Wisconsin Highway Research Program (WHRP)

Research Proposal

Submitted to the
Technical Oversight Committee
Geotechnical Engineering

Proposal Information	
1. Title of Research Proposal Determination of Resilient Modulus Values for Typical Plastic Soils of Wisconsin	
2. Amount Requested $50,689	**3. Duration Of Project** Anticipated start date: October 2007 Duration in months: 18 months
Organization Information	
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Principal Investigator Information	
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Problem Statement:

The Wisconsin Department of Transportation (WisDOT) is in the process of implementing Mechanistic/Empirical (M/E) procedures and methods for pavement design. One of the major factors in the M/E approach is the inclusion of the resilient modulus of the subgrade soils. WisDOT has not used resilient modulus values for past pavement designs and, as a result, does not have sufficient data or experience to supply these values for Wisconsin soils. WisDOT also does not have the resources available to enter into project specific testing.

Therefore, WisDOT initiated a research project through Wisconsin Highway Research Program (WHRP) to determine the resilient modulus values of selected Wisconsin subgrade soils. The research was awarded to the University of Wisconsin-Milwaukee research team (the PI of this proposal) under WHRP Project ID 0092-03-11, which will be referred to as Phase I in this proposal.

Phase I of the resilient modulus research was completed and a final report by Titi et al. (2006) entitled "Determination of Typical Resilient Modulus Values for Selected Soils in Wisconsin" was published in May 2006. The report provided extensive data on resilient modulus values for the 15 submitted soils over a range of moisture and density conditions. The report also provided extensive data on a full range of more typical soil parameters for the selected soils. Using these typical soils' parameters, Titi et al. (2006) then attempted to conduct analyses to determine if correlations could be found between certain parameters and the actual resilient modulus values. The analyses found that accurate correlations could not be found if the 15 soils were considered as a whole. This related back to the condition that the 15 soils covered a full range of textures and levels of plasticity. Titi et al. (2006) found that if the tested soils were divided into groups with similar properties, correlations could be developed. The analyses put the tested soils into the following three groups.

1) Coarse grained, non-plastic soils. (<50% P200, NP)
2) Coarse grained, plastic soils (<50% P200, PI >0)
3) Fine grained soils (>50% P200, PI>0)

However, in subdividing the 15 selected soils into the three groups above, the number of soils within each group became small. Employing extensive regression analyses, Titi et al. (2006) developed empirical formulas for each of the three soil groupings for the factors k_1, k_2, and k_3 necessary to calculate estimated resilient modulus values. Although the formulas where developed for soils within the boundaries of the defined groups, Titi et al. (2006) cautioned that applying the equations to materials with parameters beyond those of specific soils tested had not been validated.

WisDOT has conducted further analyses to test the validity of Titi et al. (2006) formulas over a wide range of conditions for each of the identified soil groups. It was found that for the coarse grained, non-plastic soils (Group 1), the formulas gave reasonable results for the normal range of conditions anticipated for this group. However, when analyzing the coarse grained, plastic soils (Group 2) and the fine grained soils (Group 3), it was found that the predicted resilient modulus values became increasingly questionable as the formula/soil parameters increasingly varied from those of the specific soils tested in these groups. This is thought to relate directly back to the small number of soils available for testing and analyses within each of these groups. It is the conclusion of WisDOT that while the predictive formulas for Groups 2 and 3 are valid for the narrow range of soils' conditions tested and analyzed, these formulas are not valid for the broader range of soil conditions typical for these groups. It was also concluded that additional testing of a broader spectrum of soils was necessary to refine and improve the predictive formulas.

Research Objectives

The primary objective of this research project is to develop (and/or expand, improve) and validate a methodology for estimating the resilient modulus of various Wisconsin subgrade soils from basic soil properties (Level 2 input parameters in the mechanistic-empirical pavement design). The following specific objectives are identified for successful accomplishment of this research:

1. Conduct repeated load triaxial tests to determine the resilient modulus of Wisconsin soils selected by WisDOT engineers. These soils will also be subjected to different laboratory tests to obtain their physical and compaction properties. The obtained test results will augment and expand the test data conducted during Phase I of the resilient modulus research.
2. Develop/expand/modify resilient modulus correlations (models) that were proposed in Phase I between the resilient modulus constitutive model parameters (k_1, k_2, & k_3) and basic soil properties. The new correlations will be validated for wide range of Wisconsin soils and conditions.

Background and Significance of Work

Mechanistic-empirical pavement design procedures described by NCHRP Project 1-37A are based on the existing technology in which state of the art models and databases are utilized. Design input parameters are required generally in three major categories: (1) traffic; (2) material properties; and (3) environmental conditions. The mechanistic-empirical design identifies three levels of design input parameters in hierarchical way. This provides the pavement designer with flexibility in achieving pavement design with available resources based on the significance of the project. The three levels of input parameters apply to traffic characterization, material properties, and environmental conditions. The following is a description of these input levels:

1. Level 1: These design input parameters are the most accurate, with highest reliability and lowest level of uncertainty. They require the designer to conduct laboratory/field testing program for the project considered in the design. This requires extensive effort and would increase cost.
2. Level 2: When resources are not available to obtain the high accuracy level 1 input parameters, then level 2 inputs provide an intermediate level of accuracy for pavement design. Level 2 inputs can be obtained by developing correlations among different variables.
3. Level 3: Input parameters that provide the highest level of uncertainty and the lowest level of accuracy. They are usually typical average values for the region. Level 3 inputs might be used in projects associated with minimal consequences of early failure such as low volume roads.

