Characterization of Crushed Bases in Wyoming

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Project Title:
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Research Needs:
In Wyoming, the characterization of local subgrade materials was recently completed by the principal investigators in the ongoing research project (RS04(213)) funded by the Wyoming Department of Transportation (WYDOT). Subgrade materials of all soil types were collected from twelve locations throughout the state of Wyoming for a laboratory test program. Particularly, a resilient modulus (M_r) test procedure was developed by modifying the American Association of State Highway and Transportation Officials (AASHTO) T 307 (2007) and incorporating Wyoming's practices (Henrichs 2015). The resilient modulus of each subgrade material was measured, constitutive models for the resilient modulus were calibrated and a design catalog of M_r values for the subgrade materials was developed. Furthermore, M_r values of subgrade materials were estimated from the back-calculation of Falling Weight Deflectometer (FWD) deflection data collected from twenty-five test sites in Wyoming (Hellrung 2015). The back-calculated resilient modulus values were subsequently corrected to laboratory equivalent values.

Since the ongoing research focuses on the characterization of unbounded subgrade materials, granular crushed base serving as one of the intermediate layers in a pavement system for both flexible and rigid pavement was not characterized. Although the resilient modulus of crushed base was estimated from the back-calculation method, extreme differences in resilient modulus

values between the base and subgrade materials were observed with subgrades having higher resilient modulus values (Hellrung 2015). In an effort to combat the issue of extreme differences in base and subgrade back-calculated modulus values, a fixed-layer approach was utilized by fixing the base layer modulus so as to improve the accuracy of the back-calculation by reducing the calculated root-mean-square error (RMSE). Additionally, a wider range of back-calculated modulus values for the base layer, between 10,000 psi and 80,000 psi, was considered during the back-calculation process so as to obtain more realistic subgrade modulus values at which comparison of measured and back-calculated subgrade resilient modulus values was feasible. These current limitations along with having no measured base modulus for similar comparative studies, prevent the realistic characterization of the base properties and limit the comprehensive implementation of the Mechanistic-Empirical Pavement Design Guide (MEPDG) in Wyoming.

A research project funded by the Virginia Department of Transportation (VDOT) was recently completed with the primary objective of developing a catalog of resilient modulus values for aggregate base materials (Hossain and Lane 2015). The research generated representative base resilient modulus values for the implementation of MEPDG in Virginia. They concluded that there were large variations in resilient modulus values among difference sources of granular crushed base aggregate in Virginia, and moisture variation can result in substantial change in resilient modulus values. Also, resilient modulus values of base aggregate depend on gradation, rock type and moisture content. The amount and nature of fines affect the moisture sensitivity of resilient modulus. They recommended that further research is needed to understand the moisture sensitivity and effect of plastic fines on the base resilient modulus.

Since the MEPDG, which is also being implemented by WYDOT, requires granular crushed base aggregate to be characterized using a resilient modulus value, a research to quantitatively characterize the properties of base aggregates is indispensable to fill in the current knowledge gaps. Furthermore, the effects of gradation, rock type and texture, moisture content and fine content on the modulus values of local base aggregates have yet to be determined. These factors potentially influencing the base modulus should be considered in the proposed research. Measured base modulus will be utilized to improve the estimation of modulus of local base materials through the calibration of constitutive models and development of a catalog of properties of local base materials.

Research Objectives:

The proposed research serves as a complementary study to enhance the pavement design in Wyoming through the characterization of base materials. This research project has the following objectives:

1) Characterize the properties of local base materials;
2) Understand the effects of rock type, moisture content, fine content and gradation on base modulus;
3) Improve base modulus estimations; and
4) Facilitate the full MEPDG implementation in the state of Wyoming.

Research Methods:

The proposed research is structured as a two-year effort based on the current needs of filling in the knowledge gaps encountered in the ongoing research project as well as integrating research outcomes in a framework that can be readily adopted by WYDOT and other DOTs. This research

will utilize standard field and laboratory data provided by WYDOT, use existing WYDOT's cyclic triaxial equipment and adopt analytical methodologies from the ongoing research project to complete the proposed research tasks. It is envisioned that the aforementioned research objectives will be achieved by completing five major tasks described below.

Task 1: Literature Review

This task will focus on conducting a literature review pertinent to the characterization of base material properties for the mechanistic-empirical pavement design procedure. The review will include the following: 1) summarize the current state of knowledge and the current state of practice related to the characterization and estimation of base properties in the implementation of MEPDG in Wyoming as well as other states; 2) study current specifications and guidelines pertinent to the base material inputs, prepared by state DOTs and national agencies, such as AASHTO and FHWA; and 3) examine any related analytical and experimental studies and information for potential adaptation and application in Wyoming. The literature review will be facilitated by the excellent libraries, high speed internet, and extensive interlibrary loan capabilities at the University of Wyoming (UW). The research team will utilize many useful sources in conducting this task, including the link to federal and state libraries and databases given on the WYDOT's Research Center website (http://www.dot.state.wy.us/home/planning_projects/research-center/links-to-federaland-state-libraries-and-databases.html).

