction of Resilient Modulus from Soil Index Properties

Author(s): George, K. P.

Date: 2004

Publisher: University of Mississippi, University; Mississippi Department of Transportation; Federal Highway Administration

Abstract/Synopsis: Subgrade soil characterization in terms of Resilient Modulus (M sub R) has become crucial for pavement design. For a new design, M sub R values are generally obtained by conducting repeated load triaxial tests on reconstituted/undisturbed cylindrical specimens. Because the test is complex and time-consuming, in-situ tests would be desirable if reliable correlation equations could be established. Alternately, M sub R can be obtained from correlation equations involving stress state and soil physical properties. Several empirical equations have been suggested to estimate M sub R. The main focus of this study is to substantiate the predictability of the existing equations and evaluate the feasibility of using one or more of those equations in predicting the M sub R of Mississippi soils. This study also documents different soil index properties that influence M sub R. Correlation equations developed by the Long Term Pavement Performance (LTPP) program, Minnesota Road Research Project, Georgia DOT, Carmichael and Stuart Drumm et al., Wyoming DOT, and Mississippi DOT are studied/analyzed in detail. Eight road (subgrade) sections from different districts are selected and soils tested (TP 46 Protocol) for M sub R in the laboratory. Other routine laboratory tests are conducted to determine physical properties of the soil. Validity of the correlation equations are addressed by comparing measured M sub R to predicted M sub R. In addition, variations expected in the predicted M sub R due to inherent variability in soil properties is studied by the method of point estimates. The results suggest that LTPP equations are suited for purposes of predicting M sub R of Mississippi subgrade soils. For fine-grain soils, even better predictions are realized with the Mississippi equation. A sensitivity study of those equations suggests that the top five soil index properties influencing M sub R include moisture content, degree of saturation, material passing the #200 sieve, plasticity index and density.

Application/Use: This study is directly applicable resilient modulus estimates for pavement design in Mississippi.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: Resilient modulus is a key component in pavement design. Accurate estimates of subgrade resilient modulus from other soil properties result in improved and more cost-effective pavement designs. Similar benefits can be realized by understanding the sensitivity of subgrade resilient modulus to changes in soil properties. With this knowledge, seasonal considerations can be properly incorporated in the design.

Future Benefit: Quantifying variability in resilient modulus will continue to add benefit as it will remain a key component in pavement design even as agencies transition to the M-E PDG.

Title: Researcher's Guide to the Long-Term Pavement Performance Layer Thickness Data

Author(s): Jiang, Y. J; Selezneva, O. I; Mladenovic, G.

Date: 2004

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: The accuracy of layer thickness data has a great impact on the outcome of practically all analyses of pavement performance. A large amount of data related to layer material type and thickness data have been collected as part of the Long Term Pavement Performance (LTPP) program. The main purposes of this researcher's guide for the LTPP thickness data are to: (1) Explain to the LTPP data users what and where different types of layer material type and thickness data reside in the LTPP database, as well as the limitations of the data; (2) Present LTPP thickness within-section variability; (3) Summarize as-designed versus as-constructed layer thickness comparisons; and (4) Provide guidelines to search for the most appropriate thickness information for different research purposes. Field sampling, materials testing, and other layer thickness data collection activities utilized by LTPP are discussed, along with the characterization of the within-section thickness variation and designed versus constructed thickness data variations for the LTPP sections. Findings from this study are applicable to pavement design reliability and construction quality assurance applications.

Application/Use: This guide can be used by those interested in accessing layer thickness information from the LTPP database.

Contribution: Improvement in Knowledge

Present Benefit: Layer thickness information is essential to the majority of pavement analyses. By providing information on the sources and types of layer data in the LTPP database, this guide aides researchers in selecting appropriate information.

Future Benefit: The document will continue to be beneficial as LTPP data is utilized in future research efforts. The M-E PDG implementation process will likely involve LTPP test sections to locally validate/calibrate the prediction models. A key component in this analysis will be accurately accounting for layer thicknesses and material types.

Title: Assessment of Selected LTPP Material Data Tables and Development of Representative Test Tables

Author(s): Titus-Glover, L; Mallela, J; Jiang, Y. J; Ayers, M. E; Shami, H. I.

Date: 2003

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: This report documents an evaluation of selected Long Term Pavement Performance (LTPP) material data tables as of January 2000. Issues addressed include the availability, characteristics, and quality of the data in the selected tables. Anomalies in the data were identified and corrected where possible, and the "cleaned-out" data were used in developing representative data tables. Recommendations for adjustments in the current data collection process are also presented.

Application/Use: This study improved the quality of materials data in the LTPP database and served as a planning tool for future data collection.

Contribution: Improvement in Knowledge

Present Benefit: The benefit of this study was improved quality of data available in the LTPP database. Additionally, information on variability in materials data is useful to those applying the data.

Future Benefit: Materials data will be used by agencies calibrating and validating the M-E PDG to local conditions. The LTPP database contains extensive materials information that will prove beneficial in this process.

Title: Automated Pavement Analysis in Missouri Using Ground Penetrating Radar

Author(s): Cardimona, S; Willeford, B; Webb, D; Hickman, S; Wenzlick, J; Anderson, N.

Date: 2003

Publisher: University of Missouri, Rolla; Missouri Department of Transportation; Federal Highway Administration

Abstract/Synopsis: Current geotechnical procedures for monitoring the condition of roadways are time consuming and can be disruptive to traffic, often requiring extensive invasive procedures (e.g., coring). Ground penetrating radar (GPR) technology offers a methodology to perform detailed condition assessment of existing roadways, with the added advantage over other techniques of being rapid and cost-effective. This project and report were split into four different sections based on the type of roadway being surveyed. The first section presents the results of a GPR survey over portions of Interstate 44 near Springfield, Missouri. The goal of this survey was to evaluate concrete pavement layer thickness and continuity within the specific study regions. The second section applies GPR techniques to a survey along Interstate 70 across the state of Missouri. Goals of this survey were threefold: 1) determine layer thicknesses every tenth mile; 2) update history information related to types of pavements that make up I70 across Missouri; and 3) note regions where the radar signal appears anomalous. The third section applies GPR techniques to 35 test pavements of the Strategic Highways Research Program LTTP sites across the state of Missouri. The result is a correlation of GPR reflection character and GPR-derived layer thickness estimates with design information for each test pavement. In the last section of the report, GPR surveys were performed over 42 miles of secondary highways to determine the thickness of the asphalt pavement and also to determine if indications of potential maintenance problem areas could be identified. Asphalt surface layering proved to be the easiest to image, creating a strong signal in the GPR data. Not as consistently clear is the concrete-to-base rock interface where the dielectric contrast between these two media is not always strong enough to create a high amplitude reflected signal. It was also determined by correlation of GPR data and coring that anomalous areas could be characterized, especially to recognize pavement where the asphaltic cement was stripping from the aggregate.

Application/Use: The study is directly applicable those interested in using GPR data to collect layer information

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: The LTPP database provides material property and layer thickness data for test sections across the country. With this information, evaluations can be performed comparing GPR results with known layer information. Variability, error, and bias can then be quantified.

Future Benefit: The future benefit of this study and the availability of layer thickness information in the LTPP database can advance GPR technology. GPR technology has the potential to provide huge benefits in acquiring inventory information for pavement management, pavement evaluation, and design purposes.

Title: Effects of Excessive Pavement Joint Opening and Freezing on Sealants

Author(s): Lee, S. W; Stoffels, S. M.

Date: 2003

Publisher: American Society of Civil Engineers

Journal Title: Journal of Transportation Engineering Vol. 129 No. 4

Abstract/Synopsis: The primary purposes of joint sealing in jointed concrete pavements are to minimize moisture infiltration through the joints, to reduce moisture-related distress (such as pumping), and to prevent the intrusion of incompressible material into joints to minimize pressure-related distress (such as spalling). However, the dilemma of whether to or not to seal frequently has arisen since the benefit of improvement in pavement performance with joint sealing could not be clearly demonstrated in a number of prior studies. Premature failure of sealant has been considered as a major cause of the ineffectiveness of joint seal. Poor construction quality and material properties of sealant have been considered as problems that induce the premature failure of joint seal. In this study, other causes, which are related to the shortcomings of the AASHTO joint seal design method, which may induce premature failure of joint seal, are addressed. The first cause is in situ joint openings larger than AASHTO predictions. Variability of joint openings in a given pavement section, including erratic large openings at a considerable portion of joints, has been discussed. High chances of adhesion-type failure are plausibly related with such erratic large openings. The relationship between sealant damage and the ratio of in situ maximum joint opening to permissible sealant elongation was demonstrated in this study based on the observations from 90 joints in 16 jointed concrete long term performance pavement special pavement studies (LTPP SMP) sites. The second cause is joint freezing (defined as joints showing no movement). At frozen joints, joint seals are likely to be redundant, and a waste of money. A method for joint seal design with survival criteria is suggested in this study. In this model, joint openings are estimated based on the Lee-Stoffels model, a probabilistic model that can predict the magnitudes of joint opening with its probabilities. Joint seal designs for 16 LTPP SMP sites, based on this survival model, indicated that some sections should have sealant-type changed, to permit more elongation with the given joint reservoir, whereas other sections do not need joint seal.

Application/Use: The findings presented are useful in joint design and sealant material selection.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Proper design and material selection of joints is essential in mitigating pumping, spalling, faulting, and other damage in PCC pavement. This paper provides information on joint opening variation that is useful in determining the joint reservoir and sealant type.

Future Benefit: The SMP experiment conducted as part of the LTPP program provides data on joint opening linked with performance and climatic information. This is extremely valuable in understanding pavement response variation with changes in season and will continue to benefit the pavement community.

Title: Estimation of Pavement Layer Thickness Variability for Reliability-Based Design

Author(s): Jiang, Y; Selezneva, O; Mladenovic, G; Aref, S; Darter, M.

Date: 2003

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Journal Title: Transportation Research Record No. 1849

Abstract/Synopsis: Estimating the variability of key pavement design inputs is essential to reliability-based pavement design. The thickness of most pavement layers has a great impact on the outcome of practically all analyses of pavement performance. The within-section layer thickness variability is investigated here, as is the extent of the mean layer thickness deviation from its design thickness. Pavement layer thickness data (elevation and core measurements) from a large number of newly constructed flexible and rigid pavement sections in the Long-Term Pavement Performance (LTPP) program were examined. To determine the distribution type of the thickness data, a combined statistical test for skewness and kurtosis showed that (a) thickness variations within a layer indicate a normal distribution for 86 percent of 1,034 layers and (b) the mean thickness deviations from the design values may be assumed to be normally distributed for a layer having a given type and design thickness. The estimated thickness-within-layer variability values and the estimated typical thickness deviations derived from LTPP data may serve as benchmarks for use in pavement design reliability, construction quality assurance specifications, and other research studies. In addition, statistical comparisons of layer thickness variability indicators were made between the elevation and core layer thickness data to determine whether there are systematic differences between these two measuring methods. These results will be very useful to both researchers and practitioners who develop or use reliability-based pavement design procedures.

Application/Use: The information provided in this paper can be used by those accessing LTPP layer information.

Contribution: Improvement in Knowledge

Present Benefit: Layer thickness information is essential to the majority of pavement analyses. By providing information on the sources and types of layer data in the LTPP database as well as variability, this paper aides researchers in selecting appropriate information.

Future Benefit: The document will continue to be beneficial as LTPP data is utilized in future research efforts. The M-E PDG implementation process will likely involve LTPP test sections to locally validate/calibrate the prediction models. A key component in this analysis will be accurately accounting for layer thicknesses and material types. This paper will be extremely beneficial in this regard.

Title: Evaluation of Seasonal Effects on Subgrade Soils

Author(s): Heydinger, A. G.

Date: 2003

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1821

Abstract/Synopsis: One objective of the Federal Highway Administration's Long-Term Pavement Performance (LTPP) program is to determine climatic effects on pavement performance. The LTPP instrumentation program includes seasonal monitoring program (SMP) instrumentation to monitor the seasonal variations of moisture, temperature, and frost penetration. Findings from the SMP instrumentation are to be incorporated into future pavement design procedures. Data from SMP instrumentation at the Ohio Strategic Highway Research Program Test Road (US-23, Delaware County, Ohio) and other reported results were analyzed to develop empirical equations. General expressions for the seasonal variations of average daily air temperature and variations of temperature and moisture in the fine-grained subgrade soil at the test site are presented. An expression for the seasonal variation of resilient modulus was derived. Average monthly weighting factors that can be used for pavement design were computed. Other factors such as frost penetration, depth of water table, and drainage conditions are discussed.

Application/Use: The results from this study are applicable to pavement design in Ohio.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The study provides insight on the seasonal variations in subgrade soils. This information can be used to incorporate seasonal considerations in pavement design and allow for subgrade resilient modulus values to be adjusted based on season. The findings from this study may also be useful in selecting design features that mitigate conditions of low strength subgrade.

Future Benefit: Information on seasonal variability will continue to be of interest as pavement design moves towards the M-E PDG.

Title: Long Term Pavement Performance: Guide for Determining Design Resilient Modulus Values for Unbound Materials

Date: 2003

Publisher: Federal Highway Administration

Abstract/Synopsis: This CD-ROM provides users with a comprehensive background on the resilient modulus test for soil and aggregate materials and information on using test results in pavement design. Most information contained in this tool is based upon findings from the Long Term Pavement Performance (LTPP) Program. Among other topics, this includes details on the usefulness of test results in pavement design, background of the test procedure, and techniques that can be used to reduce within- and between-laboratory variability. This tool consists of three primary modules. Also included is a PowerPoint slide presentation that discusses the content and use of this tool.