The AASHTO T 307: “Determining the Resilient Modulus of Soils and Aggregate Materials,” is the current protocol for determination of resilient modulus of soils and aggregate materials using laboratory testing. The test procedure is based on the SHRP Protocol P46 in which repeated load triaxial test is specified for determining the resilient modulus. It includes major changes to the test procedure regarding sample conditioning and loading cycles.

The repeated load triaxial test consists of applying a cyclic deviator stress (σ_d) on a cylindrical specimen under confining pressure (σ_c) and measuring the axial recoverable strain (ε_r). Resilient modulus (M_r) determined from the repeated load triaxial test is defined as the ratio of the repeated axial deviator stress to the recoverable or resilient axial strain:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \qquad (1)$$

Determining resilient modulus requires extensive laboratory testing to furnish a useful data information. It also requires examination of different test results to reveal some of the resilient modulus characteristics. However, project specific testing is impractical due to the test complexity and test requirements cost. Several research studies (e.g., Titi et al. (2006), Ooi et al. (2004), and Yau and Von Quintus (2004)) were conducted to develop correlations between resilient modulus and fundamental soil properties such as moisture content, soil density, and plasticity characteristics. Such correlations were developed using regression analysis techniques. Some of these studies are specific to soils in certain geographical areas, and other studies used certain test procedures and sampling.

The quality of the data to be used to develop resilient modulus correlations must be good. Carmichael and Stuart (1985) reported that many of the data that were used in previous regression studies encountered some problems such as lack of observations, variety of test procedures, lack of range in predictor values, colinearity, confounding of data and inconsistent sample sizes. It was also reported by Karasahin et al. (1994) that the use of multivariate nonlinear regression might not be acceptable for the evaluation of resilient modulus model parameters since it can be operator-sensitive.

Titi et al. (2006) conducted a comprehensive resilient modulus investigation on selected Wisconsin soils through WHRP. This research project was initiated by WisDOT 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 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.

Titi et al. (2006) selected the resilient modulus constitutive equation adopted by NCHRP Project 1-37A for their study. The general resilient modulus model is a constitutive equation that was developed through NCHRP project 1-28A and was selected for implementation in the *upcoming* AASHTO Guide for the Design of New and Rehabilitated Pavement Structures. The resilient modulus model can be used for all types of subgrade materials and is defined by (NCHRP 1-28A):

$$M_r = k_1 P_a \left(\frac{\sigma_b}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_3} \qquad (2)$$

where:

M_r = resilient modulus
P_a = atmospheric pressure
σ_b = bulk stress = $\sigma_1 + \sigma_2 + \sigma_3$
σ_1 = major principal stress
σ_2 = intermediate principal stress = σ_3 in axisymmetric condition (triaxial test)
σ_3 = minor principal stress or confining pressure in the repeated load triaxial test
τ_{oct} = octahedral shear stress
k_1, k_2 and k_3 = material model parameters

Comprehensive statistical analysis was performed to develop correlations between basic soil properties and the resilient modulus model parameters k_1, k_2, & k_3. 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 as shown in Figure 1. In order to inspect the performance of the models developed in this study, comparison with the models developed based on 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.

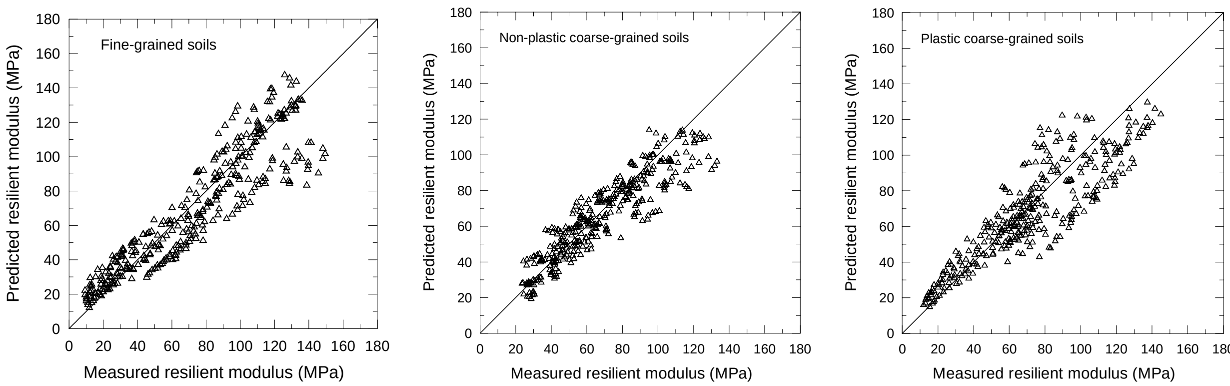


Figure 1: Predicted versus measured resilient modulus of Wisconsin soils (Titi et al. 2006)

The equations developed by Titi et al. (2006), that correlate resilient modulus model parameters (k_1, k_2, & k_3) to basic soil properties for fine-grained and coarse-grained soils can be utilized to estimate Level 2 resilient modulus input for the mechanistic-empirical pavement design. These equations (correlations) are based on statistical analysis of laboratory test results that were limited to the soil physical conditions specified. Estimation of resilient modulus of subgrade soils beyond these conditions was not validated.

