Development of Flexible Pavement Database for Local Calibration of MEPDG

ANNUAL REPORT FOR FY 2009

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Overall

This study is pursued to develop a flexible pavement database and populate the database with data required for calibration of the new Mechanistic-Empirical Pavement Design Guide (MEPGD). By providing local material properties and local calibration, Oklahoma Department of Transportation (ODOT) would be able to obtain near *Level 1* reliability for *Level 2* or *Level 3* material inputs. Results from this study are expected to provide pavement design professionals with appropriate tools and better understanding of how the new MEPDG will allow optimization of materials, and evaluate and incorporate new materials into designs.

To achieve the objective of this study, the following tasks have been identified: (1) review existing literature pertaining to the MEPDG; (2) collect available resilient modulus (M_R) data of subgrade soils (both unstabilized and stabilized) and determine their MEPDG input parameters; (3) gather available M_R data of granular base materials and determine their MEPDG input parameters; (4) evaluate asphalt binders, certified by ODOT, and determine their MEPDG input parameters; (5) evaluate asphalt mixtures, certified by ODOT, and determine their MEPDG input parameters; and (6) report findings of this study to ODOT. Tasks 2 through 4 are being performed by a team at the University of Oklahoma (OU), under the supervision of Dr. Zaman. Task 5 is being performed by a team at Oklahoma State University (OSU), under the supervision of Dr. Cross. Tasks 1 and 6 are being conducted jointly by both the teams. This report encompasses an overview and task-wise progress made during the first year of this two-year study.

Activities in FY2009 included collecting and processing of resilient modulus (M_R) data on subgrade soils and granular base materials throughout Oklahoma, and populating pertaining databases. Other activities in FY2009 included identifying asphalt binder types and sources, and collecting them for laboratory testing.

M_R data along with routine soil test data were collected from four major sources: ODOT Materials Division, Burgess Engineering in Moore, Terracon Consulting, and ODOT-funded projects at OU. As part of his doctoral studies at OU, Ebrahimi (2006) compiled M_R data for 97 soil specimens from 16 counties. Additional M_R data for 404 soil specimens from 24 counties, including some counties in the earlier database, were appended into the database. Thus, the current database contains M_R data of 501 soil specimens from 35 counties including some of the 16 counties used by Ebrahimi (2006).

Also a new M_R database has been developed for stabilized subgrade soils. This database has been populated with M_R data of 48 soil specimens from four different soil series (Port Series, Kingfisher series, Vernon series, and Carnasaw series). Furthermore, another M_R database for granular base materials has been developed and data for 40 aggregate samples for three aggregate types (Meridian, Richard Spur, and Sawyer) have been used to populate this database.

To obtain input parameters for asphalt binders for *Level 1* design, three commonly used binders in Oklahoma, namely PG 64-22, PG 70-28, and PG 76-28, have been identified. Based on demographic locations and availability of these binders, the following local producers have been identified: Valero (P/S code: m00352) at Ardmore, and NuStar (P/S code: m00347) at Catoosa. Another producer will be selected in consultation with ODOT. In the past, the OU team performed rheological testing of binders produced by Valero. However, further laboratory testing of these binders produced by Valero will be necessary as per recommendations of the MEPDG. Asphalt binders from Valero and NuStar have already been collected in cooperation with ODOT. A binder test plan matrix has been developed. Specifics of the progress made during FY2009 are being reported in monthly progress reports, and an overview of task specific activities is presented in this annual progress report.

Overview of Work Accomplished

To accomplish the objectives of this project, an elaborated task list (see Table 1) and a timeline (see Table 2) have been developed.

Task 1: Literature Review

The mechanistic-empirical pavement design guide (MEPDG) was developed in 2004 under the NCHRP project 1-37A (NCHRP 2004). It replaces the empirical 1993 AASHTO Design Guide (Hossain 2009; Kim et al. 2009). There are three levels of analysis and design in the MEPDG: *Level 1* provides the highest level of design reliability, *Level 2* gives the intermediate level of design reliability, and *Level 3 provides* the lowest level of design reliability.