Application/Use: This CD-ROM is directly applicable to those interested in resilient modulus testing of unbound material.

Contribution: Improvement in Knowledge; Advancement in Technology; Implementation/Usage.

Present Benefit: The development and work conducted under the LTPP program has significantly improved the testing protocols for resilient modulus testing. This product helps materials engineers and laboratory personnel understand the test procedures. Accurate and reliable results are essential for quality pavement design recommendations.

Future Benefit: Resilient modulus data is a key component of new M-E design practices. Having accurate and repeatable data will improve the performance of pavements as designs will be based on actual conditions.

Title: LTPP Data Analysis: Daily and Seasonal Variations in Insitu Material Properties

Author(s): Drumm, E. C; Meier, R.

Date: 2003

Publisher: National Cooperative Highway Research Program

Journal Title: NCHRP Web Document No. 60

Abstract/Synopsis: As part of the Long Term Pavement Performance (LTPP) Seasonal Monitoring Program (SMP), pavement sites across North America were instrumented to periodically measure the temperature and moisture conditions inside the pavement and some of the environmental factors that affect those conditions. Coupled with periodic falling weight deflectometer (FWD) tests to determine the stiffness of the pavement layers, this program has produced a data set that can be used to investigate daily and seasonal changes in pavement material properties and relate those changes to the changes in structural capacity that would necessitate load restrictions. This report presents the results of such an analysis of this data set.

Application/Use: This report can be used by those interested in the proper timing of load restrictions and seasonal changes in pavement response.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The SMP portion of LTPP has accumulated a vast amount of in situ condition data. Temperature, moisture content, and frost penetration estimates throughout the year can be derived from the information collected. This data coupled with performance monitoring can provide correlations between response and season. This is beneficial for such endeavors as seasonal load restrictions.

Future Benefit: The need to understand material response changes in light of seasonal variations continues to grow as pavement design practices move toward an M-E approach. The SMP data collected as part of LTPP will be beneficial in addressing many of these issues.

Title: Temperature Correction of Backcalculated AC Modulus

Author(s): Fernando, Emmanuel G.

Date: November 2003

Publisher: Texas Department of Transportation

Abstract/Synopsis: Research efforts resulted in the development of the Modulus Temperature Correction Program (MTCP), which incorporates procedures for predicting pavement temperature and the seasonal variation of backcalculated AC modulus. MTCP runs under the Windows® operating system and requires Microsoft Excel®, version 97 or later. By having an automated procedure, TxDOT pavement engineers can more effectively consider seasonal variations in structural strength in the design of pavements, analysis of super heavy load routes, and evaluation of axle weight restrictions.

Application/Use: The program for correcting modulus values for temperature can be used by those using FWD data for pavement design purposes.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: Properly adjusting backcalculation results to a reference temperature is a critical step in pavement evaluation using FWD data. This program was developed based on data collected at LTPP SMP sites. Data available from the sites included pavement temperature (surface and subsurface) and climatic data taken in conjunction with FWD testing. This information was the foundation for the development of the MTCP.

Future Benefit: The benefit provided by LTPP will continue to grow as pavement engineers use the MTCP as part of their backcalculation process. Accurate modulus values are critical to proper rehabilitation selection and design.

Title: Using LTPPBind VS.1 to Improve Crack Sealing in Asphalt Concrete Pavements

Author(s): Nieves, A.

Date: 2003

Publisher: Federal Highway Administration

Journal Title: Application Notes

Abstract/Synopsis: The Federal Highway Administration's (FHWA's) Long-Term Pavement Performance (LTPP) program originally developed the software program LTPPBind to help highway agencies select the most suitable and cost-effective Superpave asphalt binder performance grade for a particular site. LTPPBind determines both high and low pavement temperatures for a given project location. Normally, temperatures from LTPPBind are used to determine the grade classification of asphalt cement used for asphalt concrete paving. Sealant manufacturers quickly realized that crack-sealing materials in any given climate would be exposed to and would need to function within the same pavement temperatures that LTPPBind identifies. LTPPBind, therefore, can help highway agencies select the appropriate crack-sealing materials and procedures for different climates and conditions. Using LTPPBind to design and select crack-sealing treatments will help improve pavement performance, ensure longer-lasting treatments, reduce repairs, and decrease life-cycle costs.

Application/Use: LTPPBind software can be used to select the appropriate PG binder grading for a given climate and design reliability. It is also useful in selecting crack sealant with material properties that match climatic demands of the project.

Contribution: Cost Savings; Implementation/Usage.

Present Benefit: Improper binder selection in pavement design can lead to premature pavement failures and costly repairs. LTPPBind provides the means to select PG binder grading that matches the climatic demands and reliability of the project. Similarly, LTPPBind can be beneficial in selecting appropriate crack sealant. Crack sealant with the appropriate material properties will not fail prematurely. This improves pavement performance and slows future deterioration.

Future Benefit: Proper selection of binder and crack sealant will lead to an overall improvement in pavement condition. As agencies implement pavement management programs with optimal maintenance timing, it is critical to select crack sealant that will perform well for many years. This reduces costs and improves performance.

Title: Utilizing the Falling Weight Deflectometer in Evaluating Soil Support Values of Pavement Layers

Author(s): Tawfiq, K.

Date: 2003

Publisher: FAMU-FSU College of Engineering; Florida Department of Transportation

Abstract/Synopsis: Soil Support Value (SSV) is one of the subgrade parameters that are needed for pavement rehabilitation. It is an empirical measure of the stiffness value of the foundation soil. It is similar to the modulus of subgrade reaction except that the SSV is a dimensionless property like the LBR and CBR measures being used for pavement design. The SSV used to be obtained from the Dynaflect testing technique. Since the Florida Department of Transportation (FDOT) decided to discontinue the use of the Dynaflect test for pavement evaluation and replace it with the Falling Weight Deflectometer

<u>Contribution:</u> Improvement in Knowledge; Advancement in Technology.

<u>Present Benefit:</u> The LTPP database was a valuable resource for this study. The FWD data collected at the site, along with material properties and layer information, were used to evaluate the relationship between various backcalculation techniques. This has allowed FDOT to understand the differences between FWD and Dynaflect equipment.

<u>Future Benefit:</u> As FDOT continues collecting FWD data to estimate subgrade strength properties, the benefit of this study will increase. Designs based on accurate subgrade conditions result in cost-effective pavement improvements and better overall pavement conditions.

Title: Back-Calculation of Layer Parameters for LTPP Test Sections, Volume II: Layered Elastic analysis for Flexible and Rigid Pavements

Author(s): Von Quintus, H. L; Simpson, A. L.

Date: 2002

Publisher: Fugro-BRE, Incorporated; Federal Highway Administration

Abstract/Synopsis: This report documents the procedure and steps used to back-calculate the layered elastic properties (Young's modulus and the coefficient and exponent of the nonlinear constitutive equation) from deflection basin measurements for all of the Long-Term Pavement Performance (LTPP) test sections with a level E data status. The back-calculation process was completed with MODCOMP4 for both flexible and rigid pavement test sections in the LTPP program. The report summarizes the reasons why MODCOMP4 was selected for the computations and analyses of the deflection data, provides a summary of the results using the linear elastic module (Young's modulus) for selected test sections, and identifies those factors that can have a significant effect on the results. Results from this study do provide elastic layer properties that are consistent with previous experience and laboratory material studies related to the effect of temperature, stress-state, and season on material load-response behavior. In fact, over 75 percent of the deflection basins analyzed with the linear elastic module of MODCOMP4 resulted in solutions with a root mean squared (RMS) error less than 2.5 percent. Those pavements exhibiting deflection-softening behavior with Type II deflections basins were the most difficult to analyze and were generally found to have RMS errors greater than 2 percent. In summary, the nonlinear module of MODCOMP did not significantly improve on the number of reasonable solutions, and it is recommended that nonlinear constitutive equations not be used in a batch mode basis.

Application/Use: This report can be used by those interested in layered properties on LTPP test sections. The study also provides information on the accuracy of backcalculation techniques.

Contribution: Improvement in Knowledge

Present Benefit: The development of layered elastic properties for all LTPP test sections is beneficial to researchers interested in FWD data collection and analysis. This data can be used to evaluate other backcalculation procedures as well as investigate variability, error, and bias of the existing data.

Future Benefit: The performance data available in the LTPP database can be used to develop relationships between layered properties and performance. This will be particularly useful in adjusting transfer functions for the M-E PDG.

Title: Benefiting from LTPP - A State's Perspective

Author(s): Hoffman, G.

Date: 2002

Publisher: Federal Highway Administration

Journal Title: Public Roads Vol. 65 No. 6

Abstract/Synopsis: For more than a decade, the U.S. Federal Government, the States, and Canadian provinces have invested in the Long-Term Pavement Performance Program (LTPP), a 20-year pavement research project. During its first 10 years, LTPP gathered, processed, and analyzed data describing the structure, service conditions, and performance of more than 2,500 pavement test sections in North America. This article provides a discussion of the values and benefits of LTPP to date from the perspective of the author's experience with the Program in the state of Pennsylvania.

Application/Use: This article is useful in providing state highway agencies examples of how the LTPP program can be used in many aspects of their operation.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The LTPP program has a wide variety of products that can be used by state highway agencies. This includes data collection/equipment protocol, performance data from across the country, as well as many research results. This information can supplement ongoing research at the state-level or can be implemented directly. In either case, cost savings can be realized by tapping the LTPP resource.

Future Benefit: The LTPP program will continue to add benefit as new research needs arise. In particular, local calibration and validation of the M-E PDG will rely heavily on LTPP data.

Title: Determination of Pavement Layer Stiffness on the Ohio SHRP Test Road Using Non-Destructive Testing Techniques

Author(s): Sargand, Shad

Date: October 2002

Publisher: Ohio Department of Transportation

Abstract/Synopsis: In 1994-96, the Ohio Department of Transportation (ODOT) constructed a 3.5-mile long test pavement on US 23 in Delaware County for the Strategic Highway Research Program. This project contained a total of 40 test sections of asphalt concrete and Portland cement concrete pavement in the SPS-1, SPS-2, SPS-8 and SPS-9 experiments of the Specific Pavement Studies program. The overall objectives of this research study were to evaluate the stiffness of the test sections on this experimental pavement as the new material layers were added to the sections, and to evaluate various analysis software packages currently available for the backcalculation of layer moduli. While the Ohio SHRP Test Road was constructed in an area of flat terrain believed to have relatively uniform subgrade, FWD measurements indicated considerable subgrade variability between sections and within individual sections. None of the subgrade sections was considered to be good, about half were fair and the other half were poor to very poor. As expected, much of the variability was mitigated as successive material layers were placed in the sections, and especially with the addition of stabilized materials. Stiffness equivalencies were developed for the six types of base material used on the test road, and for AC and PCC pavement used on these bases. The final stiffness of the completed sections was consistent with early performance, in that the first six asphalt concrete sections which failed had the highest measured deflections with both the FWD and Dynaflect just prior to being opened to traffic. An excellent correlation was developed between FWD and Dynaflect output on the completed asphalt concrete pavement sections and clear trends were also apparent on PCC pavement, though the limited range of readings on PCC with both devices made it difficult to develop a definitive correlation on rigid pavement. The stiffness of the completed AC and PCC pavement sections, and load transfer across PCC pavement joints were quite similar when measured with the FWD and Dynaflect, demonstrating the usefulness of both instruments in evaluating structural performance. Four elastic layer programs were evaluated for their ability to calculate the moduli of the various material layers in the 40 test sections. Of these, MODULUS4.2 performed the best and was the most user friendly program to run. To obtain consistent results on any specific project, a standard operating procedure needs to be developed for those conditions and the analysis program being used, and the procedure needs to be closely followed for all calculations.

Application/Use: This evaluation can be used by pavement designers and others using FWD data to evaluate existing conditions.

Contribution: Improvement in Knowledge.

Present Benefit: The analysis provides valuable information on in situ layer properties linked to actual field performance. Additionally, correlations between non-destructive testing equipment (i.e., FWD and Dynaflect) will aide in utilizing data from multiple sources. The study also provides results on various backcalculation procedures, a vital tool for pavement analysis and design.

Future Benefit: The Ohio Test Road offers a unique opportunity to evaluate performance of over 40 pavement configurations exposed to the same climate and traffic. The layer properties information along with long term performance measurements will be crucial to evaluating the M-E PDG.

Title: LTPP Data Analysis: Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality

Author(s): Stubstad, R. N.

Date: 2002

Publisher: National Cooperative Highway Research Program; Consulpav International

Journal Title: NCHRP Web Document 52

Abstract/Synopsis: The objective of this research study was to determine whether the Falling Weight Deflectometer (FWD) can effectively be used to assist in the quality control/quality assurance (QC/QA) process during pavement construction. This report shows that the FWD data are of reasonable quality and certainly of sufficient quantity to be used with confidence to estimate material properties--mainly stiffnesses or moduli--and their variations at each layer interface during new or reconstructed pavement construction. The traditional test results, although not as extensive as FWD data, were also reasonable and appeared to cover most of the wide variety of pavement designs and construction locations represented by the Long Term Pavement Performance (LTPP) Specific Pavement Studies (SPS) database. Following an introductory chapter, Chapter 2 presents the use of specific pavement test parameters from DataPave and the National Information Management System database that can be used to characterize pavement construction quality. These include both the FWD deflection data, and analyses thereof, and traditional construction quality data categories. Chapter 3 covers the relationships between FWD-associated data and conventional QC/QA data types. Relationships between all of these data are developed, discussed and plotted. Chapter 4 consists of the conclusions and research recommendations.