Benefits

WisDOT is moving toward implementation of mechanistic-empirical design for pavements and has committed significant time and resources towards this effort. Resilient modulus of subgrade soils is required as input parameter in the mechanistic-empirical design process. To achieve accurate and efficient pavement designs, it is essential to accurately determine the resilient modulus of the subgrade soils. Without this study, WisDOT would use very conservative general values for soils input. This would significantly diminish the effectiveness and benefits on mechanistic-empirical pavement design.

The benefits of the mechanistic-empirical pavement design, which uses the resilient modulus to characterize subgrade soils, are widely recognized in the pavement community (e.g., NCHRP, FHWA, AASHTO). According to the research team of the NCHRP project 1-37A, the mechanistic-empirical design will reduce premature failure of pavements, which will result in $1.14 billion of annual savings in pavement rehabilitation cost. This estimation was based on probabilistic life cycle cost analysis under certain assumptions (e.g., 20 years design life).

Implementation

The successful completion of this research project will provide WisDOT with a significant contribution towards implementing a mechanistic-empirical pavement design. This study will provide WisDOT with models (correlations) to determine the resilient modulus using Equation 2 (the resilient modulus model adopted by NCHRP 1-37A) of Wisconsin subgrade soils based on soil type and conditions. These correlations can be used directly to evaluate k_1, k_2, and k_3 in Equation 2 by using simple soil tests. This will provide Level 2 design input parameters for mechanistic-empirical pavement design.

Detailed Work Plan

The research team will conduct following tasks will:

Task 1: Review the Resilient Modulus Research Conducted on Phase I under WHRP Project ID 0092-03-11

The research team completed Phase I research on the resilient modulus of Wisconsin soils and published a final report in May 2006. The research team developed the work plan of Phase I that included testing and analysis of the results in the context of the mechanistic-empirical pavement design. As a result of this research, the following were published by the research team on Phase I:

1. "*Determination of Typical Resilient Modulus Values for Selected Soils in Wisconsin*," Research Report for WHRP Project ID 0092-03-11, submitted to Wisconsin Department of Transportation, May 2006.
2. "*Evaluation of Resilient Modulus of Typical Wisconsin Soils*," Geotechnical Practice Publication No. 1, American Society of Civil Engineers, pp. 335-346. (2004).
3. "*Effect of Sample Size on Resilient Modulus of Cohesive Soils*," Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering (ICSMG), Osaka, Japan, Vol. 2, pp. 499-502. (September 2005)
4. "*Evaluation of Resilient Modulus Model Parameters for Mechanistic Empirical Pavement Design*," Journal of the Transportation Research Board, No. 1967, Transportation Research Board, Washington, D.C., pp.89-100. (November 2006).

Therefore, the research team fully understands what has been done in Phase I and will use their knowledge and expertise in conducting Phase II (the current proposal) in a similar way.

It should be noted that Publication No. 4 in the list above (the TRB paper) was classified by TRB as *a practice ready paper*. In addition, the paper was nominated for the K.B. Woods Award. This award is given each year by the Transportation Research Board for the best paper in the area of design and construction.

The research team will review their work on Phase I and will educate the students involved in the research project. In addition, the research team will conduct a comprehensive literature review to obtain the latest information on this subject. Useful information can be obtained especially with some state DOTs are reporting their research and evaluation of resilient modulus in the context of the mechanistic-empirical pavement design.

Task 2: Obtain the Results of WisDOT Analysis & Evaluation of Resilient Modulus Research Conducted under WHRP Project ID 0092-03-11

The research team will meet with WisDOT engineers, after arranging with the Geotechnical TOC, to obtain the results of their analysis performed to evaluate the resilient modulus models of Phase I in the context of the mechanistic-empirical pavement design. This task will provide the research team with valuable information and data as it will lead to identification of the "missing gap" of soil types and testing conditions. Testing conditions therefore can be identified to include these spectra so that models can be developed and validated over a comprehensive range of soils and conditions.

Task 3: Selection of Wisconsin Soils for Resilient Modulus Testing in Accordance with Phase II Requirements

Phase II of the resilient modulus research (the current RFP) requires that the soils to be tested should cover types and conditions to augment and expand the research performed in Phase I. The research team will meet with WisDOT engineers under the direction of the Geotechnical TOC to identify these soils and conditions. It should be noted that the research team will be in frequent communication with WisDOT engineers during the testing phase to report the work progress. According to the RFP, WisDOT would take the responsibility to obtain the identified materials and deliver samples of appropriate volume to the research team. WisDOT anticipated that approximately 12 soil types will be supplied to the research team.