Table 1 Project Task List

Task ID	Task Description
Task 1	Literature Review (OU and OSU)
Task 2	Soil MEPDG Input Parameters (OU Lead) Subtask 2.1: Identify Source of Data Subtask 2.2: Collect Soil M_R data along with routine test data Subtask 2.3: Process and Clean Raw Data Subtask 2.4: Populate collected Soil M_R Data Subtask 2.5: Perform Statistical Modeling Subtask 2.6: Determine MEPDG Input parameter for Oklahoma Soil
Task 3	Granular Base MEPDG Input Parameters (OU Lead) Subtask 3.1: Identify Source of M_R Source Subtask 3.2: Collect Aggregate M_R Data along with other routine test data Subtask 3.3: Populate collected Aggregate M_R Data Subtask 3.4: Perform Statistical Modeling Subtask 3.5: Determine MEPDG Input parameter for Oklahoma Aggregates
Task 4	Binder MEPDG Input Parameters (OU Lead) Subtask 4.1: Identify Binder Type and Source Subtask 4.2: Collect Asphalt Binders from Selected Refineries Subtask 4.2: Determine Binder Properties Subtask 4.2.1: RTFO Aging Subtask 4.2.2: DSR Tests Subtask 4.2.3: Brookfield Rotational Viscosity (Optional) Subtask 4.3: Determine MEPDG Input Parameters for Asphalt Binders
Task 5	HMA MEPDG Input Parameters (OSU Lead) Subtask 5.1 S-2 Mixtures Subtask 5.2 SMA Mixtures
Task 6	Reporting (OU and OSU) Subtask 6.1: Monthly Report Subtask 6.2: Yearly Report Subtask 6.3: Final Report

Table 2 Timetable for the Research Tasks (October 2008-Sept. 2010)

Task No.	Qarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8
Task 1	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	
Task 2	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx		
Task 3	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx			
Task 4					xxxxxx	xxxxxx	xxxxxx	xxxx
Task 5	xxxxxx	xxxxxx	Xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	
Task 6	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx

Subgrade Soils

Resilient modulus (M_R) for subgrade soil is an important input parameter for the MEPDG. Actual laboratory M_R testing data is required for *Level 1* input. For *Level 2* input, however, M_R data is derived from other routine soil properties. In case of *Level 3* input, default M_R values based on soil classifications are used. Having a M_R database (MRDB) of local materials is expected to assist better evaluation of new roads and better use of available materials (Wang 2009). Several Departments of Transportation (DOTs) have already created or in process of creating MRDBs for their local soils, and they have found these databases to be very useful tools to improve their processes for pavement design and evaluation (Titi et al. 2006; Hopkins 2004; Ping 20003).

Hossain (2009) studied 124 soils collected throughout Virginia and performed resilient modulus, soil index properties, standard Proctor, and California Bearing Ratio (CBR) tests. It was reported that there existed no statistically significant correlations between M_R and other properties, with the exception of those for the quick shear test. It was recommended that the M_R database be used to characterize subgrade soils for *Level 1* and use the quick shear test to predict the M_R values for *Level 2* design.

Toward implementing the MEPDG for cementitiously stabilized subgrade layers, it is recommended by NCHRP (2004) to obtain material properties including M_R or Elastic modulus (M_E), unconfined compressive strength (UCS), and moisture susceptibility for

Level 1 input. However, such data for stabilized subgrade soils are extremely limited in public domain (Solanki et al. 2009; Snethen et al. 2008). Solanki et al. (2009) determined M_R values of cementitiously stabilized (Lime, Class C Fly Ash aka CFA, and Cement Kiln Dust aka CKD) soils from different counties in Oklahoma. Four different types of soils, namely Port Series (P-soil), Kingfisher series (K-soil), Vernon series (V-soil) and Carnasaw series (C-soil), have been studied and effects of different dosages of these additives on M_R have been identified. In that study, the dosage level of stabilizing agents was 0%, 3%, 6%, and 9% for lime, 0%, 5%, 10%, and 15% for CFA and CKD. These data were included in the database(s) developed in the present study.

Snethen et al. (2008) studied chemically stabilized (CKD, Fly ash, Portland cement, and lime) subgrade soils in Oklahoma. These researchers measured unconfined compressive strength (UCS) and M_R, and field performance parameters using Dynamic Cone Penetrometer and PANDA Penetrometer. It was reported that AASHTO-MEPDG *Level 2* correlation equations significantly underestimate M_R values of stabilized soils. Because of scarcity of M_R data of chemically stabilized soils, it was recommended to use M_R = 1500xCBR for stabilized soils until better correlations are established.

Granular Base

Similar to subgrade soils, the MEPDG recommends the use of resilient moduli for all unbound layers (NCHRP 2004). In case M_R test data on unbound materials is unavailable, it is determined by correlating with other laboratory and/or field test data. Yohannes et al. (2009) characterized several unbound granular materials for pavement applications including the MEPDG by conducting M_R tests. These researchers also used a 3-D discrete element method (DEM) based model, capable of accounting for aggregate shape, coefficient of friction, gradation, stiffness and other properties, to estimate M_R. It was reported that good agreement was observed between measured and estimated M_R. Thus, data for M_R was generated for local materials in Minnesota.