Application/Use: This report can be used by those interested in the analysis of FWD data.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: The LTPP database provides sufficient information to develop robust relationships between FWD data and traditional QC/QA data. The correlations provided may be useful in applying the advantages of FWD data collection to construction quality measures.

Future Benefit: FWD data, coupled with construction and performance data, will allow additional research efforts in this area. This may be expanded to evaluate long term performance impacts of quality variation during construction using FWD as the link between the two.

Title: Study of LTPP Laboratory Resilient Modulus Test Data and Response Characteristics

Author(s): Yau, A; Von Quintus, H. L.

Date: 2002

Publisher: Fugro-BRE, Incorporated; Federal Highway Administration

Abstract/Synopsis: The resilient modulus of every unbound structural layer of the Long-Term Pavement Performance (LTPP) Specific Pavement and General Pavement Studies Test Sections is being measured in the laboratory using LTPP test protocol P46. A total of 2,014 resilient modulus tests have passed all quality control checks and are included in the LTPP database with a Level E data status. As of October 2000, there were 1,639 resilient modulus tests yet to be performed. In some cases, these missing tests may have been performed, but did not achieve a Level E status (did not pass all quality control checks) in the LTPP database. However, these test results have not been evaluated in detail. This report documents the first comprehensive review and evaluation of the resilient modulus test data measured on pavement materials and soils recovered from the LTPP test sections. The resilient modulus data were reviewed in detail to identify anomalies or potential errors in the database. From this review, a total of 185 resilient modulus tests were identified with possible problems or data entry errors. These tests were reported to the Federal Highway Administration for further review and/or retesting. The resilient modulus test data were found generally to be in excellent condition with less than 10% of the tests exhibiting potential anomalies or discrepancies in the data. The resilient modulus test data were then studied for the effect of test variables, such as the test and sampling procedures, on the resulting resilient moduli. These data were analyzed by material code for the base and subbase aggregate layers and by soil type for the subgrade. Sampling technique (auger versus test pit) was found to have the most effect on the crushed stone aggregate and uncrushed gravel base materials. For the subgrade soils, sampling technique (Shelby tubes versus auger samples) had the most effect on the clay soils. Sampling technique was found to have little to no effect on the sand base/subbase materials and sand soils. The resilient modulus data were further investigated to evaluate relationships between resilient modulus and the physical properties of the unbound materials and soils. Using nonlinear regression optimization techniques, equations for each base and soil type were developed to calculate the resilient modulus at a specific stress state from physical properties of the base materials and soils. The primary result from these studies is that the resilient modulus can be reasonably predicted from the physical properties included in the LTPP database, but there is a bias present in the calculated values. Thus, until additional test results become available to improve or confirm these relationships, it is recommended that at least some laboratory tests be performed to measure the resilient modulus for unbound pavement materials and soils.

Application/Use: The use of this study is two-fold. First, the study has improved the quality of data in the LTPP database. Second, the effect of variables on results and prediction equation will be useful in pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The availability of high quality resilient modulus values along with other material properties is one of the key benefits of the LTPP database. The data represents material from across the country. The variety and representation is a solid basis for regression analysis as well as variability/bias studies.

Future Benefit: The availability of resilient modulus data will be useful in local calibration/validation of the M-E PDG as well as sensitivity analyses as part of the implementation.

Title: Variability of Concrete Materials Data in the Long-Term Pavement Performance Program

Author(s): Tayabji, S. D; Wu, C-L.

Date: 2002

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1813

Abstract/Synopsis: As part of a study sponsored by the National Cooperative Highway Research Program, research was conducted to evaluate the variability of concrete materials data in the Long-Term Pavement Performance (LTPP) program. The following materials-related data were studied: (a) compressive strength, (b) flexural strength, (c) split tensile strength, and (d) modulus of elasticity. The variability was determined in terms of the standard deviation and coefficient of variability. The strength and stiffness data used came from the General Pavement Study (GPS) as well as the Specific Pavement Study (SPS) test sections. The analysis of data indicates that, in general, the LTPP program GPS test sections as well as the LTPP program SPS test sections exhibit characteristics of well-controlled construction projects with respect to the strength- and stiffness-related properties of concrete. The results of the analysis indicate that on well-controlled concrete pavement construction projects it would not be unreasonable to produce concrete that has a coefficient of variation of 15 percent or less for compressive strength, flexural strength, split tensile strength, and the modulus of elasticity. The findings from the analysis can be used to refine statistics-based quality assurance/quality control procedures for concrete acceptance and to define the measures of variability to be used in mechanistically based concrete design procedures.

Application/Use: This study is useful to those interested in material properties of concrete pavements.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP data provides a large quantity of materials property data that can be used in variability studies. This is beneficial in pavement design as well as construction specification development and monitoring. Understanding inherent variability is essential in developing quality specifications.

Future Benefit: The concrete material property information available in the LTPP database will support many future research projects. This may include other variability studies or investigations of the contribution of these properties on long term performance.

Title: Backcalculation of Layer Parameters for Performance / LTPP Test Sections, Volume I: Slab on Elastic Solid and Slab on Dense-Liquid Foundation Analysis of Rigid Pavements

Author(s): Khazanovich, Lev; Tayabji, Shiraz D; Darter, Michael I.

Date: 2001

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Conference Title: Ninth International Conference on Asphalt Pavements

Abstract/Synopsis: This report documents the results of backcalculation of layer material properties for rigid pavements included in the Long Term Pavement Performance (LTPP) program in the United States and Canada using deflection testing data. This study backcalculated the layer material properties for rigid pavements using the slab on elastic solid foundation and the slab on dense-liquid foundation procedures. The "best fit" algorithm was used after consideration of alternative methods of backcalculation. Pre-processing and post-processing utility software were developed to facilitate data handling. The backcalculation analysis was conducted for all General Pavement Studies (GPS), Special Pavement Studies (SPS), and Seasonal Monitoring Program (SMP) test sections. Data tables that include backcalculation parameters were developed for inclusion in the LTPP Information Management Systems (IMS). Key findings include the following: 1) The "best fit" method was selected as the primary backcalculation method for both dense-liquid (DL) and elastic solid (ES) subgrade models, 2) Reasonable backcalculation results were obtained for the large majority of GPS, SPS, and SMP sections. Typical modulus values and ranges are provided for the PCC slab, many types of bases, and the subgrade, 3) Strong correlations were found between backcalculated parameters using DL and ES subgrade models, 4) Temperature curling during the day had a profound effect on the results of backcalculation [making it important to conduct falling weight deflectometer (FWD) basin testing early in the morning to reduce variability in backcalculated values], 5) Poor correlation was found between backcalculated and laboratory elastic moduli of the concrete slab, and 6) A bonded interface between the slab and base produced the best layer moduli for a large majority of the sections (center slab backcalculation).

Application/Use: This study can be used by those interested in evaluating concrete layer properties by means of FWD data.

Contribution: Improvement in Knowledge

Present Benefit: This report provides backcalculation results for LTPP test sections as well as a complete evaluation of the results. This information will be beneficial in understanding the impact of data collection conditions on backcalculation results. Addtionally, the computations will be used in other pavement research projects.

Future Benefit: The results from this study will provide future benefit in the areas of pavement evaluation, in situ material properties, and pavement design.

Title: Characterization of Mechanical Properties and Variability of PCC Materials for Rigid Pavement Design

Author(s): Mallela, J; Titus-Glover, L; Ayers, M. E; Wilson, T. P.

Date: 2001

Publisher: International Society for Concrete Pavements

Conference Title: Seventh International Conference on Concrete Pavements. The Use of Concrete in Developing Long-Lasting Pavement Solutions for the 21st Century

Abstract/Synopsis: The objective of this paper is to describe an analysis of strength data from the LTPP SPS-2 experiment. The paper studies the rate of strength gain under the varied influences of climate/curing conditions, specimen type, and cement type. The variability of strength data obtained from a given project and the differences between "as specified" and "as-built" strengths were also investigated. Both strength development and variability are important input parameters for pavement design and reliability analysis. Finally, commonly cited relationships between the various strength parameters were analyzed. The paper provides typical concrete material inputs to the rigid pavement mechanistic-empirical design process.

Application/Use: This paper is directly applicable to materials engineers and pavement designers involved with concrete pavement.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Evaluations of concrete pavement material properties provides knowledge needed to properly design and select materials for a project. This study provides insight into concrete strength and the effect of other factors on strength gain. This is of particular interest to materials engineers as related to construction specifications and inspection. Designers are benefited by understanding differences between design properties and actual as-built parameters. This not only aides in designing pavements but may also be useful to materials engineers in refining specifications to reduce variability.

Future Benefit: Proper design and quality construction are of utmost importance to long-term pavement performance. This paper provides information that will be useful in future rigid pavement projects and will also addresses components of the M-E PDG.

Title: Evaluation of Moisture Sensitivity Properties of ADOT Mixtures on US 93. Volume I - Final Report

Author(s): Sebaaly, Peter E; Eid, Zein; Epps, Jon A.

Date: 2001

Publisher: University of Nevada, Reno; Arizona Department of Transportation; Federal Highway Administration

Abstract/Synopsis: In 1993, the Arizona Department of Transportation (ADOT) constructed pavement test sections as part of the Long Term Pavement Performance (LTPP) Specific Pavement Studies (SPS). The test sections are located on US 93 north of Kingman, Arizona, and consist of both SPS-1 and SPS-9 experiments constructed at the same location. As early as 1996 it was reported that fatigue cracking was occurring in the SPS-9 Superpave sections. A field visit in 1998 by personnel from ADOT, LTPP and the FHWA revealed that the SPS-9 Superpave test sections were experiencing premature fatigue cracking while the SPS-1 test sections which used Marshall Mix designs had not experienced any distress. The survey team concluded that moisture sensitivity may be the primary cause of the premature fatigue of the Superpave designed HMA mixtures. An investigation into this premature failure was subsequently initiated. This report describes the performance of the SPS-9 sections and documents the laboratory evaluation of mixtures and cores from the three sections in an effort to assess the appropriateness of the Superpave moisture damage requirements. The three evaluated sections included: a Superpave designed section with 1" nominal maximum size; a Superpave designed section with 3/4" nominal maximum size; and an ADOT Marshall designed section with 3/4" nominal maximum size.

Application/Use: This study is useful to Arizona for adopting Superpave mix design procedures.

Contribution: Improvement in Knowledge; Advancement in Technology; Lessons Learned.

Present Benefit: The LTPP SPS-9 experiment offers side-by-side comparisons of Superpave mixtures and agency standard mixtures. Because all other factors are constant, the study provided an excellent means of comparing mixture performance. This study has provided Arizona DOT with information on the difference between the mix design procedures. The findings may be used to adjust mix design specifications to meet the needs in Arizona.

Future Benefit: Performance data collected at SPS-9 experiments will be useful in evaluating long term performance of Superpave mixture relative to agency standard mixtures. This information will be useful in refining mix design procedures to optimize performance in a given region.

Title: Evaluation of Superpave Fine Aggregate Angularity Specification

Author(s): Chowdhury, A; Button, J; Kohale, V; Jahn, D.

Date: 2001

Publisher: Texas Transportation Institute; Aggregates Foundation for Technology, Research and Education

Abstract/Synopsis: The validity of the Superpave fine aggregate angularity (FAA) requirement is questioned by both the owner agencies and the paving and aggregate industries. The FAA test is based on the assumption that more fractured faces will result in higher void content in the loosely compacted sample; however, this assumption is not always true. Some agencies have found that cubical shaped particles, even with 100 percent fractured faces, may not meet the FAA requirement for high-volume traffic. State agencies are concerned that local materials previously considered acceptable and which have provided good field performance, cannot meet the Superpave requirements. Researchers evaluated angularity of 23 fine aggregates representing most types of paving aggregates used in the USA using seven different procedures: FAA test, direct shear test, compacted aggregate resistance (CAR) test, three different image analyses, and visual inspection. The three image analyses techniques included Hough Transform at University of Arkansas at Little Rock (UALR), unified image analysis at Washington State University (WSU), and VDG-40 videograder at Virginia Transportation Research Council (VTRC). A small study was performed to evaluate relative rutting resistance of hot-mix asphalt (HMA) containing fines with different particle shape parameters using the Asphalt Pavement Analyzer (APA). The FAA test method does not consistently identify angular, cubical aggregates as high quality materials. There is a fair correlation between the CAR stability value and angle of internal friction (AIF) from the direct shear test. No correlation was found between FAA and CAR stability or between FAA and AIF. Fairly good correlations were found between FAA and all three image analysis methods. Some cubical crushed aggregates with FAA values less than 45 gave very high values of CAR stability, AIF, and “angularity” from imaging techniques. Moreover, the three image analysis methods exhibited good correlation among themselves. A statistical analysis of the Strategic Highway Research Program-Long-Term Pavement Performance (SHRP-LTPP) database revealed no significant evidence relationship between FAA and rutting. This lack of relationship is not surprising since many uncontrolled factors contribute to pavement rutting. The APA study revealed that FAA is not sensitive to rut resistance of HMA mixtures. Image analysis methods appear promising for measuring fine aggregate angularity. Until a suitable replacement method(s) for FAA can be identified, the authors recommend that the FAA criteria be lowered from 45 to 43 for 100% crushed aggregate. Analysis of the FAA versus rutting data should be examined later as the amount of data in the SHRP-LTPP database is expanded.