Task 4: Conduct Laboratory Testing Program to Evaluate Soil Properties and Resilient Modulus of Wisconsin Soils

A comprehensive laboratory testing program will be conducted on Wisconsin soils selected in Task 3. The objective of this experimental program is to investigate the effects of several variables such as soil type, grain size distribution, liquid limit, plastic limit, moisture content, and density (unit weight) on the resilient modulus of the selected soils. It should be noted that the procedures, methodologies, and equipment used in Phase I will be used in Phase II to produce consistent test results database. The following laboratory tests will be conducted for characterization of each selected soil:

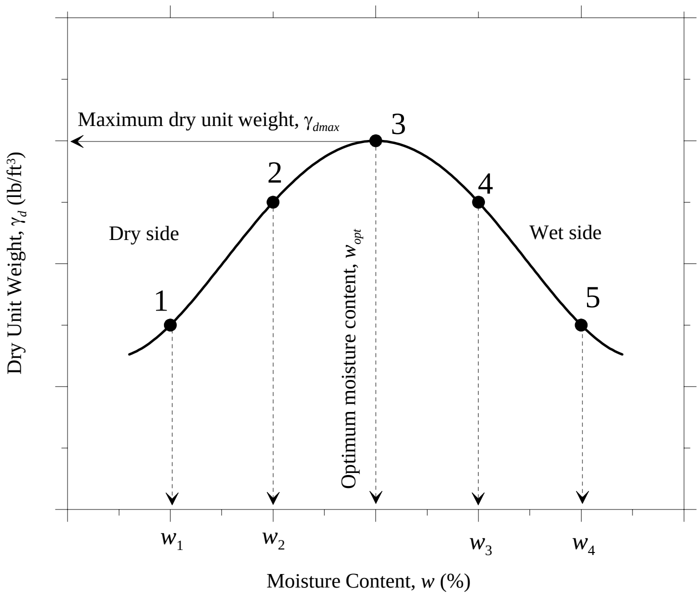
Physical Properties:
Particle size analysis (sieve analysis and hydrometer); Atterberg Limits tests (Plastic Limit and Liquid Limit); ASTM soil classification according to Unified Soil Classification System (Gravel%, sand%, silt%, clay%, C_u, C_c); AASHTO soil classification (Group Index); and Specific Gravity. The physical properties of the investigated subgrade soils will provide the means necessary for the correlation with resilient modulus. Laboratory tests will be conducted following the standard test procedures used by WisDOT. Therefore, physical property tests will be conducted according to the standard procedures of the American Society for Testing and Materials (ASTM).

Compaction Characteristics:
Standard Proctor compaction test will be conducted to obtain the moisture-density (unit weight) relationship for the selected soils. The maximum dry unit weight (γ_{dmax}) and the corresponding optimum moisture content (w_{opt}) will be determined for each soil. The Standard Procter test will be conducted following AASHTO T99: *Standard Method of Test for Moisture – Density Relations of Soils Using a 2.5-kg (5.5 lb) Rammer and a 305-mm (12-in) Drop*.

Repeated Load Triaxial Test (Resilient Modulus):
The repeated load triaxial test will be conducted, to determine the resilient modulus of the investigated soils, following AASHTO T307*: Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials*. The test will be conducted on compacted soil specimens that were prepared in accordance with the procedure described by AASHTO T 307.

The resilient modulus is significantly affected by moisture content and unit weight (density) of the soil. Therefore, it is necessary to investigate the effects of moisture content and unit weight on the resilient modulus of the selected soils. In order to account for these two variables and to provide more data points to validate the statistical models, five levels of moisture content and the corresponding unit weight on the compaction curve will be considered for each soil. These levels, shown in Figure 2, are maximum dry unit weight (γ_{dmax}) and the optimum moisture content (w_{opt}), 95% of γ_{dmax} and the corresponding two moisture contents (one the dry side and one on the wet side), and 93% of γ_{dmax} and the corresponding two moisture contents (one the dry side and one on the wet side). Five specimens of each selected soil (one specimen at each specified level of moisture content and dry unit weight) will be prepared for resilient modulus testing. It should be noted that the proposed 93% of γ_{dmax} may change (as an example to 90% or 92%) for soil specimens depending on the soil type and conditions. This change may be necessary for some soil types to cover a wide range of data to validate k_i models as described by Task 2 of this work plan.

A repeatability investigation will be conducted to ensure that high quality test results can be obtained. This is essential since the data will be used to develop/modify/expand and validate the resilient modulus correlations developed for use in the mechanistic-empirical pavement design. Table 1 presents a summary of tests and test factorial for Phase II.