Task 2: Identify Base Materials and Determine Standard Properties

Working closely with WYDOT's Materials and Testing Program, a minimum of ten representative base materials with grading W and L or similar grading from past or current road projects will be identified for standard aggregate testing and subsequent resilient modulus experiment described in Task 3. The standard properties of each base material will be determined by WYDOT as part of their testing requirement for road projects. The standard properties include classification, gradation, rock type, density-moisture relationship determined in accordance with AASHTO T 99 (2010) and R-value determined in accordance with ASTM D2844 (2007). The relationship between moisture content and R-value will be determined as part of WYDOT standard testing plan. The research team will be responsible for compiling and summarizing the standard test results for subsequent data analysis and correlation study described in Task 4.

Task 3: Resilient Modulus Experiment

Base materials identified in Task 2 will be prepared for resilient modulus testing conducted in this task. Base materials will be prepared, compacted and tested following the modified resilient modulus test protocol T 307 developed for WYDOT by the research team (Henrichs 2015) as part of the outcomes of the ongoing research project. If necessary, the existing modified test protocol will be revised to reflect Wyoming standard practices on testing base aggregate. If the in-situ base condition is available, base materials will be prepared and compacted to target values similar to in-situ wet density and moisture content. Also, base materials will be prepared and compacted at target moisture contents within 2% below the optimum moisture content. To determine the effect of moisture content on base modulus, additional M_r tests will be performed on the same base material prepared and compacted at moisture contents used for the R-value test in Task 2. Test specimens will be preferably compacted to a minimum dry unit weight greater than 90% of its maximum value. A vibratory compaction will be performed when preparing base

specimens. The resilient modulus experiment will be conducted following the preconditioning and fifteen test sequences described in the modified T 307. Experiment will be conducted using the cyclic triaxial test equipment under an Interlaken Series 3300 test frame currently installed at WYDOT's Materials and Testing Program. After completing the resilient modulus test, all base specimens will be subjected to a static triaxial loading with 5 psi confining pressure until failure, which is referred as the "quick shear test" described in the modified T 307 (Henrichs 2015).

Task 4: Data Analysis and Correlation Study

Measured resilient modulus values will be plotted as a function of deviator and confining stresses for each base material. Typical trends of measured modulus values will be identified and described in terms of classification, rock type, R-value, and the Proctor or in-situ density and moisture content. Measured standard test results and resilient modulus values will be compared for the following correlation studies and deliverables:

1) Design tables of resilient modulus values for base materials as a function of significant variables, such as R-value, will be developed. A methodology similarly developed for subgrade modulus values by Henrichs (2015) will be adopted.
2) The stress dependent constitutive model in terms of the three regression coefficient (k_1, k_2 and k_3) recommended in the MEPDG as given by Eq. (1) will be calibrated using the measured resilient modulus values through non-linear regression analysis, where P_a is the atmospheric pressure, θ is the bulk stress and τ_{oct} is the octahedral shear stress.

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_3} \quad (1)$$

3) Correlation relationships between standard test results, such as R-value, and resilient modulus values will be developed using multi-regression analysis techniques.
4) Measured resilient modulus of base materials will be used to verify against the back-calculated modulus values determined from the ongoing project by Hellrung (2015).

The outcomes of this task will provide WYDOT with locally calibrated predictive models for estimating resilient modulus of base materials based on standard base properties. This study will enhance the MEPDG's Level 2 design process and facilitate pavement design in Wyoming.

Task 5: Reporting

To update the progress of the research project, quarterly progress reports will be submitted via email to WYDOT's Research Program and Materials and Testing Program. A final report containing all aspects of the proposed research will be prepared and submitted to WYDOT at the conclusion of the project. The final report will include outcomes of the proposed Tasks 1 to 4. The research findings of the project will be disseminated to designers and practitioners in the fields of geotechnical and pavement engineering through technical presentations at local, regional and national conferences.

Expected Outcomes:

The research outcomes will provide WYDOT as well as other transportation agencies nationwide the necessary models to estimate resilient modulus for granular crushed base materials. The locally calibrated resilient modulus for base materials from this proposed research and subgrade materials from the ongoing research will enhance the pavement design efficiency and facilitate the full implementation of MEPDG in the state of Wyoming. It is believed that the research

outcomes will be of immediate interest to geotechnical engineers, pavement engineers, practitioners, design personnel working for WYDOT, and other entities in Wyoming. The research outcomes can be used as a reference for other states DOT while implementing the MEPDG and a basis for future research.