Application/Use: The findings directly apply to the Superpave mix design and the fine aggregate requirements.

Contribution: Improvement in Knowledge; Advancement in Technology

<u>Present Benefit:</u> The results from this study evaluate different techniques to test fine aggregates for use in Superpave mixtures. The LTPP database provided a means of correlating fine aggregate properties to long term rutting performance. The LTPP database provides material properties as well as performance data from pavements across the country.

<u>Future Benefit:</u> The report will be referenced by others looking into the aggregate specifications of the Superpave mix design. The LTPP database will be used as a source of further research evaluating the impact mixture properties on long-term performance.

Title: Laboratory Characterization of Materials & Data Management for Ohio - SHRP Projects (U.S. 23)

Author(s): Masada, T.

Date: 2001

Publisher: University of Ohio, Athens; Ohio Department of Transportation; Federal Highway Administration

Journal Title: Transportation Research Record No. 1778

Abstract/Synopsis: About a decade ago, the Federal Highway Administration (FHWA) set up a national study called the Long-Term Pavement Performance (LTPP) under the Strategic Highway Research Program (SHRP) to extend pavement life through investigation of different pavement designs under various loading, environmental, subgrade soil, and maintenance conditions. The study involved many different materials and stressed the importance of collecting field and laboratory test data on their mechanistic properties. In the current study, mechanistic properties of the pavement materials involved in the Ohio-SHRP project were measured according to the SHRP Protocols. The test program encompassed a wide array of materials and their properties, ranging from basic index properties of the subgrade soils to resilient modulus of soils and asphalt concrete to static modulus of portland cement concrete and creep modulus of asphalt concrete. Any trends observed in the test results were pointed out to enhance our understanding of how each pavement material behaves. In some cases, previously published empirical relationships correlating basic and advanced material properties were reevaluated in light of the latest test results. A need for integrating a large volume of data that existed for the Ohio-SHRP project was recognized even prior to the initiation of the current study. As a result, a computer-based database was developed, packaged into a CD-ROM disk, and attached to this report. This user-friendly database allows a fast and easy access to all the mechanistic properties presented in this report as well as general information related to the Ohio-SHRP project.

Application/Use: The information contained in this report can be used by pavement and materials engineers.

Contribution: Improvement in Knowledge

Present Benefit: The material properties, mechanistic properties, climatic and performance data collected as part of the program is extremely valuable to pavement research. Evaluation of material property correlations can be performed as well as the influence of these properties on mechanistic behavior. The in situ conditions can also be linked to pavement response and long-term performance. This provides the basis for implementing an M-E design approach.

Future Benefit: The data amassed as part of the project will provide benefit in validating and calibrating the M-E PDG.

Title: LTPP Data Analysis: Factors Affecting Pavement Smoothness

Author(s): Perera, R.W; Kohn, S. D.

Date: 2001

Publisher: National Cooperative Highway Research Program; Soil and Materials Engineers, Incorporated

Journal Title: NCHRP Web Document 40

Abstract/Synopsis: In this research project, data available in the Long Term Pavement Performance (LTPP) Information Management System (IMS) were used to determine the effect of factors such as design and rehabilitation parameters, climatic conditions, traffic levels, material properties, and extent and severity of distress that cause changes in pavement smoothness. For the purposes of this research, the International Roughness Index (IRI) was used as the measure of pavement smoothness. The LTPP program consists of two complementary programs, the General Pavement Studies (GPS) and Specific Pavement Studies (SPS). Chapter 1 of this project report provides an introduction. Chapter 2 presents the review of literature related to factors affecting pavement smoothness and roughness development in pavements. Chapter 3 presents the data elements that were selected for analysis and data synthesis methods that were used with the data obtained from the IMS. Chapter 4 presents the data analysis methods that were utilized during the study. Chapter 5 describes roughness characteristics of new pavements, and describes the results obtained from the SPS-1 and SPS-2 experiments. Chapter 6 describes roughness characteristics of rehabilitated pavements, and describes results obtained from SPS-5 and SPS-6 experiments. Chapter 7 presents the results obtained for GPS experiments in the first design phase, which are GPS experiments 1 through 5. Chapter 8 presents the results obtained for GPS experiments 6 and 7, which are overlaid pavements. Chapter 9 presents the conclusions and recommendations for future research.

Application/Use: This study is valuable to those involved in selecting and designing pavements, including rehabilitation alternatives.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The findings from this report are beneficial because they quantify the contribution of various design parameters as well as rehabilitation techniques to roughness accumulation. This is important to designers attempting to select the most appropriate alternative with consideration given to end user cost and perception.

Future Benefit: The evaluation conducted as part of this project will continue to be useful. Currently, rehabilitation is the most common type of major asphalt concrete pavement improvement. Quantifying the relationship between strategy and roughness accumulation will prove to be beneficial in the years to come. This information can be used to select treatment options that will provide pavements that remain smoother for longer periods of time.

Title: Parameter Study of Load Transfer and Curling Effects on Rigid Pavement Deflections

Author(s): Lee, Y-H; Sheu, R-S.

Date: 2001

Publisher: National Center for Asphalt Technology

Conference Title: Second International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control. Segundo Simposio Sobre Manutencao e Rehabilitacao de Pavimentos e Controle Technologico

Abstract/Synopsis: Extensive re-backcalculation analysis of test sections of the Long Term Pavement Performance (LTPP) general pavement studies indicated that extreme difficulties in interpreting in situ deflection measurements of rigid pavements have been encountered, probably due to the effects of temperature curling, moisture warping, and loss of subgrade support. Thus, effects of adjacent slabs and temperature curling on rigid pavement deflections were examined in this work. The ILLISLAB finite element program was used for the analysis. Both dense liquid and elastic solid foundation options were analyzed. To allow the analysis of a curled slab resting on an elastic solid foundation, some proper corrections were made and verified. Two additional dimensionless variables were identified for the curling effects on elastic solid foundation. Both doweled and undoweled joints were treated as having shear load transfer only. Many factorial finite element runs were carefully selected and conducted to obtain generalized deflection databases. Prediction models for deflection adjustment factors were developed using local regression techniques. Ongoing research is underway to develop an integrated backcalculation program to facilitate analysis of more practical rigid pavement backcalculation problems.

Application/Use: This study is applicable to those interested in evaluating FWD data on concrete pavements.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study offers backcalculation results for rigid test sections in the LTPP database, which can be used by others interested in material layer properties. Adjustments made for slab curl may be useful to individuals analyzing FWD data. Also, the prediction models and deflection adjustment factors may also be incorporated into other pavement evaluations.

Future Benefit: This study will provide benefit to those using FWD data to conduct pavement evaluations. The LTPP database is beneficial in this regard as it allows various backcalculation procedures to be evaluated and refined, which can then be applied to other projects.

Title: Test Method for Determining the Creep Compliance, Resilient Modulus and Strength of Asphalt Materials using the Indirect Tensile Test Devise

Author(s): FHWA-LTPP Technical Support Services Contractor LAW PCS

Date: August 2001

Publisher: Office of Infrastructure R&D Long-Term Pavement Performance Team, HRDI-13 Federal Highway Administration

Abstract/Synopsis: This LTPP program protocol describes procedures for determination of Creep Compliance, Resilient Modulus (Mr), and Strength of hot mix asphalt concrete (HMA) using indirect tensile test techniques. This protocol is partially based on test standards AASHTO TP9-94 (Edition 1B), ASTM D4123, and the procedures outlined in Section 4.4 (Roque, et al) of this protocol. This protocol describes three distinct procedures for the determination of (1) creep compliance, (2) resilient modulus, and (3) tensile strength. This procedure requires three test specimens obtained from the same general area of the pavement test section. Each specimen is subject to creep compliance at -10, 5, and 25 °C (14, 41, and 77 °F), resilient modulus determinations at 5, 25, and 40 °C (41, 77, and 104 °F) and a strength test at 25 °C (77 °F). Therefore, three replicate test results are obtained for each specimen set.

Application/Use: The results from this project are used to determine resilient modulus values for use in flexible pavement design.

Contribution: Cost Savings; Advancing Technology; Implementation/Usage.

Present Benefit: Resilient modulus is a critical component in the design of flexible pavements. The study's evaluation of new and existing resilient modulus test methods was conducted to develop one procedure that would provide the most representative results. This improves the accuracy of resilient modulus estimates leading to more efficient pavement designs.

Future Benefit: The M-E PDG requires both bound and unbound materials resilient modulus inputs for use in the performance prediction of flexible pavements. Improved methods of estimating resilient modulus will lead to better performance predictions and optimized pavement design selections.

Title: Washington State Department of Transportation Superpave Implementation

Author(s): Leahy, R. B; Briggs, R. N.

Date: 2001

Publisher: Transportation Research Board

Abstract/Synopsis: The Washington State Department of Transportation (WSDOT) has investigated components of the Strategic Highway Research Program (SHRP)/Superpave technology to include performance-grade (PG) binder usage and specification validation, gyratory mix design, the Superpave Shear Tester, and field performance of Superpave mixes. With a focus on field performance, validation of the binder specification in respect to low-temperature cracking was accomplished using binder and field performance data from 28 projects. The results were encouraging: the original SHRP algorithm for binder selection correctly "predicted" field performance in 22 cases. The original SHRP algorithm was subsequently refined as part of the Federal Highway Administration's Long-Term Pavement Performance (LTPP) Program. The LTPP algorithm used for binder selection correctly predicted field performance in 26 cases. Since 1993, of the 44 WSDOT projects with a Superpave technology component, 17 parallel Hveem and Superpave mix designs have been conducted. In 13, Superpave design asphalt content was equal to or greater than the Hveem design asphalt content, although the difference was insignificant. A conventional Hveem mix design was conducted on 18 projects using a PG binder (Hveem-PG). The remaining 26 projects were considered to be Superpave because 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 indices trigger maintenance: pavement structural condition (PSC), rutting, or International Roughness Index (IRI). Although "young," all 44 projects are performing well. The average values of rutting, PSC, and IRI are all below the "trigger" values. In rutting and PSC, performance of Hveem-PG and Superpave projects is virtually identical. However, ride quality of Superpave projects is rougher than that of Hveem-PG binder projects.

Application/Use: This is directly applicable to the implementation of Superpave mixtures in Washington State.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: LTPPBind was developed as part of the LTPP program to assist in the proper selection of PG binder for a climate and design reliability. Proper binder selection of is an essential component of cost-effective pavement design. This study provides insight into Hveem and Superpave mixtures in Washington State.

Future Benefit: The LTPPBind software will continue provide benefit to materials engineers selecting PG binder for a given project. The study will be referenced by other agencies looking at the performance of Superpave mixtures.

Title: Characterizing Seasonal Variations in Pavement Material Properties for Use in a Mechanistic-Empirical Design Procedure

Authors: Ovik, J. M; Birgisson, B; Newcomb, D. E.

Date: 2000

Publisher: University of Minnesota, Minneapolis; Minnesota Department of Transportation

Abstract/Synopsis: Recent advances in flexible pavement design have prompted agencies to move toward the development and use of mechanistic-empirical (M-E) design procedures. This report analyzed seasonal trends in flexible pavement layer moduli to calibrate an M-E design procedure specific to Minnesota. Seasonal trends in pavement layer moduli were quantified using data from the Minnesota Road Research Project (Mn/ROAD) and Long Term Pavement Performance Seasonal Monitoring Program (LTPP SMP) sites located in Minnesota. The relationships investigated were between climate factors, subsurface environmental conditions, and pavement material mechanical properties. The results show that pavement layer stiffness is highly responsive to changes in the average daily temperature and available moisture. Five seasons were used to characterize the seasonal variations in pavement layer moduli for design purposes. Seasonal factors were used to quantify the cyclic variations in the pavement layer stiffness for a typical year. The maximum stiffness of the pavement layers is reached when temperatures are cooler. The hot mix asphalt layer moduli are at a minimum in the summer when temperatures are high. The granular base layer moduli are at a minimum during the early spring-thaw period when excess moisture is unable to drain. Finally, the fine-grained subgrade layer moduli are at a minimum in late spring and summer due to the low permeability and slow recovery of the material. The Integrated Climate Model (ICM) was used in this study to compare predicted data to actual data from Mn/ROAD. It was found that the ICM data compared favorably, however, the ICM was not able to predict the spring-thaw period.

Application/Use: This report is directly applicable to pavement design in the Minnesota region.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Findings from this study provide useful information on the mechanistic property changes in pavement materials. This can be used to make cost-effective design decisions on effective subgrade resilient modulus values.

Future Benefit: The study will provide future benefit in calibrating and implementing the M-E PDG in the Minnesota area.

Title: Computed Parameters: Moisture Content for Unbound Materials at Seasonal Monitoring Program Sites

Date: 2000

Publisher: Federal Highway Administration

Abstract/Synopsis: Moisture content plays a significant role in the performance of pavements. Variation in the amount of moisture in the subgrade can change the volume of swelling soil, which may result in detrimental deformation of the pavement structure. An increase in moisture in the subgrade and unbound base can weaken the bearing capacity of these materials, affecting the pavement's response to loads and, ultimately, pavement service life. The moisture content of unbound materials at the Long Term Pavement Performance (LTPP) Seasonal Monitoring Program (SMP) sites is computed based on the dielectric constant determined through the use of time-domain reflectometry and soil property data contained in the LTPP Information Management System (IMS) database. A discussion of the use of time-domain reflectometer (TDR) probes and the values derived from them can be found in the computed parameters document, "An Input for moisture Calculations--Dielectric Constant from Apparent Length" (Publication No. FHWA-RD-99-201).