Point	Unit Weight (γ)	Moisture content (w)
1	93% γ_{dmax} (dry side)	w_1
2	95% γ_{dmax} (dry side)	w_2
3	γ_{dmax}	w_{opt}
4	95% γ_{dmax} (wet side)	w_3
5	93% γ_{dmax} (wet side)	w_4

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Figure 2: Unit weight and moisture levels at which soils will be prepared for laboratory resilient modulus testing.

Table 1: **Test Factorial for Wisconsin Subgrade Soils**

Test	Number of Tests	Total Number of Tests
Physical Properties:		
Grain size distribution (sieve analysis)	2*×12	24
Grain size distribution (hydrometer)	2×12	24
Atterberg limits (Plastic Limit)	2×12	24
Atterberg limits (Liquid Limit)	2×12	24
Specific gravity	2×12	24
Compaction Properties:		
Standard Proctor test (moisture density curve)	2×5×12	120
Resilient Characteristics		
Repeated load triaxial test (resilient modulus)	2×5×12	120

*Two samples of each of the 12 selected soil types will be tested to ensure test repeatability.

Task 5: Analyses of Test Results and Development of Models to Predict Resilient Modulus

The research team will conduct comprehensive analysis on the results of the repeated load triaxial test and will plot relations between resilient modulus and stresses (confining and deviator stress) as shown in Figure 3. This will be the first step to evaluate, expand and modify the models proposed in Phase I.

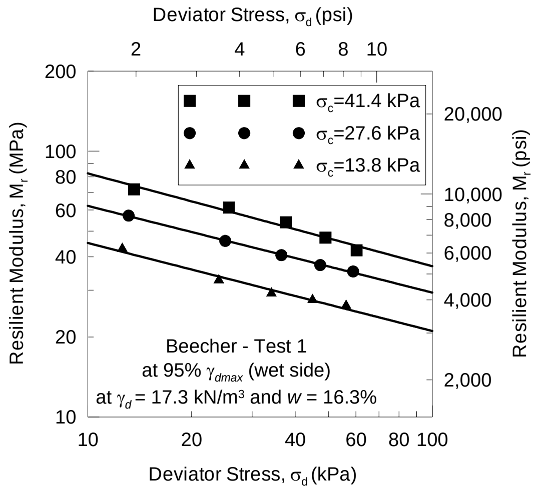

Figure 3: Variation of resilient modulus with stresses for Wisconsin soil specimen tested at 95% of maximum dry unit weight and moisture content on the wet side.

Comprehensive statistical analysis will be conducted on the laboratory test results to evaluate, modify, and expand the models that relate k_1, k_2, and k_3 to soil properties for all soil groups. The RFP emphasized on coarse grained, plastic soils (<50% P200, PI >0) and fine grained soils (>50% P200, PI>0). Analysis will be conducted on these two groups if WisDOT engineers provide the research team with soils that belong to these groups only. The first group will be included if WisDOT engineers provide the research team with soils that belong to the first group, which is coarse grained, non-plastic soils (<50% P200, NP).

Therefore, the research team will extract all test data from Phase I and will add the results of Phase II to create a new large data population for statistical analysis. It should be noted that the research team believes (based on their work on resilient modulus) that testing soil specimens on wider range of unit weight and moisture content (such as 93% of γ_{dmax}) will lead to valid models over large spectrum of Wisconsin soils with various conditions.

The resilient modulus model parameters k_1, k_2 and k_3 will be determined for all soil types. These parameters will be then correlated to fundamental soil properties using regression analysis. The values of resilient modulus model parameters (k_1, k_2 and k_3) will alternatively be used as dependent variables while various fundamental soil properties will be treated as independent variables. Various combinations of soil properties (independent variables) will be used in the regression analysis. The general multiple linear regression model is expressed as:

$$k_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \in \qquad (3)$$

where:

k_i is the dependent variable for the regression, (model parameters k_1, k_2 or k_3), β_0 is intercept of the regression plane, β_i= regression coefficient, x_i = the independent variable, (fundamental soil property or a combination of soil properties), and $\in$ is random error.

It should be noted that general nonlinear models that include factorial and polynomial regression will be attempted in this study.

Sets of independent variables are specified to reflect soil type and current soil physical condition. Independent variables available from basic soil testing that represent soil type and current soil physical condition are: percent passing sieve #4 ($P_{No.4}$), percent passing sieve #40 ($P_{No.40}$), percent passing sieve #200 ($P_{No.200}$), liquid limit (*LL*), plastic limit (*PL*), Plasticity Index (*PI*), Liquidity Index (LI), amount of sand (%Sand), amount of silt (%Silt), amount of clay (%Clay), water content (*w*) and dry unit weight (γ_d). The optimum water content (w_{opt}.) and maximum dry unit weight (γ_{dmax}), coefficient of uniformity (C_u), coefficient of curvature (C_v) and combinations of variables will be included.