Relevance to Strategic Goals:
The project outcomes will address four of the strategic goals associated with the MPC program and the U.S. Transportation Research Board as well as the USDOT's requested emphasis areas described as follows:

1) *State of Good Repair* – Better design of roads that would prolong service life of roadways and lower maintenance cost.
2) *Safety* – Reduce potential road accidents due to road closure or traffic diversion for road maintenances and repairs. Also, road accidents can be minimized with a better road performance having little or no distresses.
3) *Economic Competiveness*– Increase the efficiency of pavement design and lower overall construction duration and cost.
4) *Environmental Sustainability* – Reduce unnecessary pavement thicknesses/materials and the use of non-renewable natural resources, such as fossil fuels, during construction.

Educational Benefits:
A Master-degree student majoring in civil engineering has been enrolled in September 2015 to assist principal investigators to complete this project. The MEPDG will be introduced in a required civil engineering course, CE3500: Transportation Engineering, and will be integrated as part of the curriculum for the civil engineering course CE 4510/5510: Pavement Design for Airports and Highways.

Work Plan:
The projected duration for the research presented in this proposal is 25 months. A detailed schedule per task is shown in Table 1. The project is scheduled to begin in January 1st, 2016 through January 31, 2018.

Table 1. Proposed schedule for the research tasks.

Task		2016				2017				2018
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1
1	Literature Review									
2	Identify Base Materials and Determine Standard Properties									
3	Resilient Modulus Experiment									
4	Data Analysis and Correlation Study									
5	Reporting									

Project Cost:
Total Project Costs: $128,925.00
MPC Funds Requested: $64,348.00
Matching Funds: $64,577.00 Source of Matching Funds: **Wyoming Department of Transportation**

The detailed budget is shown in Table 2. The total WYDOT cost for the study is $64,577 of which the WYDOT Materials Office will keep $3,000 to train a UW graduate student to run the resilient modulus test at the lab. $61,577 will be used by UW along with the Federal match to do all the tasks as described in the proposal.

Table 2. Budget.

University Transportation Centers Program
Mountain-Plains Consortium

Project Title: Characterization of Crushed Bases in Wyoming

University of Wyoming
Grant Year: 2016-2018

Categories	MPC Contribution	WYDOT Contribution	Total
Center Director Salary			
Faculty Salaries	$12,635	$18,271	$30,905
Administrative Staff Salaries			
Staff Fringe Benefits	$5,881	$8,505	$14,387
Student Salaries	$13,650	$19,650	$33,300
Student Fringe Benefits	$61	$88	$150
Total Personnel Salaries	$26,285	$37,921	$64,205
Total Fringe Benefits	$5,943	$8,593	$14,536
TOTAL Salaries & Fringe Benefits	**$32,228**	**$46,514**	**$78,742**
Travel	$0	$4,000	$4,000
Equipment	$0	$0	$0
Supplies	$0	$800	$800
Contractual	$0	$0	$0
Construction	$0	$0	$0
Other Direct Costs (Specify)*	$17,940	$0	$17,940
TOTAL Direct Costs	$50,168	$51,314	$101,482
F&A (Indirect) Costs[$]	$14,180	$10,263	$24,443
TOTAL COSTS (UW)	**$64,348**	**$61,577**	**$125,925**
Federal Share	**$64,348**		$64,348
Matching Share		**$61,577**	$61,577
TOTAL COSTS (WYDOT)[&]	$0	**$3,000**	$3,000
OVERALL COSTS	**$64,348**	***$64,577***	$128,925

Other Direct Costs Must Be Defined in Remarks

*Other direct dost includes graduate student tuition, fees and insurance

[$]An indirect cost rate of 44% was charged to federal share (MPC) and 20% was charged to the matching share (WYDOT)

[&]WYDOT training cost for UW gradaute student

TRB Keywords:
Pavement, Mechanistic-Empirical Pavement Design Guide, Resilient Modulus, Base Material.

References:

American Association of State Highway and Transportation Officials. (2007). Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials. AASHTO T-307. Washington, D.C.

American Association of State Highway and Transportation Officials (AASHTO). (2010). Standard Method of Test for Moisture-Density Relations of Soils Using a 5.5-lb Rammer and a 12-in. Drop. AASHTO T 99. Washington, D.C.

American Society for Testing and Materials (ASTM) D2844 (2007). Standard Test Method for Resistance *R*-Value and Expansion Pressure of Compacted Soils. ASTM International, West Conshohocken, PA.

Hellrung, D. (2015). Back-calculation of the Subgrade Resilient Modulus for Mechanistic-Empirical Pavement Design in Wyoming. Master Thesis, University of Wyoming, Department of Civil and Architectural Engineering, Laramie, WY.

Henrichs, Z. (205). Measurement of the Resilient Modulus of Subgrade Materials for Mechanistic-Empirical Pavement Design Guide in Wyoming. Master Thesis, Department of Civil and Architectural Engineering, University of Wyoming, Laramie, WY.

Hossain, M.S, and Lane, D.S. (2015). Development of a Catalog of Resilient Modulus Values for Aggregate Base for Use with the Mechanistic-Empirical Pavement Design Guide (MEPDG). Report No. FHWA/VCTIR 15-R13, Virginia Center for Transportation Innovation and Research, Charlottesville, VA, 43 p.