Application/Use: This report is useful to pavement designers, materials engineers, and researchers.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study is beneficial in documenting procedures that can be used to estimate moisture content from TDR traces. This approach could be used by others collecting in situ moisture condition data to estimate seasonal variability in subgrade resilient modulus for design purposes.

The end result of this project was the addition of valuable moisture data in the LTPP database. This information, coupled with performance monitoring and response data, will be extremely useful to researchers.

Future Benefit: The TDR equipment specification, installation protocols, and data will continue to add value. Trace data is available for the development of new interpretation techniques and moisture content estimates. Additionally, the equipment and installation practices can be applied to other applications.

Title: LTPP Rigid Pavement FWD Deflection Analysis and Backcalculation Procedure

Author(s): Khazanocich, L; McPeak, T. J; Tayabji, S. D.

Date: 2000

Publisher: American Society for Testing and Materials

Conference Title: Symposium on Nondestructive Testing of Pavements and Backcalculation of Moduli: Third Volume

Abstract/Synopsis: This paper presents the results of a falling weight deflectometer deflection analysis study performed as a part of data analysis study under the Long Term Pavement Performance (LTPP) program. The paper presents backcalculation procedures for rigid pavements adapted in this study and discusses the results of backcalculation. Backcalculation was performed using dense liquid (DL) and elastic solid (ES) subgrade models. Although backcalculated parameters determined in this study were found to be realistic for the majority of the LTPP rigid pavement sections, the study also uncovered some limitations of the current backcalculation procedures due to factors such as temperature at the time of testing, slab curling conditions, time of day and time of year.

Application/Use: This study can be used by those interested in evaluating concrete layer properties utilizing FWD data.

Contribution: Improvement in Knowledge

Present Benefit: This report provides backcalculation results for LTPP test sections as well as a complete evaluation of the results. This information will be beneficial in understanding the impact of data collection conditions on backcalculation results. Additionally, the computations will be used in other pavement research projects.

Future Benefit: The results from this study will provide future benefit in the areas of pavement evaluation, in situ material properties, and pavement design.

Title: Subgrade Characterization for Highway Pavement Design

Authors: George, K. P; Uddin, Waheed

Date: 2000

Publisher: University of Mississippi, University; Mississippi Department of Transportation; Federal Highway Administration

Abstract/Synopsis: Subgrade soil characterization expressed in terms of Resilient Modulus (M sub R) has become crucial for pavement design. For a new design, M sub R values are generally obtained by conducting repeated triaxial tests on reconstituted/ undisturbed cylindrical specimens. Because of the complexities encountered with the test, in-situ tests would be desirable, if reliable correlation can be established. In evaluating existing pavements for rehabilitation selection, subgrade characterization is even more complex. The main focus of this study is to determine subgrade M sub R employing a Dynamic Cone Penetrometer (DCP), especially the automated version. In support of the study, side-by-side Falling Weight Deflectometer (FWD) tests are also conducted. Twelve as-built test sections reflecting typical subgrade soil materials of Mississippi are selected and tested with DCP and FWD before and after pavement construction. Undisturbed samples are extracted using a Shelby tube, and tested in repeated triaxial machine for M sub R. Other routine laboratory tests are conducted to determine physical properties of the soil. In analyzing the data, the soils tested are categorized into two groups, fine- and coarse-grain soils. DCP results (DCP index, penetration/blow) from tests conducted directly in the prepared subgrade are employed to develop regression models for laboratory M sub R prediction. The predictability of the model is substantiated by repeating DCP tests at an independent site. Models for in-situ modulus prediction are also developed in the study. Deflection measurements facilitated the calculation of in-situ modulus, for which three programs were used: MODULUS 5, FWDSOIL and UMPED. The MODULUS 5 backcalculated subgrade modulus shows good agreement with the laboratory M sub R. The FWDSOIL backcalculation program predicts subgrade moduli which are slightly lower than the laboratory M sub R. With emplacement of pavement structure (lime treated subgrade, lime fly ash subbase, and several inches of asphalt concrete) atop the subgrade, the subgrade backcalculated moduli are enhanced, coarse-grain soil showing a larger increase than the fine-grain soil. This latter result, namely the enhancement of subgrade moduli, is substantiated employing the data compiled from 20 Long Term Pavement Performance (LTPP) pavement sections in Mississippi. In order to analyze the automated DCP results, software designated Dynamic Cone Penetrometer ANalysis (DCPAN), has been developed. With the regression equation incorporated in the software, real time laboratory as well as backcalculated subgrade modulus calculations are plausible in the field.

Application/Use: This study is directly applicable resilient modulus estimates for pavement design in Mississippi.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Resilient modulus is a key component in pavement design. Accurate estimates of subgrade resilient modulus from other soil properties result in improved and cost-effective pavement designs. Similar benefits can be realized by understanding the sensitivity of subgrade resilient modulus to changes in soil properties. The LTPP database provided data from 20 test sections that were beneficial in completing this report.

Future Benefit: Quantifying variability in resilient modulus will continue to add value as it will remain a key component in pavement design even as agencies transition to the M-E PDG.

Title: Temperature Predictions and Adjustment Factors for Asphalt Pavement

Author(s): Lukanen, E. O; Stubstad, R; Briggs, R.

Date: 2000

Publisher: Braun Intertec Corporation; Federal Highway Administration

Abstract/Synopsis: This report presents the results of an analysis of the response that deflections and backcalculated asphalt moduli have to the pavement temperature. The study used deflection and temperature data from 40 sites monitored in the Seasonal Monitoring Program of the Long Term Pavement Performance (LTPP) program. The report presents improved methods of estimating the temperature within an asphalt pavement based on the measurement procedures used for the LTPP program. The data necessary to estimate the temperature within the asphalt included the surface temperature, time of day, depth below the surface, and the average air temperature from the previous day. Backcalculation of the asphalt modulus from the deflection data of the 40 sites was related to pavement temperature, and a method of estimating what the modulus of the asphalt would be at different temperatures is presented. Deflection and deflection basin shape factor response to temperature was also evaluated, resulting in relationships for each of the items evaluated with pavement temperature. Items evaluated include the deflection under the load plate (center sensor), center sensor minus offset sensors, center sensor divided by offset sensors, AREA factor, and the F-1 factor. The relationships were then used to develop procedures for adjusting for the effects of temperature.

Application/Use: The findings and relationships developed in this study are directly applicable to FWD data collection and analysis.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Knowing the relationship between FWD backcalulation and pavement temperature is essential in using FWD data for design and evaluation purposes. Results obtained from FWD data are dependent on the temperature during data collection. This study identifies adjustments to be made to standard temperatures for use in design and evaluation processes. Accurate temperature-response relationships result in improved designs.

Future Benefit: The SMP experiment conducted as part of LTPP will continue to benefit the pavement community. SMP data includes in situ material properties, climatic, and response data. This information can be used to study the effect of season and temperature on pavement response.

Title: Variations in Backcalculated Pavement Layer Moduli in LTPP Seasonal Monitoring Sites

Author(s): Briggs, R. C; Lukanen, E. O.

Date: 2000

Publisher: American Society for Testing and Materials

Conference Title: Symposium on Nondestructive Testing of Pavements and Backcalculation of Moduli: Third Volume

Abstract/Synopsis: Seasonal variations in structural parameters were calculated from falling weight deflectometer data on 25 long term pavement performance (LTPP) flexible seasonal monitoring sections. In all, 23,976 deflection basins were analyzed. The deflection basins were collected monthly between the fall of 1993 and the spring of 1995. The test locations were distributed around North America from Saskatchewan to South Texas and from Idaho to Maine. The sections all consisted of asphalt surfacing and granular bases over subgrades. Asphalt thicknesses ranged from 46 to 277 mm. Seasonal variations observed on selected sections in this database and documented in this paper include variations in asphalt materials with temperature, variations in moduli of the unbound materials with precipitation, and variations in moduli of unbound materials due to freeze/thaw.

Application/Use: This paper is applicable to the evaluation of FWD data as well as seasonal variation.

Contribution: Improvement in Knowledge

Present Benefit: Understanding changes in material properties due to seasonal variation in temperature, precipitation, and frost condition is beneficial to pavement designers and materials engineers. This allows pavement rehabilitation or reconstruction alternatives to properly account strength changes throughout the year, ultimately leading to more cost-effective designs.

Future Benefit: The ability to estimate in situ material properties in the various seasons will be necessary for designing pavements in accordance with the M-E PDG.

Title: Computed Parameters: An Input for Moisture Calculations - Dielectric Constant from Apparent Length

Date: 1999

Publisher: Federal Highway Administration

Abstract/Synopsis: Time domain reflectometer (TDR) probes are used in the Long Term Pavement Performance (LTPP) Seasonal Monitoring Program to obtain the moisture content in unbound base and subgrade materials. The TDR technique is based on the measurement of the travel time by an electromagnetic wave induced into a waveguide, in this application, a moisture probe. The apparent length is the length between the beginning and end points on the waveform that correspond to the beginning and end of the metal tube portion of the moisture probe. This apparent length of the probe can be used to calculate the dielectric constant of the material surrounding the probe. The dielectric constant is an input to the calculation of moisture content.

Application/Use: This report can be used by those interested in moisture content monitoring.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study is beneficial in documenting procedures that can be used to estimate moisture content from TDR traces. This approach could be used by others to collecting in situ moisture condition data to estimate seasonal variability in subgrade resilient modulus for design purposes.

The end result of this project was the addition of valuable moisture data in the LTPP database. This information coupled with performance monitoring and response data will be extremely useful to researchers.

Future Benefit: The TDR equipment specification, installation protocols, and data will continue to be of benefit. Trace data is available for the development of new interpretation techniques and moisture content estimates. Additionally, the equipment and installation can be applied to different applications.

Title: Determination of Resilient Modulus for Maine Roadway Soils

Authors: Smart, A. L; Humphrey, D. N.

Date: 1999

Publisher: University of Maine, Orono; Maine Department of Transportation

Abstract/Synopsis: The Maine Department of Transportation commissioned this study to examine methods of obtaining resilient modulus for use in pavement design. Resilient modulus is a measure of soil layer stiffness and is highly subjective to density, moisture content, soil fabric structure, compaction method, laboratory equipment compliance, and technician skill. As a result, several alternative test methods have been proposed. These alternative test methods include resilient modulus correlation to results from torsional shear and resonant column tests, a modified gyratory test machine normally used for testing asphalt concrete specimens, and a small-scale falling weight deflectometer (FWD) device. The study used resilient modulus test data of 14 Maine soils published by Law Engineering (1992). Soil index property data and FWD data were obtained from the Strategic Highway Research Program's Long Term Pavement Performance (LTPP) database. Three methods for determining resilient modulus were examined: (1) backcalculation of resilient modulus using computer software, (2) determination of the K sub n constants for various constitutive resilient modulus equations by linear regression analysis, and (3) correlations between resilient modulus and soil property data and stress state. Computer backcalculation was done using MODCOMP 4 and MODULUS 5.1. The backcalculated resilient moduli did not compare well with the laboratory moduli when the programs automatically estimated the depth to hard layer and outliers were neglected. The K sub n constants for 7 common constitutive relationships were developed for 14 Maine soils using linear regression. Two equations correlating resilient modulus to dry density, water content, grain size distribution and stress state were also generated from linear regression techniques. California bearing ratio (CBR) does not correlate well with resilient modulus, therefore, no correlations involving CBR were examined.

Application/Use: This study will be used by materials and pavement engineers looking for resilient modulus estimates ob subgrade materials in the Maine area.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: Accurate estimates for subgrade resilient modulus are necessary for proper pavement design. The models developed will be a useful pavement design tool, particularly in projects where resilient modulus data was not obtained. Information on the relationship between FWD backcalculated results and measured resilient modulus can be useful in design as well.

Future Benefit: Pavement designs in Maine may be based on correlation derived from this study. Additional benefit will be realized as the M-E PDG is implemented and used for pavement evaluation and design.

Title: Evaluation of In-Situ Moisture Content at Long-Term Pavement Performance Seasonal Monitoring Program Sites

Authors: Jiang, Y. J; Tayabji, S. D.

Date: 1999

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1655

Abstract/Synopsis: Time domain reflectometry (TDR) has become one of the most reliable nondestructive methods for measuring in situ soil moisture content. TDR sensors developed by the Federal Highway Administration are being used in the Long-Term Pavement Performance (LTPP) Seasonal Monitoring Program (SMP) to monitor the in situ moisture content at 64 LTPP sites. The main goal of this study is to develop procedures to produce good estimates of in situ gravimetric moisture content. All the TDR traces in the LTPP information management system database that were recorded at LTPP SMP test sections were processed using the approach described in this paper. To estimate the in situ gravimetric moisture content, methods were selected to interpret TDR traces. An algorithm and a computer program, Moister, were developed to implement these TDR interpretation methods. Then the apparent length of the TDR trace and the dielectric constant of the unbound material were computed. Models were developed to relate dielectric constant with in situ volumetric moisture content. Finally, gravimetric moisture content was computed using the volumetric moisture content value and dry density of the soil. A diagnostic study of the computed gravimetric moisture content was also conducted to evaluate the reasonableness of the computed moisture content.