The following are examples of models developed for fine-grained soils during Phase I by the research team:

$$k_1 = 404.166 + 42.933PI + 52.260\gamma_d - 987.353\left(\frac{w}{w_{opt}}\right) \tag{4}$$

$$k_2 = 0.25113 - 0.0292PI + 0.5573\left(\frac{w}{w_{opt}}\right) \times \left(\frac{\gamma_d}{\gamma_{d\max}}\right) \tag{5}$$

$$k_3 = -0.20772 + 0.23088PI + 0.00367\gamma_d - 5.4238\left(\frac{w}{w_{opt}}\right) \tag{6}$$

Task 6: Evaluation of the Resilient Modulus Models Developed in Phase II in the Context of the Mechanistic-Pavement Design

During the course of conducting the statistical analysis (in Task 4), the research team will communicate with WisDOT engineers through the Geotechnical TOC to carry out an evaluation scheme of the new proposed models and to assess their capabilities within the context of the mechanistic-empirical pavement design. The research team will perform in part some these analyses. This will provide the research team with information on the performance of the models and will work in part as a validation process.

Task 7: Validation of the Proposed Models through Predicting Laboratory Testing and Evaluations against LTPP Database

The research team will conduct a validation scheme that includes one soil type from each group to validate the proposed models. Each selected soil will be subjected to basic soil properties in which the results will be used in the model to predict the resilient modulus. Thereafter, the research team will carry out the repeated load triaxial test to determine resilient modulus values. The predicted results will be compared to the measured results and statistical parameters will be presented.

In addition, similar to what has been done in Phase I, the research team will search for available LTPP data and will use the developed models to predict the resilient modulus values. Also, the current data will be used to evaluate LTPP models and any new models available in the literature.

Task 8: Final Report

A draft final report documenting the entire research effort will be submitted to WisDOT for review at the end-of-the project. Comments of WisDOT engineers will be addressed in the final report. The final report will provide a comprehensive summary of laboratory test results, analysis, and models development. The final report will be prepared in accordance with the WisDOT publication guidelines. Eighty five copies of the final report will be produced and delivered to WHRP as required.

Work Time Schedule

The following schedule provides a time frame for the execution of each task:

Task Number	Year 1				Year 2	
	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 1	Quarter 2
Task 1	X					
Task 2	X					
Task 3	X	X	X	X		
Task 4	X	X	X	X	X	
Task 5			X	X	X	X
Task 6				X	X	X
Task 7					X	X
Task 8					X	X

Reports

1. The research team will submit quarterly reports in accordance with WHRP requirements.
2. The research team will submit the final report at the completion of the project as described in Task 8.

Qualifications of Research Team

Dr. Hani Titi, the Principal Investigator, is an Associate Professor in the Department of Civil Engineering and Mechanics at UW-Milwaukee and is a registered Professional Engineer. Dr. Titi has more that 18 years of experience in advanced experimental research and analysis, especially in problems related to pavements and geotechnical engineering. During his current position at UW-Milwaukee and previous position Louisiana Transportation Research Center and Louisiana Department of Transportation and Development, he conducted advanced research and served as PI and Co-PI for projects funded by different entities including: Wisconsin Highway Research Program (WHRP)/Wisconsin Department of Transportation, Minnesota Department of Transportation, Midwest Regional University Transportation Center, and Louisiana Department of Transportation and Development. The following are selected completed pavement related projects in which he was involved:

1. Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin. Wisconsin Department of Transportation, Wisconsin Highway Research Program, ($103,049). PI: Dr. Hani Titi and Co-PI Dr. Sam Helwany.
2. Mechanistic/Numerical Methodology for Improved Performance of Highway Pavements, UWM Graduate School Research Committee Award, ($14,901) PI: Dr. Hani Titi
3. Guidelines for the Surface Preparation/Rehabilitation Of Existing Concrete and Asphaltic Pavements Prior to an Asphaltic Concrete Overlay. Wisconsin Department of Transportation, Wisconsin Highway Research Program, ($64,997). PI: Dr. Haifang Wen – Bloom Consultants. Co-PI: Dr. Hani Titi

Dr. Titi is a member of TRB committees (AFP20, AFP30, and AFS30), a member of NCHRP panel D2431, and the Secretary of the ASCE-Geo-Institute Pavement Engineering Committee. Dr. Titi is the author and co-author of more than 45 publications (journal, conference and research reports) in the area of geotechnical and pavement engineering. The following are selected pavement related publications:

1. Titi, H.H., Elias, M.B., and Helwany, S. (2006) “Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin,” Research Report, Wisconsin Department of Transportation, Wisconsin Highway Research Program, Madison, WI.
2. Elias, M.B. and Titi, H.H. (2006). “Evaluation of Resilient Modulus Model Parameters for Mechanistic Empirical Pavement Design,” Journal of the Transportation Research Board, No. 1967, Geology and Properties of Earth Materials 2006, Transportation Research Board, Washington, D.C., pp.89-100.
3. Wen, H., Titi, H.H., and Berry, D. (2006). “Study of Best Practices for Pre-Overlay Repair and Asphalt Overlay,” Proceedings of the 2006 Airfield and Highway Pavement Specialty Conference, American Society of Civil Engineers, Atlanta, GA, pp 815-823.
4. Elias, M.B., Titi, H.H., and Helwany, S. (2004) “Evaluation of Resilient Modulus of Typical Wisconsin Soils,” Geotechnical Practice Publication No. 1, GeoJordan: Advances in Geotechnical Engineering with Emphasis on Dams, Highway Material, and Soil Improvement, American Society of Civil Engineers, pp. 335-346.
5. Rasoulian, M., Titi, H.H., and Martinez, M. (2005). “Evaluation of Narrow Transverse Contraction Joints in Jointed Plain Concrete Pavements,” Proceedings of the International Conference on Concrete Pavements, Colorado Springs, Co, pp. 357-371.
6. Carroll, D.A., Cheng, R., Eger III, R., Grusczynski, L., Marlowe, J. and Titi, H. H. (2004). “Highway Preventive Maintenance Implementation: Comparing Challenges, Processes, and Solutions in Three States,” Journal of the Transportation Research Board No. 1877, National Research Council, Washington, D.C., pp. 10-16.
7. Titi, H. H. (2004.) “Parameters of Jointed Plain Concrete Pavements for Customization of the HIPERPAV-Wisconsin System,” Research Report Submitted to The Transtec Group, Inc., Austin, TX, p. 46.

Sam Helwany

Dr. Sam M. Helwany is an Associate Professor of geotechnical engineering at the University of Wisconsin Milwaukee. He obtained his Ph.D. in 1993 at the University of Colorado at Boulder. He obtained his MS degree in geotechnical engineering and his Bachelor degree of civil engineering at the University of Colorado-Denver. Sam is a registered professional engineer. His main expertise is in the area of large-scale testing and numerical modeling of soil-structure interaction problems. He has conducted and analyzed numerous large-scale field and laboratory tests on soil structures subjected to static and dynamic loads. Sam is currently involved in the following research projects: (1) Investigation of Vertical Members to Resist Surficial Slope Instabilities, Wisconsin Highway Research Program, 2004-2005, $29,714 (Helwany, Co-PI). (2) Development and Full Scale Testing of an Alternate Foundation System for Post and Panel Retaining Walls, Wisconsin Highway Research Program And Wisconsin Department Of Transportation, 2007-2008, $80,000 (Helwany, PI). (3) Construction Vibration Attenuation With Distance And Its Effect On The Quality Of Early-Age Concrete, Wisconsin Highway Research Program And Wisconsin Department Of Transportation, HNTB, 2006-2007, $225,000 (Helwany, Co-PI).

Dr. Helwany has worked on the following research projects: (1) Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin, Wisconsin Highway Research Program, $103,000 (Helwany, Co-PI). (2) Design and Construction of Geosynthetic Reinforced Soil (GRS) Abutments for Bridge Support, National Cooperative Highway Research Program, 2001-2003, $300,000, Helwany, Co-PI (with Dr. Wu, PI, and Dr. Tatsuoka, Co-PI). (3) Evaluation of the AASHTO 18-kip Equivalency Concept, 1996-98, $338,028, Sponsored by Texas Department of Transportation, Helwany, Co-PI (with Dr. Hudson, PI). (4) Dynamic Lateral Earth Pressure on Underground Structures, 1997-98, $125,000, Sponsored by Air Force Office for Scientific Research (AFOSR), Helwany, PI (with Drs. Ko, Pak, and Chowdhury, Co-PI's). (5) The Effects of Facing Rigidity on the Performance of GRS Structures. 1994, $125,000, This research project was sponsored by Japan Railways and performed at the Institute of Industrial Science-The University of Tokyo. The project involved the design of full-scale experiments and finite element analyses of geosynthetic-reinforced embankments for the "Bullet Train". (6) Pile Set-Up, Graduate School-UWM, 2000, $15,000 (Helwany, PI). (7) Evaluation of Bridge Approach Settlement Mitigation Techniques, Wisconsin Highway Research Program, 2000-2004, $100,000 (Helwany, PI). (8) Analysis and Design of Dies for Polymer Extrusion. UW Applied Research Program. 2004, $41,393 (Helwany, PI)

Facilities Available

UWM Library:

The library has extensive collections of periodicals, literature, and related books. Materials that are not available in the UWM Library can be obtained through its Interlibrary Loan department. In addition, the PI has access to the information retrieval files of technical literature abstracts such as TRIS and ASCE engineering database.

Geotechnical & Pavement Engineering Laboratories:

The proposed research project will be conducted at the Geotechnical & Pavement Laboratory of the Department of Civil Engineering and Mechanics at UW-Milwaukee. The laboratory is equipped with the necessary instruments and tools to successfully accomplish the objective of the research project. The following is a description of the main equipment:

Servo-hydraulic Dynamic Materials Testing System

Figures 4, 5 and 6 show a state of the art Instron FastTrack 8802 closed loop servo-hydraulic dynamic materials test system at UW-Milwaukee. The system utilizes 8800 Controller with four control channels of 19-bit resolution and data acquisition. A computer with FastTrack Console is the main user interface. This is a fully digital controlled system with adaptive control that allows continuous update of PID terms at 1 kHz, which automatically compensates for the specimen stiffness during repeated load testing. The loading frame capacity of the system is 250 kN (56 kip) with a series 3690 actuator that has a stroke of 150 mm (6 in.) and with a load capacity of 250 kN (56 kip). The system has two dynamic load cells 5 and 1 kN (1.1 and 0.22 kip) for measurement of the repeated applied load. The load cells include integral accelerometer to remove the effect of dynamic loading on the moving load cell. Triaxial cells with maximum sample diameter of 6 in. are also available.