The OU team has been involved in M_R testing of granular (unbound) bases for more than a decade (Zaman et al. 1998,1999; Khoury and Zaman 2002; Khoury et al. 2003). These researchers have also studied the effect of stabilizing agents (CFA, CKD, and FBA) on M_R. These data are included in the present database(s).

Asphalt Mixes and Binders

The performance of HMA depends on both asphalt mix and asphalt binder properties. Binder test data or binder grading (depending on design input level) is combined with dynamic modulus (E*) equations to derive E* for the design life of asphalt pavements. The MEPDG incorporates this important performance-based material characteristic by developing master curve for E* of asphalt mix that defines the time-temperature dependency including aging (NCHRP 2004). The estimation process of E* in the master curve at various hierarchical input levels of the MEPDG are presented in the following subsections:

- *Level 3* does not require any laboratory E* testing of asphalt mixes. Rather, predictive equations are used to obtain E* of an asphalt mix. Typical A_i (regression intercept in viscosity versus temperature curve) and VTS_i (regression slope of viscosity temperature susceptibility) values of asphalt mix are provided in the MEPDG software based on binder's PG, viscosity or penetration grading. The master curve for E* of asphalt mix is then developed.
- Similar to *Level 3*, no laboratory testing of E* for asphalt mix is required *at Level 2* design. Predictive equations are used to obtain E* of asphalt mix. However, complex modulus (G*) and phase angle (δ) of RTFO-aged asphalt binder over a range of temperature are used as inputs. Alternatively, binder viscosity or stiffness can be used as input. A_i and VTS_i for the mix-compaction temperature is then determined. The master curve for E* is then developed.
- Level 1 requires laboratory tests at loading frequencies and temperatures of interest to determine E* for the given asphalt mix. Asphalt binder testing of Level 1 is similar to that of Level 2. A_i and VTS_i for the mix-compaction temperature are estimated from binder test data. The master curve for E* that accurately defines time-temperature dependency including aging is then developed.

Flintsch et al. (2007) conducted laboratory testing on 11 plant mixes with a PG 64-22 binder toward implementing the MEPDG in Virginia. These researchers determined MEPDG *Level 1* inputs for these mixes. However, they used *Level 3* inputs for the asphalt binder which is a major limitation of that study.

Bahia et al. (2009) suggested that actual values of complex modulus (G*) and phase angle (δ) at various testing temperatures be used as inputs into the MEPDG rather than simply binder's PG grade. This approach leads to more reliable estimate of pavement performance. Clyne and Marasteanu (2004) tested nine certified asphalt binders used in Minnesota from six refineries around the state and created an inventory of their rheological properties. They conducted dynamic shear rheometer (DSR) tests to predict critical temperatures for rutting and fatigue cracking, and performed bending beam rheometer (BBR) tests to evaluate the critical temperature for thermal cracking. A database was developed and populated it with these data. Similar studies have been conducted by other researchers and are available in the literature (Carpenter 2007; Daniel and Lachance 2005).

Task 2: Soil MEPDG Input Parameter (OU Lead)

Toward fulfilling this task, the following initiative has been taken:

- Indentified major sources and contacts to obtain soil M_R data. ODOT Materials Division, Burgess Engineering and Testing, Inc., Terracon Consulting, and OU Materials Laboratory were identified as primary sources of data.
- M_R data along with routine soil test data for 97 soil samples from 16 different counties in Oklahoma, presented by Zaman et al. (2009) and Ebrahimi (2006), has been retrieved. Routine soil test data include soil classifications (AASHTO and Unified Classification System), index properties (Atterberg limits), percent passing in sieves #4 and #200, standard Proctor test data. Depending on the availability, quick shear data was also collected for some soils.
- Similar data available at ODOT for projects since 2002 have been collected, in cooperation with ODOT Materials Division (Christopher Clarke and Scott Cosby). These data were received in different forms including project reports, Excel spreadsheet, or flat files. Data received as formal project reports completed between 2007 and 2009 were extracted and entered manually into the database. Data received in the form of Excel spreadsheet was copied over and appended into the database, whereas raw data that received as flat files were processed to calculate M_R values. A Microsoft® Excel-based macro was developed to process

these raw data. To this end, M_R data along with routine test data for 334 soil specimens from 27 counties have been appended into the database.

- Appended M_R data along with routine soil test data for 66 soil specimens from five counties completed by Terracon Consulting.
- A new M_R database for stabilized subgrade soil has been created. It includes M_R data for 48 soil samples involving four soil series (P-soil, K-soil, V-soil and C-soil) and three additives (lime, CFA and CKD) and different dosage levels (0%, 3%, 6%, and 9% for lime, 0%, 5%, 10%, and 15% for CFA and CKD). These data have been used to populate the database.