Application/Use: This report is useful to pavement designers, materials engineers, and researchers.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study is beneficial in documenting procedures that can be used to estimate moisture content from TDR traces. This approach could be used by others collecting in situ moisture condition data to estimate seasonal variability in subgrade resilient modulus for design purposes.

The end result of this project was the addition of valuable moisture data in the LTPP database. This information coupled with performance monitoring and response data will be extremely useful to researchers.

Future Benefit: The TDR equipment specification, installation protocols, and data will continue to add value. Trace data is available for the development of new interpretation techniques and moisture content estimates.

Title: Evaluation of Rigid Pavement Joint Seal Movement

Authors: Morian, D. A; Suthahar, N; Stoffels, S.

Date: 1999

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1684

Abstract/Synopsis: The subject of sealing concrete pavement joints has been studied for many years, and a wealth of technology exists for successfully installing pavement joint seals. However, in practice, a great deal of inadequate performance has been observed by highway agencies in the United States in recent years. A primary reason for the observed problems is inadequate control of construction processes. Another very significant factor affecting the performance of joint seals is climatic conditions. Examined are the effects of climate on the movement of rigid pavement joints. Temperature, joint movement, and other data collected as a part of the Long-Term Pavement Performance (LTPP) program data collection for seasonal sites have been used to assess actual joint movements in various climatic conditions throughout the United States and Canada. These measured data are compared with theoretically calculated joint movements. In most cases the actual movements appear to be greater than those theoretically predicted. On the basis of measured joint openings from LTPP seasonal sections, the conclusion is made that the measured joint opening values are greater than joint opening values calculated using the AASHTO equation. The data also provide evidence that irregular joint openings are present at all the sites evaluated.

Application/Use: This study is directly applicable to rigid pavement design including both joint and sealant design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP SMP experiment has provided value in terms of sufficient data availability to support this analysis. The findings from the report can be used to understand the accuracy of the AASHTO joint opening equation and can be used to evaluate joint designs and sealant materials.

Future Benefit: Data from the SMP experiment will continue to provide an avenue to study specific responses resulting from variations of in situ conditions. There is currently no other source of data that matches the quantity and detail of the LTPP database.

Title: LTPPBind: A New Tool for Selecting Cost-Effective SuperPave Asphalt Binder Performance Grades

Date: 1999

Publisher: Federal Highway Administration

Journal Title: Product Brief

Abstract/Synopsis: A limited amount of pavement temperature data was available when the Strategic Highway Research Program (SHRP) developed its Superpave system. As such, specifications for SHRP's Superpave Performance Grade (PG) asphalt binders were based on the lowest and highest temperatures expected at a site. Recently, the Long Term Pavement Performance (LTPP) program used data from its Seasonal Monitoring Program to quantify the relationship between air and pavement temperatures. This evaluation resulted in the development of improved low and high pavement temperature models for selecting Superpave PG asphalt binders. Now these improved models are available in a new software program called LTPPBind. This Product Brief explains what LTPPBind is, who can benefit from it, its various tools and features, and the LTPPBind system requirements.

Application/Use: LTPPBind software can be used to select the appropriate PG binder grading for a given climate and design reliability. It is also useful in selecting crack sealant with material properties that match climatic demands of the project.

Contribution: Cost Savings; Implementation/Usage.

Present Benefit: Improper binder selection in pavement design can lead to premature pavement failures and costly repairs. LTPPBind provides the means to select PG binder grading that matches the climatic demands and reliability of the project. This improves pavement performance and reduces the probability of premature failure. Similarly, LTPPBind can be beneficial in selecting an appropriate crack sealant. Crack sealant with the appropriate material properties will not fail prematurely. This improves pavement performance and slows future deterioration. An estimated $50 million/year has been saved as a result of designers utilizing the LTPPBind software.

Future Benefit: Proper selection of binder and crack sealant will lead to an overall improvement in pavement performance. As agencies implement pavement management programs with optimal maintenance timing, it is critical to select crack sealants that will perform well for many years.

Title: Preliminary Evaluation of LTPP Continuously Reinforced Concrete (CRC) Pavement Test Sections

Authors: Tayabji, S. D; Selezneva, O; Jiang, Y. J.

Date: 1999

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: As part of the study reported here, analysis of data from the Long Term Pavement Performance (LTPP) GPS-5 test sections was conducted to identify factors that influence long-term crack spacing in continuously reinforced concrete (CRC) pavements and to determine the effect of crack spacing on pavement performance. Data from the 85 test sections from the GPS-5 experiment were analyzed. Due to the limitations of the available data and the lack of certain key data, the study was not able to produce definitive findings on factors that affect long-term crack spacing and CRC pavement performance. Lack of early-age cracking due to ambient weather conditions at the time of construction will continue to limit the value of GPS-5 to produce meaningful data on factors affecting early-age cracking. Continued monitoring of GPS-5 sites and subsequent data analysis should yield information on how CRC pavement cracking and performance changes with time, loading, and other factors. It is expected that as additional data from the GPS-5 experiment become available, it will be possible to perform more in-depth analysis of the test data to derive definitive results. Results to date, as presented in this report, do indicate that CRC pavements have the potential to provide long-term, low-maintenance service life as evidenced by the many well-performing sections in the LTPP GPS-5 experiment.

Application/Use: This study is directly applicable to pavement engineers involved with design, construction, and maintenance of CRCP.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: The LTPP database contains inventory and performance data for CRCP test sections. This information is beneficial in evaluating current CRCP design practices as well as understanding key design factors in performance. This type of research can lead to refinements in current design practices, thereby creating more cost-effective designs.

Future Benefit: The data available through LTPP will continue to provide a means of evaluating pavement performance to enhance design, construction, and maintenance activities. This will lead to improved performance at reduced overall cost.

Title: Selection and Evaluation of Performance-Graded Asphalt Binders for Virginia

Author(s): Prowell, B. D.

Date: June 1999

Publisher: Virginia Transportation Research Council

Abstract/Synopsis: This study recommended and evaluated performance-graded (PG) binders for use in hot mix asphalt in Virginia. Ten conventional viscosity-graded asphalt cements, representing the asphalt typically available in Virginia, were graded under the PG system to develop a cross reference with the new system. Based on the past performance of the viscosity-graded asphalt and the PG binder testing, PG 64-22 binder was selected as the base grade of asphalt for Virginia.

Laboratory studies were performed with the Georgia loaded-wheel tester and asphalt pavement analyzer to evaluate the use of increasing the high-temperature binder grade for heavy or slow-moving traffic. Based on the success of these studies and field trial sections, two new mix types, SM-2D and SM-2E, both 50-blow Marshall mixes with PG 70-22 and PG 76-22 binder, respectively, were developed. A lower laboratory compaction effort will increase the asphalt content for durability, and the stiffer binder will prevent rutting. A large database of field rut depth data was developed for Virginia Department of Transportation surface mixes with the asphalt pavement analyzer. The data were used to estimate maximum rut depth criteria for quality assurance and evaluation of future asphalt mix designs, binders, and stabilizers.

Application/Use: This is directly applicable to materials specification in Virginia.

Contribution: Cost Savings; Advancement in Technology.

Present Benefit: This study utilized the LTPPBind program as part of the evaluation to recommend PG 64-22 for use in Virginia. The temperature prediction algorithm provides insight into the range of temperatures to be expected within a specific geographic area, which can be used to determine reliability. Selecting the appropriate binder for a given climatic setting can increase the pavement's resistance to thermal cracking and improve overall performance.

Future Benefit: LTPPBind will continue to provide value to the pavement community as agencies use it to make well informed decisions on binder selection for AC pavements as well as crack sealant materials.

Title: Videotapes Explain the How and Why of LTPP's Revised Resilient Modulus Laboratory Tests and Procedures

Date: 1999

Publisher: Federal Highway Administration

Journal Title: Product Brief

Abstract/Synopsis: The Long Term Pavement Performance (LTPP) program developed a standardized laboratory procedure to measure the resilient modulus of subgrade materials, along with a related laboratory startup and calibration verification procedure. To help highway agencies understand the new procedure, three videotapes have been produced by the Federal Highway Administration through a cooperative agreement with the Minnesota Department of Transportation. The videotapes explain the how and why of LTPP's revised resilient modulus laboratory tests and procedures. This Product Brief describes the resilient modulus videotapes and discusses who can benefit from them.

Application/Use: This CD-ROM is directly applicable to those interested in resilient modulus testing of unbound material.

Contribution: Improvement in Knowledge; Advancement in Technology; Implementation/Usage.

Present Benefit: The development and work conducted under the LTPP program has significantly improved the testing protocols for resilient modulus testing. This product helps materials engineers and laboratory personnel understand the test procedures. Accurate and reliable results are essential for reliable pavement design decisions.

Future Benefit: Resilient modulus data is a key component of the new M-E design practices. Having accurate and repeatable data will improve the performance of pavements as designs will be based on better quality information.

Title: Analyses Relating to Pavement Material Characterizations and Their Effects on Pavement Performance

Authors: Von Quintus, H; Killingsworth, B.

Date: 1998

Publisher: Brent Rauhut Engineering, Incorporated; Federal Highway Administration

Abstract/Synopsis: This report presents the analysis conducted on relating pavement performance or response measures and design considerations to specific pavement layers utilizing data contained in the Long Term Pavement Performance (LTPP) Program National Information Management System. The goal of this research activity was to enhance implementation and use of the 1993 American Association of State Highway and Transportation Officials (AASHTO) Design Guide through improved materials characterizations. Specifically, the focus of this research activity was to identify the differences that exist between laboratory measured and backcalculated resilient moduli; determine the applicability of the C values, drainage coefficients, and relative damage factors that are included in the Design Guide; and provide procedures to adequately consider the seasonal variation of material properties as related to flexible pavement designs. Based on these results, design pamphlets have been prepared in support of the AASHTO Design Guide. These design pamphlets are documented and included in other reports. The results reported here form the basis and background for those design pamphlets.

Application/Use: This study is directly applicable to flexible pavement design.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: This study is beneficial in understanding how the 1993 AASHTO design procedure relates to actual performance. The LTPP database provided the data required to complete the evaluation. The findings can be used to improve the design process and make better decisions on the selection of design input factors. This will improve performance and lead to more cost-effective pavement designs.

Future Benefit: The LTPP database will be used in a similar fashion to calibrate and validate the M-E PDG. The comprehensive nature of the LTPP data will be valuable in this regard as there is currently no other source of quality data that would support such an endeavor.

Title: LTPP Seasonal Asphalt Concrete (AC) Pavement Temperature Models

Authors: Mohseni, A.

Date: 1998

Publisher: Pavement Systems (PavSys); Federal Highway Administration

Abstract/Synopsis: SUPERPAVE binders are selected based on the lowest and highest pavement temperatures expected at a job. The original SUPERPAVE specifications were developed with limited data for validating the low-temperature algorithm for pavement temperatures. The lowest air temperature was assumed for the lowest pavement temperature. In areas with extremely low temperatures, this conservative approach has led to the selection of more restrictive binder grades than may be necessary. These binder grades usually require that modifiers be added to the asphalt, which increases the cost of the project. The initial round (Loop-1) of the Long Term Pavement Performance study's Seasonal Monitoring Program (LTPP-SMP) - the collection of pavement and air temperatures at 30 test sites throughout North America - was completed in 1995. The availability of these data makes it possible to evaluate and refine existing pavement temperature algorithms. Two new temperature data bases that combine the SMP data with weather station data from the original SUPERPAVE binder specifications were developed under this study. These data bases are used as tools throughout the study to further refine the existing low- and high-temperature models. This report proposes revisions to the Strategic Highway Research Program (SHRP) Performance Grading System for asphalt binder selection. Revised models for determining the low- and high-temperature component of SUPERPAVE performance-based binders are presented and compared with existing models and resulting performance grades.

Application/Use: This study is directly applicable to binder selection in AC pavements.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The pavement and air temperature data collected at LTPP-SMP sites provided an excellent source to make refinements in prediction algorithms. Improved models result in more accurate estimates of actual pavement temperatures. With this information, materials engineers can select the appropriate binder without excessive conservatism, thereby reducing costs without sacrificing performance.

Future Benefit: The LTPP-SMP data will continue to benefit the pavement community. The data can be used to model temperature and moisture changes in pavements and correlate these variations to pavement response. The information will be extremely valuable in moving towards an M-E pavement design approach.

Title: Seasonal Instrumentation of SHRP Pavements - The University of Toledo

Authors: Heydinger, A. G; Randolph, B. W.

Date: 1998

Publisher: Toledo University; Ohio Department of Transportation; Federal Highway Administration

Abstract/Synopsis: Seasonal Monitoring Program (SMP) instrumentation was installed in five sections at the Ohio Test Pavement in Delaware County, Ohio using Strategic Highway Research Program (SHRP) protocols developed for the Long-Term Pavement Performance (LTPP) group of the Federal Highway Administration (FHWA). The SMP instrumentation monitors pavements for temperature and pavement bases and subgrade soils for variations of moisture, temperature and frost penetration. Time Domain Reflectometry (TDR) instrumentation was installed onsite in two sections for monitoring the moisture. Thermal conductivity sensors (TCS) were installed in four sections to measure soil moisture suction. Laboratory soil-water characteristic tests were conducted on remolded subgrade soil. The TDR volumetric moisture contents typically varied by 10 percent to 15 percent from the driest to the wettest periods, but sometimes the variations were larger. The lower water contents occurred during the late winter/early spring months and the higher contents occurred during the late summer early fall months. This reflects the climatic conditions that occurred. Some of the TDR moisture contents exceeded 40 percent, which is greater than the soil porosity and therefore not possible. An equation for TDR volumetric water content developed for the FHWA yields lower water contents. Most of the TCS are no longer within calibration. Data from sensors in calibration indicate very low matric suctions, which is consistent with high water contents. Soil-water characteristic relationships were obtained for the subgrade soil using triaxial and pressure plate apparatus. The relationships from the two tests are comparable. The soil exhibits some hysteresis when comparing drying and wetting curves.