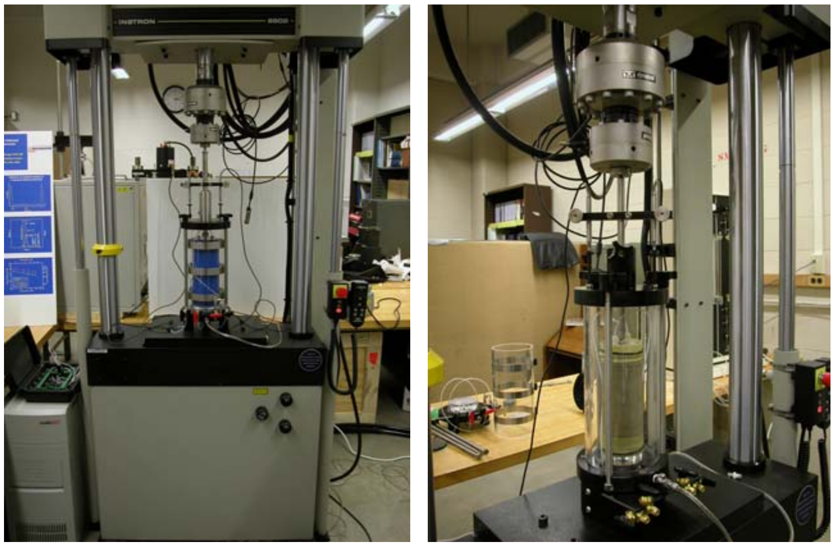

Figure 4: The UWM servo-hydraulic closed-loop dynamic materials test system will be used in this study

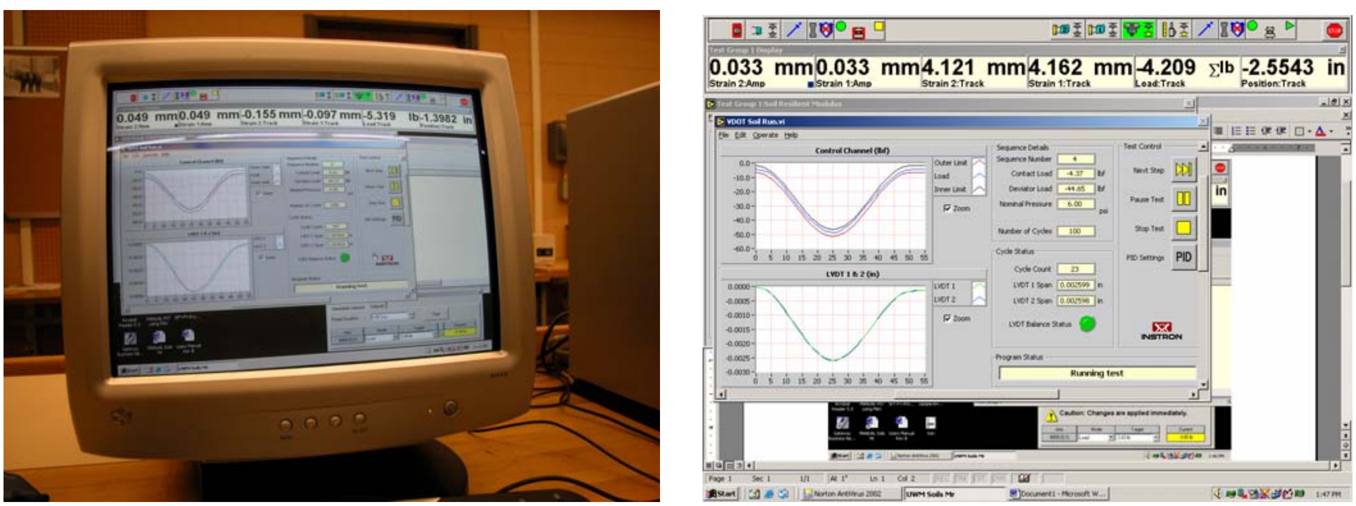

Figure 5: Computer program used to control and run the repeated load triaxial test for determination of resilient modulus

 

Figure 6: Special mold designed to prepare soil specimens according to AASHTO T 307 requirements

<u>Equipment for Measurement and Determination of Soil Properties:</u>
These include the following: Dynamic repeated load and static triaxial test, grain size analysis shakers (sieve analysis), temperature-controlled hydrometer path, specific gravity determination equipment, Atterberg limits (plastic and liquid limit of soils), automatic soil compactor (Standard and Modified Proctor test), digital-controlled ovens, automated direct shear test system, automated soil consolidation system, vibratory table for determination of relative density of cohesionless soils, unconfined compression test system, drying ovens, etc.

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