Task 3: Granular Base MEPDG Input Parameter (OU Lead)

The following initiatives have been taken to complete this task:

- M_R data available in ODOT-sponsored projects (Zaman et al. 1998; Tian et al. 1998; Zhu et al. 1998; and Pandey et al. 1998) have been extracted and manually entered into a new database. This database includes M_R data along with strength parameters (unconfined compressive strength, curing time, elastic modulus) and aggregate properties for 40 aggregate samples for three aggregate types (Meridian, Richard Spur, and Sawyer).

Task 4: Binder MEPDG Input Properties (OU Lead)

The OU team has evaluated three PG binders (PG 64-22, PG 70-28, and PG 76-28) collected from Valero refinery (P/S code m00352), as part of previously funded projects. After reviewing NCHRP 1-37A recommendations, it appears that additional DSR testing will be required to determine the MEPDG *Level 1* inputs. Although this task was originally planned to begin in FY10, an early start of this task will give an advantage to complete the project in a timely manner. Toward completing this task, the following initiatives have been undertaken:

- NuStar (P/S code m00347) has been identified as the second source of binders. With assistance from ODOT Materials Division (Marcella Donovan), PG 64-22, PG 70-28 and PG 76-28 binder samples (five one-gallon buckets for each binder

type) were collected. The third source of binder will be identified in consultation with ODOT and bulk samples collected.

- Based on the MEPDG recommendations, a test matrix (see Table 3) for determining *Level 1* input parameters for asphalt binders has been prepared.

Table 3 Asphalt Binder Test Matrix for the MEPDG Input Level 1

Test Parameters and Designation	Aging Condition	Testing Temperature	PG 64-22	PG 70-28	PG 76-28
G* and δ (AASHTO T315)	RTFO	55°F (12.7°C)	X	X	X
		70°F (21.1°C)	X	X	X
		85°F (29.4°C)	X	X	X
		110°F (43.3°C)	X	X	X
		115°F (46.1°C)	X	X	X
		130°F (54.4°C)	X	X	X

Task 5: HMA MEPDG Input parameters (OSU Lead)

The following has been completed on this task. Five SMA mixtures were identified from the ODOT data base. Mix designs were obtained and aggregates sampled so that the mixtures could be reproduced in the laboratory. One source of asphalt cement, PG 76-28 from Valero, was selected for use with all SMA mixtures. For a comparison, aggregates from ODOT S-4 mixtures from the same SMA contractor or from similar aggregates were obtained. Laboratory compacted S-4 mixtures will be produced using the same Valero PG 76-28 asphalt cement. Samples will be tested for rutting resistance using the Hamburg Loaded Wheel Tester and by performing the flow number test. Dynamic modulus will be performed on all samples as well. The original test plan called for testing ODOT S-2 mixtures as well. However, difficulty was encountered finding S-2 mixtures and ODOT stated that S-2 mixtures were rarely specified on ODOT projects and recommended discontinuing S-2 testing.

Difficulties were encountered with OSU's dynamic modulus test set-up and testing was halted until the machine could be repaired and recalibrated. Work on the machine is scheduled for November, 2009. Due to the difficulties in dynamic modulus testing, all other testing was delayed as well, mainly due to mixture storage issues. Mixture testing

resumed in September and Hamburg testing is underway on the SMA and S-4 mixtures. It was decided to retest all previously tested mixtures. Dynamic modulus and flow number testing should start in December or January, after repair and recalibration of the dynamic modulus equipment. Work is currently behind schedule but we still anticipate finishing on schedule.

Task 6: Reporting (OSU and OU)

Monthly reports explaining the progress of the reporting period have been provided to ODOT. Annual report for Fiscal year 2009 is being delivered herein.

Plan for Fiscal Year 2010

Overall the project is on track. The FY10 activities will include the following:

a) Continue reviewing existing literature available in public domain during the reporting period.
b) Perform regression analyses on soil M_R data of subgrade soils and determine model parameters K_1, K_2, and K_3 for local materials.
c) Perform regression analyses on M_R data granular base materials and determine model parameters K_1, K_2, and K_3 for local materials.
d) Evaluate asphalt binders (PG 64-22, PG 70-28 and PG 76-28) collected from Valero (P/S code: m00352), NuStar (p/s code: m00347), and the other source (to be determined in consultation with ODOT), and determine their MEPDG input parameters (complex modulus (G*) and phase angle (δ) under RTFO-aged condition).
e) Evaluate dynamic modulus (E*) of S4 mixes and append the database.
f) Evaluate E* of SMA mixes and populate the database.
g) Finish Hamburg rut testing of SMA and S-4 mixes.
h) Evaluate flow number test for SMA and S-4 mixes.
i) Organize meetings with ODOT personnel to discuss the progress.
j) Continue submitting monthly progress reports.

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