Application/Use: The findings from this study can be used to understand the instrumentation and data collected at the Ohio Test Pavement.

Contribution: Cost Savings; Improvement in Knowledge; Lessons Learned.

Present Benefit: This study provides information on the in situ seasonal changes of pavement structures. With this information, designers can properly account for changes in subgrade strength throughout the year to determine cost-effective pavement structural designs. The study also provides information on the equipment used to collect in situ data. Valuable insights into the capabilities of this equipment can be gleaned from this report.

Future Benefit: Equipment evaluation information provided here can be used by those interested in monitoring in situ conditions at other locations. Additionally, the information can be used to interpret the data collected at the site. The data will be beneficial in calibrating and validating the M-E PDG as well as using the M-E PDG for pavement design purposes.

Title: Backcalculation of Layer Moduli of LTPP General Pavement Study (GPS) Sites

Authors: Killingsworth, B; Von Quintus, H.

Date: 1997

Publisher: Brent Rauhut Engineering, Incorporated; Federal Highway Administration

Abstract/Synopsis: This report details the activities and processes by which the re-backcalculation of Long Term Pavement Performance (LTPP) General Pavement Study (GPS) test sections were completed. It details how the backcalculation program was selected, lists the GPS sections re-backcalculated, presents the results of the revised backcalculations and discusses the problem sections that were encountered. The report is also accompanied by a database that contains results from the original Strategic Highway Research Program (SHRP) backcalculation process and those sections that were re-backcalculated.

Application/Use: This study can be used by those interested in evaluating pavement layer properties by means of FWD data.

Contribution: Improvement in Knowledge

Present Benefit: This report provides backcalculation results for LTPP test sections as well as a complete evaluation of the results. This information will be beneficial in understanding the impact of data collection conditions on backcalculation results. Additionally, the computations will be used in other pavement research projects.

Future Benefit: The results from this study will provide future use in the areas of pavement evaluation, in situ material properties, and pavement design.

Title: Investigation of Modified Asphalt Performance Using SHRP Binder Specifications

Authors: Bahia, Hussain U; Bosscher, Peter J; Russell, Jeffrey S; Thomas, Suwitho

Date: 1997

Publisher: University of Wisconsin, Madison; Wisconsin Department of Transportation; Federal Highway Administration

Abstract/Synopsis: The Pavement Research Division of the Wisconsin Department of Transportation initiated this project as a result of concerns regarding excessive premature cracking of asphaltic pavements. The objectives of the project were to field validate the Superpave binder specification criteria and to field validate the pavement temperature estimation procedure used in the original Superpave software. Six test sections were constructed on USH 53 in Trempealeau County to monitor how weather conditions can affect pavement temperature at surface and as a function of pavement depth, using pavement instrumentation and a weather station. The asphalt cement used in the surface layer and the binder layer were varied for each test section, and the type of mixture and pavement structure were similar for the six test sections. Two modified asphalts, graded at PG 58-34 and PG 58-40, and one conventional asphalt graded as PG 58-28 (120-150 penetration grade), were used in the study to investigate the relation between thermal cracking and performance related properties of these asphalt binders. This report includes analysis of the data collected during the first 22 months of the project. The analysis resulted in developing statistical models for estimation of pavement minimum and maximum temperature from meteorological data. The models (called the Wisconsin models) were compared to the Superpave recommended model and to the more recent model recommended by the Long Term Pavement Performance (LTPP) program. The analysis indicates that there is a strong agreement between the Wisconsin model and the new LTPP model for the estimation of minimum pavement design temperature. The analysis, however, indicates that the LTPP model and the Superpave model underestimate the maximum pavement design temperature at air temperatures higher than 40 deg C. The analyses also indicate that there are significant differences between the standard deviation of air temperatures and the standard deviation of the pavement temperatures. The Wisconsin models and the pavement standard deviations are recommended for estimating the required PG grades to be used in Wisconsin. The report also includes the results of the surface condition surveys and its relation to the properties of the asphalts used in the test sections. The performance analysis could not be used for evaluating the Superpave binder criteria because all sections suffered from reflective cracking. Although there were significant differences in severity of reflective cracking, no strong correlations could be found with asphalt binder properties. The results indicate that the modified binders used in this study did not result in reduction of reflective cracking.

Application/Use: This study is directly applicable to binder selection in AC pavements in Wisconsin.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The pavement and air temperature data collected at LTPP-SMP sites provided an excellent source to develop the LTPP temperature prediction algorithms. Improved models result in more accurate estimates of actual pavement temperatures. With this information, materials engineers can select the appropriate binder without excessive conservatism, thereby reducing costs without sacrificing performance.

Future Benefit: The LTPP-SMP data will continue to benefit the pavement community. The data can be used to model temperature and moisture changes in pavements and to correlate these variations to pavement response. This information will be extremely valuable in moving towards an M-E pavement design approach.

Title: LTPP Materials Characterization Program: Resilient Modulus of Unbound Materials (LTPP Protocol P46). Laboratory Startup and Quality Control Procedure

Authors: Alavi, S; Merport, T; Wilson, T; Groeger, J; Lopez, A.

Date: 1997

Publisher: PCS/Law Engineering; ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: This document describes a procedure for resilient modulus quality control checks. The procedure evaluates the ability of laboratory personnel and the test system to complete LTPP P46 protocol for resilient modulus testing. The procedure is divided into three general phases: (1) Electronic System Performance Verification; (2) Calibration Check and Overall System Performance Verification; and (3) Proficiency Testing. The implementation of this procedure in the FHWA Contractor Laboratories has greatly reduced the within and between laboratory variability associated with the LTPP P46 test procedure.

Application/Use: This report is of value to any laboratory obtaining new testing equipment, as well as to practitioners interested in the resilient modulus of unbound materials.

Contribution: Cost Savings; Advancement in Technology; Implementation/Usage.

Present Benefit: Recognizing the need for an improved test practice, LTPP made a considerable investment into the development of the unbound resilient modulus testing protocol (P46). This document has provided valuable information in ensuring testing equipment is properly assembled and producing quality data. The protocol has provided agencies with a consistent and reliable method of obtaining resilient modulus values—a key component in pavement design and evaluation.

Future Benefit: The protocol will add future benefit as agencies continue to use resilient modulus to characterize material properties.

Title: Seasonal Variation in Material Properties of a Flexible Pavement

Authors: Watson, D K; Rajapakse, R.K.N.D.

Date: 1997

Publisher: International Road Federation

Conference Title: XIIIth World Meeting of the International Road Federation

Abstract/Synopsis: Seasonal variations in temperature and moisture cause considerable changes in the load carrying capacity of pavements in geographical areas subject to extreme freeze thaw conditions. Pavement engineers in these areas must be able to quantify the variation in the load carrying capacity of a pavement in order to design it adequately. The seasonal monitoring program (SMP) of the U.S. long term pavement permanence performance (LTPP) study of FHWA is monitoring seasonal variations in falling weight deflectometer (FWD) deflections, air temperature, rainfall, soil temperature, moisture content, and soil electrical resistance at numerous sites across North America. The present study relates changes in pavement load carrying capacity represented by the pavement layer resilient moduli to selected environmental factors on the SMP site near Oak Lake, Manitoba.

Application/Use: The findings from this study are directly applicable to flexible pavement design.

Contribution: Improvement in Knowledge

Present Benefit: Understanding changes in subgrade modulus as a function of changes in moisture content is important in pavement design. It allows designers to select pavement sections that efficiently account for these seasonal variations.

Future Benefit: As pavement design moves towards M-E PDG practices, understanding modulus changes will be an essential part of the process. The results from this study will be useful in estimating subgrade modulus values in different seasons.

Title: Asphalt Concrete Synthetic Reference Sample Program and the LTPP Asphalt Concrete Core Proficiency Sample Program

Authors: Steele, G. W.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: All laboratories conducting tests for the Long-Term Pavement Performance (LTPP) program were required to be accredited by the American Association of State Highway and Transportation Officials (AASHTO) Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests were not addressed fully by the AAP, and the LTPP decided to conduct supplemental testing. The asphalt concrete synthetic reference sample program and the asphalt concrete core proficiency sample program were among the supplemental programs approved for implementation. In the first of these two programs, a set of four specimens was circulated to all participating laboratories for testing in accordance with specified parameters. In the second program, two sets of cores (five per set) were shipped to the laboratories. Twenty-four laboratories participated in either one or both programs. Worksheets, supporting data, analyses, final comments, and conclusions are presented. A complete set of proficiency sample statements are provided.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Dynamic Linear Back Calculation of Pavement Material Parameters

Authors: Uzan, Jacob

Date: January 1994

Publisher: J. Transp. Engrg., Volume 120, Issue 1, pp. 109-126 (January/February 1994)

Abstract/Synopsis: The dynamic linear back calculation procedure for estimating pavement material properties is presented. Two approaches based on the fitting of the data in the time and frequency domain are described in detail. The time-domain approach is recommended when the deflection histories do not decay to zero at the end of the sampling window. The parameter identification procedure used to generate the sensitivity matrix and the load vector and to solve the overdetermined set of equations is described. Twenty-four test sections from the GPS of the SHRP-LTPP program are analyzed. The material properties back calculated are: (1) The moduli of elasticity for unbound base, subbase and subgrade materials; and (2) the parameters of the generalized power law of the creep compliance of the asphalt concrete. The results are compared with those of the static linear back-calculation procedure and of laboratory tests. It is found that: (1) The moduli of elasticity for unbound materials from static and dynamic analyses compare relatively well; and (2) the exponents of the power law from back calculation and laboratory results do not compare well. It is suggested that the sample tested in the laboratory may not be representative of the whole asphalt concrete layer.

Application/Use: The approach proposed in this paper can be utilized by pavement analysts and designers using FWD data in their evaluations.

Contribution: Improvement in Knowledge

Present Benefit: The methodology developed in this study is an additional tool for those in the pavement community. FWD data is useful in determining the structural adequacy of existing pavements, estimating subgrade properties, void detection, and load transfer efficiency.

Future Benefit: The data available from LTPP will benefit future studies in developing new procedures to analyze FWD data. This information will also support validation of existing procedures.

Title: Influence of Stress Levels and Seasonal Variations on in Situ Pavement Layer Properties

Authors: Noureldin, A. S.

Date: 1994

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1448

Abstract/Synopsis: Presented is a small-scale investigation of how stress levels and seasonal variations affect pavement layer characteristics. Monitoring such effects is basic to the effort conducted under the Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) studies currently under the FHWA jurisdiction. Illustrated are the influences of stress levels, seasonal temperature variations, seasonal moisture variations, and accumulated equivalent single axle loads (ESALs) on (a) center deflection (D sub o) measured by the falling-weight deflectometer; (b) in situ asphalt concrete modulus (E sub AC); (c) in situ granular layer modulus (E sub g); (d) in situ subgrade resilient modulus (MR); (e) in situ AASHTO effective structural number (SN sub eff); and (f) variability within a section for each of the structural factors above. Analysis of results suggests that MR is the parameter most affected by a change in stress level, followed by E sub g, E sub AC, and SN sub eff. On the other hand, E sub AC is the parameter most affected by the change in temperature, followed by D sub o, SN sub eff, E sub g and MR. Variations in MR and E sub g with temperature are believed to be associated indirectly with variations in E sub AC and temperature. Changes in E sub AC and temperature result in changes in stress levels imposed on the underlying pavement layers that cause variations in MR and E sub g. Accumulation of ESALs under dry conditions affect E sub AC, followed by D sub o, E sub g, SN sub eff, and MR, in order of diminishing effect. In addition, seasonal moisture variations affect D sub o and MR, followed by E sub g, E sub AC and SN sub eff. And variability within a section for each of the structural factors increases with an increase in temperature, moisture level, or accumulated ESALs. Among the structural factors, SN sub eff has the lowest within-section variability, whereas E sub g has the greater within-section variability.

Application/Use: This paper can be used by those interested in the seasonal variation of pavement responses.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: The LTPP program has devoted significant resources in establishing a data collection mechanism for subsurface moisture content, subsurface temperature, and frost penetration. The technology utilized by the LTPP program can also benefit in other applications. Additionally, the data collected at these sites provides valuable information on the daily and seasonal variation of in situ conditions, which is useful in pavement design.

Future Benefit: Understanding the changes in material properties through the seasons will be useful in refining design procedures to properly account for these variations. The SMP sites provide a link between in situ conditions and pavement response, which is a critical component to mechanistic-empirical analysis.

Title: Materials and Construction Variability Based on SHRP-LTPP Data

Authors: Hadley, W. O; Irick, P; Anderson, V.

Date: 1994

Publisher: Minnesota Department of Transportation

Conference Title: 4th International Conference, Bearing Capacity of Roads and Airfields

Abstract/Synopsis: The principal objective of the Strategic Highway Research Program Long-Term Pavement Performance (SHRP-LTPP) program was the development of a comprehensive database for pavement performance data covering a wide range of conditions and service life factors. The goal of this study was to investigate methods in which materials and construction variability could be incorporated into specific predictive equations for rigid and flexible pavement performance parameters.

Application/Use: This paper is directly applicable to materials engineering and construction quality control.

Contribution: Improvement in Knowledge

Present Benefit: A study evaluating the effect of materials and construction variability on long term performance can be useful in establishing specifications, warranties, and performance-based specifications. The LTPP data provides materials, construction (on SPS and rehabilitation projects), and performance data necessary to conduct this type of evaluation.

Future Benefit: The LTPP database will continue to be the prominent source of comprehensive national pavement performance data and will be used to support future work in this area.

Title: Round 1 Type I Unbound Granular Base Course Proficiency Sample Program

Authors: Steele, G. W; Anderson, D A; Antle, C. E.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Strategic Highway Research Program (SHRP) Protocol 46, "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils," was the specified procedure for laboratories performing resilient modulus tests on research samples of unbound granular base course material obtained from Long-Term Pavement Performance (LTPP) field sites. P46 requires a test system that includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated load component, and certain load and specimen response control, measurement, and recording components. Two elements of P46 testing were particularly important: verification that the system was calibrated and yielding reasonable results and a practical means of performing quality checks on a daily or more frequent basis. A set of eight test samples was shipped to each of nine LTPP laboratories with appropriate instructions. All participants were required to complete testing of Type I synthetic reference sample set prior to testing the Round 1 proficiency samples. Worksheets, supporting data, analyses, final comments, and conclusions are presented.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Round 1 Type II Unbound Cohesive Subgrade Soil Proficiency Sample Program

Authors: Steele, G. W; Antle, C. E; Anderson, D. A.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Strategic Highway Research Program (SHRP) Protocol 46, "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils," was the specified procedure for laboratories performing resilient modulus tests on research samples of unbound cohesive subgrade soil obtained from Long-Term Pavement Performance (LTPP) field sites. P46 requires a test system that includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated load component, and certain load and specimen response control, measurement, and recording components. Two elements of P46 testing were particularly important: verification that the system was calibrated and yielding reasonable results and a practical means of performing quality checks on a daily or more frequent basis. Worksheets, supporting data, analyses, final comments, and conclusions are presented.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Round 1 Hot Mix Asphalt Laboratory Molded Proficiency Sample Program

Authors: Steele, G. W; Antle, C E; Anderson, D. A.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: All laboratories conducting tests for the Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) program were required to be accredited by the American Association of State Highway and Transportation Official's (AASHTO's) Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests were not addressed fully by the AAP, and LTPP staff decided to conduct supplemental testing. The Hot Mix Asphalt (HMA) Laboratory Molded Proficiency Sample Program is one of those supplemental tests. Round 1 testing provided within- and among-laboratory diametral resilient modulus data for tests performed in accordance with SHRP Test Protocol P07. The objectives included drafting single operator and multi-laboratory test precision statements in testing proficiency status for SHRP laboratories, and preserving test sample information for future analysis. Worksheets, supporting data, analyses, final comments, and conclusions are presented. A complete set of proficiency sample statements in AASHTO and American Society for Testing and Materials (ASTM) format are provided.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: SHRP-LTPP Materials Characterization: Five-Year Report

Authors: Hadley, W. O; Groeger, J. L.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: The Strategic Highway Research Program (SHRP) developed two materials characterization programs: one for field sampling, and another for laboratory testing. The SHRP field materials sampling and laboratory materials testing program encompassed all 50 states; 10 Canadian provinces; and Puerto Rico. This report documents the development and execution of these programs for both the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). These topics are described separately here, although they are linked inherently. Suggestions are given for future materials characterization within the Long-Term Pavement Performance program as it continues under the Federal Highway Administration.

Application/Use: Five-year reports can be used by those interested in early program activities. These reports were also used as internal planning tools.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: Findings from status or summary reports can provide significant insight into the early activities of the program. This information can be used to understand how the program evolved and provides background on the decision process. The LTPP program was at the forefront of resilient modulus testing for unbound material and many laboratory setup and testing protocols were established through the program.

Future Benefit: Establishing a national, long-term research program requires significant planning and coordination. Program documentation since the inception of the LTPP program will be extremely beneficial to future endeavors of data users.

Title: Strategic Highway Research Programs Long-Term Pavement Performance (SHRP-LTPP) Asphalt Resilient Modulus Pilot Study

Authors: Hadley, W. O; Anderson, V.

Date: 1994

Publisher: Minnesota Department of Transportation

Conference Title: 4th International Conference, Bearing Capacity of Roads and Airfields

Abstract/Synopsis: In this paper the results of an analysis of the combined data from two of the four SHRP-LTPP regions are presented. Mr (resilient modulus) information was not yet available for two of the regions at the termination of the 5-year SHRP program. The Mr data used in this study is based upon vertical deflection compliance factors identified in the October 1992 version of the SHRP Mr Protocol P07.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Type I Unbound Granular Base Synthetic Reference Sample Program

Authors: Steele, G. W; Antle, C. E; Anderson, D. A.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Strategic Highway Research Program (SHRP) Protocol 46 was the specified test procedure for laboratories performing resilient modulus tests on samples of unbound granular base material obtained from Long-Term Pavement Performance (LTPP) field sites. P46 requires a test system that includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated load component, and certain load and specimen response control, measurement, and recording components. Two elements of P46 testing were particularly important: verification that the system was calibrated and yielding reasonable results and a practical means of performing quality checks on a daily or more frequent basis. Worksheets, supporting data, analyses, final comments, and conclusions are presented.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program

Authors: Steele, G.W; Antle, C. E; Anderson, D. A.

Date: 1994

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Strategic Highway Research Program (SHRP) Protocol 46, "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils," was the specified procedure for laboratories performing resilient modulus test on research samples of unbound cohesive subgrade soil obtained from Long-Term Pavement Performance (LTPP) field sites. P46 requires a test system that includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated load component, and certain load and specimen response control, measurement, and recording components. Two elements of P46 testing were particularly important: verification that the system was calibrated and yielding reasonable results and a practical means of performing quality checks on a daily or more frequent basis. A set of three synthetic reference samples was acquired, instructions for testing were prepared, and the set was circulated to 14 LTPP laboratories for testing. Worksheets, supporting data, analyses, final comments, and conclusions are presented.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Portland Cement Concrete Core Proficiency Sample Program

Authors: Steel, G. W.

Date: 1993

Publisher: Strategic Highway Research Program

Abstract/Synopsis: One element of quality assurance for laboratory testing that was deemed to be of key importance by the strategic Highway Research Program (SHRP) was the American Association of State Highway and Transportation Officials' accreditation program (AAP) for laboratories. All laboratories providing long-term pavement performance (LTPP) testing services were required to be accredited by AAP. It was determined that supplemental programs should be designed to provide assurance that quality test data would be obtained by using approaches similar to those provided by AAP for other tests. One supplemental program was the Portland Cement Concrete (PCC) Core proficiency Sample Program which was designed to provide precision data concerning the static modulus of elasticity, Poisson's ratio, splitting tensile strength, and compressive strength. This document provides a description of the latter.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: SHRP's Layer Moduli Backcalculation Procedure

Authors: PCS/Law Engineering

Date: August 1993

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Deflection basin measurements for the purpose of structural capacity evaluation are a key component of the Strategic Highway Research Program's (SHRP) Long Term Pavement Performance (LTPP) monitoring Program (LTPP). Because a standard method for evaluating the structural capacity of flexible pavements from deflection data does not presently exist, a SHRP program is developing a layer moduli backcalculation procedure for use in the initial analysis of the SHRP deflection data. This procedure covers not only the software but also the rules and guidelines used in applying the program. This report focuses on the standard procedure used to ensure that the LTPP deflection data analysis is as consistent, productive, and straightforward as possible. The procedure consists of a rigorous set of application rules used to generate data files for direct input into the backcalculation program - modeling of pavement structure and layer moduli ranges or initial module. Additional rules address the subsequent evaluation of the backcalculation results.

Application/Use: The approach proposed in this report can be used by pavement analysts and designers using FWD data in their evaluations.

Contribution: Improvement in Knowledge

Present Benefit: The methodology developed in this study is an additional tool for those in the pavement community. FWD data is useful in determining the structural adequacy of existing pavements, estimating subgrade properties, void detection, and load transfer efficiency.

Future Benefit: The data available from LTPP will benefit future studies looking at new procedures to analysis FWD data. This information will also support validation of existing procedures.

Title: Soil Moisture Proficiency Sample Program

Authors: Steel, G. W.

Date: 1993

Publisher: Strategic Highway Research Program

Abstract/Synopsis: This report describes the development of the Long-Term Pavement Performance (LTPP) soil sample selection process based on the American Association of State Highway Transportation Officials model. Laboratory results present the bias in determining moisture content in cohesive soil and base course aggregate samples.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing a comprehensive materials testing protocol. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available date with newly sampled materials, these documents provide the information necessary to do so.

Title: Introduction to Strategic Highway Research Program--Long-Term Pavement Performance Asphalt Concrete Resilient Modulus Testing Program

Authors: Hadley, W. O; Groeger, J. L.

Date: 1992

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1353

Abstract/Synopsis: Research is under way in the Strategic Highway Research Program's Long-Term Pavement Performance (SHRP-LTPP) project to develop and implement a test procedure for resilient modulus testing of asphalt concrete. A comprehensive test procedure has evolved over the past 3 years and is moving toward full-scale production testing in early 1992. Readers with limited exposure with the SHRP-LTPP program are provided with a feel for the test procedure that has been developed and the various activities that have been undertaken in this program to ensure consistent and reliable results.

Application/Use: This paper is directed at those interested in resilient modulus testing of unbound material.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: The development and work conducted under the LTPP program has significantly improved the testing protocols for resilient modulus testing. This paper describes some of the early work and can assist materials engineers and laboratory personnel in understanding the development of the test procedures. Accurate and reliable results are essential for adequate pavement design recommendations.

Future Benefit: Resilient modulus data is a key component of new M-E design practices. Having accurate and repeatable data will improve the performance of pavements as designs will be based on actual conditions. The protocols established by LTPP have improved the consistency and quality of resilient modulus testing.

Title: An Overview of LTPP Materials Sampling and Testing. Strategic Highway Research Program Products. Proceedings of a Specialty Conference Sponsored by the Highway Division of the American Society of Civil Engineers and the Federal Highway Administration

Authors: Pelzner, A.

Date: 1991

Publisher: American Society of Civil Engineers

Abstract/Synopsis: Background information is provided on the materials sampling and testing activities for SHRP's Long Term Pavement Performance (LTPP) program. Twenty six different tests were chosen to record the material characteristics of the pavement components of 775 sections of the General Pavement Studies (GPS). For the Specific Pavement Studies, a total of 45 tests were chosen. Twenty-six of these tests were in addition to those selected for GPS. The sampling of the various pavement sections is described. A laboratory guide has been produced that gives detailed instructions regarding sample identification, materials handling, storage, testing procedures and test reporting. Quality assurance checks have also been established. The results of the materials tests as well as many other types of pavement performance monitoring data are being entered into a large database.

Application/Use: This paper provides an overview of the processes and procedures used by LTPP in performing laboratory testing. These have been utilized to ensure uniform testing by labs providing LTPP data. In the case of resilient modulus testing, LTPP developed protocols that were a considerable improvement over existing methods.

Contribution: Cost Savings, Advancement in Technology.

Present Benefit: In documenting the appropriate methodologies to be utilized in handling and testing LTPP materials specimens, the protocols allow the test results from various laboratories to be compared without applying adjustment factors. Significant effort was expended by the LTPP program in developing comprehensive materials testing protocols. This work can be utilized by agencies for materials sampling and testing.

Future Benefit: The documents developed by LTPP regarding laboratory testing will continue to be an important reference to any analyst studying LTPP testing data. Should a researcher wish to recreate the testing on a site utilizing materials from the Materials Reference Library, or supplement the available data with newly sampled materials, these documents provide the requisite information.

Title: Operational Guidelines on Test Pits

Date: 1989

Publisher: Strategic Highway Research Program

Abstract/Synopsis: The inclusion of test pits in the materials sampling and testing activities for the General Pavement Sections (GPS) portion of the Long Term Pavement Performance (LTPP) program has been a matter of great importance to the Strategic Highway Research Program (SHRP) research, and great interest to the highway agencies involved in it. Inclusion of test pits offers the opportunity to optimize the LTPP testing efforts and to contribute vital information on the performance-related behavior of subsurface pavement layers and subgrades. The rationale for test pits is contained in the appendix of this document. Although the advantages of test pits are widely recognized, many agencies have voiced concerns about motorist and worker safety. To reach a workable balance between the research contribution of test pits and the practical problems associated with them, SHRP has adopted guidelines that include both essential and desirable elements.

Application/Use: These guidelines provide details on the materials data obtained from test pits on LTPP test sections.

Contribution: Improvement in Knowledge; Implementation/Usage.

Present Benefit: This document provides insight into some of the LTPP program's early plans for obtaining materials and layer information at existing GPS test sections.

Future Benefit: The layer structure information obtained from GPS test pits is extremely beneficial in evaluating existing and new design procedures. The materials/layer structure information available in the LTPP database will be critical to the calibration/validation of the M-E PDG.